EPA-905/9-74-011-A
VOLUME 1

WATER POLLUTION INVESTIGATION: CALUMET AREA OF LAKE MICHIGAN

IIT RESEARCH INSTITUTE

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V ENFORCEMENT DIVISION
GREAT LAKES INITIATIVE CONTRACT PROGRAM

OCTOBER, 1974

WATER POLLUTION INVESTIGATION: CALUMET AREA OF LAKE MICHIGAN

VOLUME 1

by

Richard H. Snow

IIT RESEARCH INSTITUTE

In fulfillment of

EPA Contract No. 68-01-1576

for the

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region V

Great Lakes Initiative Contract Program
Report Number: EPA-905/9-74-011-A

EPA Project Officer: Howard Zar

October 1974

This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provisions of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-905/9-74-011-A	2.	3. Recipient's Accession No.
4. Title and Subtitle Water Pollution Investigation: Calumet Area of Lake Michigan Volume 1			5. Report Date October 1974
			6.
7. Author(s) Richard H. Snow			8. Performing Organization Rept. No.
9. Performing Organization Name and Address IIT Research Institute 10 West 35th Street Chicago, Illinois 60616			10. Project/Task/Work Unit No.
			11. Contract/Grant No. 68-01-1576
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Enforcement Division, Region V 230 S. Dearborn Street Chicago, Illinois 60604			13. Type of Report & Period Covered Final Report
			14.

15. Supplementary Notes

EPA Project Officer: Howard Zar

16. Abstracts An investigation of the Calumet area of Lake Michigan was conducted. The objective was to determine trends in water quality, to determine effluent loads entering the Lake, and to predict reductions in effluents needed to achieve Lake water quality standards. The report describes the status of industrial and municipal effluent sources. Effluent data were compiled from NPDES permit applications and operating reports. These were checked by a field sampling program.

Water quality data were compiled from several sources. We also conducted field measurements in the Indiana Harbor Canal (IHC) and at 16 Lake stations. We located the plume from the IHC by aerial observation and by measurements using existing pollutants as tracers. Current meters installed in the Lake for one month allowed us to describe the mechanisms that appear to govern dispersion of the IHC plume. The report contains chapters assessing the impact of each of the more important pollutants, and gives recommendations for reduction of some effluent loads. Appendices are included on the biological impact of pollutants on the Calumet area of Lake Michigan.

17. Key Words and Document Analysis. 17a. Descriptors

Water Quality Aquatic Biology, Water Pollution

17b. Identifiers/Open-Ended Terms

Calumet Area, Indiana Harbor Canal, Lake Michigan, Great Lakes, Chemical Parameters, Biological Parameters

17c. COSATI Field/Group 13B 6F 8H

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
	20. Security Class (This Page) UNCLASSIFIED	22. Price

TABLE OF CONTENTS

VOLUME 1

TABLE OF CONTENTS (cont.)

VOLUME 2 (APPENDICES)

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

ACKNOWLEDGMENTS

IITRI personnel who contributed to this project are Ernest Dunwoody, Nagaraja Rao, Gayle Marks, Carl Swanstrom, Dr. Walter Wnek, and Henry Duncan. The project manager was Dr. Richard Snow. Edward Fochtman and Dr. Morton Klein provided consultation and supervision.

This report contains contributions from a subcontractor, Citizens for a Better Environment. Dennis Adamczyk prepared a draft of Chapter 4 and Appendix C. Dan Sweeney prepared a draft of Chapter 5.

Argonne National Laboratory provided a boat and crew for field sampling, installed current meters and processed the current data by computer. Sam Zivi, Dr. John Tokar, and Dr. Anthony Policastro contributed to planning of the field measurements and discussed dispersion of the IHC plume. John Frye, Larry Van Loon and Conrad Tome participated in the field measurements.

Two biologist consultants provided advice on biological aspects and contributed to the report. Appendix A was written by Dr. Richard Howmiller, University of California at Santa Barbara. Appendix B was written by Dr. John Gannon, University of Michigan Douglas Lake Biological Station, Pellston, Michigan.

The Hammond Water Dept. very kindly provided the use of their laboratory for preparation of water samples. Mr. A. G. Gianinni and Emmett Sutliff were very helpful. The following other water departments allowed us to take raw water samples and to inspect their water analyses: Chicago South Water Filtration Plant, Morris Kaplan; Whiting Water Plant, Albert Odlivak; East Chicago Water Plant, Mr. Kowal; Hobart Water Co. (Gary, Indiana), Keith Young.

In addition, the Chicago Water Dept. provided copies of their reports, access to data in their library, and help in finding data. Those who helped include Commissioner Richard Pavia, Philip Reed, Barbara Fox, Mr. Davoust and Mr. MacDougal.

The project was monitored for EPA by Howard Zar. He and Gary Milburn provided continuing aid concerning sources of information and advice on planning and carrying out the work.

We thank all of the above individuals and organizations for their contributions to the project.

EFFLUENTS AND WATER QUALITY IN THE CALUMET AREA OF LAKE MICHIGAN

1. INTRODUCTION, SUMMARY AND RECOMMENDATIONS

1.1 Introduction

An investigation of the Calumet area of Lake Michigan was conducted for the U.S. Environmental Protection Agency. The area extends from the 68th St. crib of the Chicago Water Dept. to Burns Ditch in Indiana. The objective was to determine trends in water quality in this part of the Lake and its tributary rivers, to determine the loads of effluents entering the Lake from industrial and municipal sources, and to relate the impact of effluents on water quality so as to predict reductions in effluents needed to achieve water quality standards in the Lake. The information will be used by the EPA as a guide to setting effluent limitations.

1.2 Summary

The main source of effluents in the area is the Indiana Harbor Canal (IHC), which carries effluents from the major steel mills, refineries, and municipal sewage treatment plants into the Lake. Effluent data were compiled from NPDES effluent permit applications, and these were checked against monthly operating data submitted by the industry to Indiana, and against effluent 24-hr sample data. A separate study on effluents, water quality, and load allocations in the Grand Calumet River/IHC system was done for the Indiana Stream Pollution Control Board by Combinatorics (1974). We have made use of much of the data compiled by Combinatorics (1974).

The permit data were found to be reasonably valid, but we checked the data further by a field sampling program. A program of field measurements was undertaken in November and December 1973, to fill gaps in the available data. Although the data available from other agencies were extensive, the observations did not locate the plume of effluents from the IHC with relation to the sampling stations. Furthermore, the flow of the IHC and the effluent loads were not measured on the same days as the Lake sampling. Our objective was to relate water quality measurements to effluent loads, and to movement and dispersion of the IHC effluents in the Lake, so that we could establish the sources of pollution and the magnitude of their effects on the Lake.

To accomplish this, we sampled the IHC and measured its flow at two points. This allowed us to check the reported effluent loads, and we found that the measured values were on the high side of the reported range for most pollutants. We analyzed the samples for the following parameters: temperature, pH, dissolved oxygen, chloride, conductivity, turbidity, fluoride, ammonia-nitrogen, total phosphorus, total coliform bacteria, total organic carbon, total solids, suspended solids, chlorophyll, volatile solids, total iron and dissolved iron.

Our sampling in the Lake was accompanied by observation and measurement of the water movement in the Lake. We found that the plume from the IHC was visible because of its purplish-brown color, so we chartered an airplane and observed and photographed the plume on sampling days. We also subcontracted with Argonne National Laboratory to install current meters in the Lake off the mouth of the IHC and near the 68th St. crib. A month-long record from these meters showed that the Lake currents flowed in a northerly direction along the shore about half the time, in a southerly direction along the shore nearly half the time, and on a few occasions it flowed out toward the middle of the Lake. Our observations allowed us to postulate mechanisms governing the flow and dispersion of the plume in the Lake, and to calculate dilution ratios.

Argonne also provided a boat for sampling the Lake at 16 stations. This Lake sampling was done on three days, November 14, November 19, and December 7, 1973. To obtain more continuity of data, we also obtained samples from raw water intakes of five municipal water treatment plants: the Chicago 68th St. crib, and the intakes of Hammond, Whiting, East Chicago, and Gary, Indiana.

We found that the plume could readily be followed both by visual observation and by plotting a combination of the following pollutants which acted as tracers, and provided a signature to positively identify the IHC effluents: total iron, conductivity, ammonia-nitrogen, coliform bacteria, chloride, pH, temperature and fluoride. Concentrations exceeding water quality standards were measured as far as five miles from shore, particularly for ammonia-nitrogen and bacteria. High chlorophyll measurements showed that the IHC effluent has a nutrient effect on algal growth.

This report contains an assessment of the previously available data, a description of our field sampling program, and chapters assessing the impact of each of the more important pollutants. The most noticeable and harmful pollutants are ammonia-nitrogen and phosphorus. Ammonia-nitrogen can be toxic to fish. Phosphorus, and to a secondary extent nitrogen, promote eutrophication of near-shore waters, and result in extensive growths of algae that clog water intake screens and form unpleasant conditions on local bathing beaches; however, phosphorus effluents from IHC have decreased 40% during the past four years, due to improved treatment by Indiana municipalities and due to a phosphorus limitation on detergents in Indiana. An increasing trend of phosphorus at the 68th St. crib was apparent for 15 years, but there has been a 20% decrease in the last two years.

Other pollutants are suspended iron, which causes a colored plume. Oil and phenol from steel mills and refineries cause unpleasant tastes in local water supplies, and require extensive use of carbon for municipal water treatment. Oil causes surface slicks that dirty pleasure boats. This oil and other organic pollutants shift aquatic life towards species that usually live in polluted waters.

Bacterial pollution from the IHC remains very high, and beaches in the Calumet area are still closed for this reason. Delays in municipal treatment construction and diversion of industrial effluents to the municipal plants is causing these difficulties.

Although the IHC is the largest source of pollutants in the Calumet area, not all of the pollution in the Lake can be traced to it. Some of the phosphorus and ammonia-nitrogen pollution in the near-shore waters could come from more distant sources.

1.3 Recommendations

The following recommendations are abstracted from specific chapters in the report.

We recommend that industries discharging wastes to municipal sewers be required to pretreat their wastes so as not to overload the East Chicago, Gary, and Hammond sewage treatment plants. The pretreatment should include provisions to prevent peak loads from entering the plants and causing upsets. An alternative solution would provide for increased capacity and additional processes at the municipal plants to handle the industrial wastes, with a sewerage charge to pay the costs. This should be undertaken only if it is shown to be more cost effective, and if it will not cause delay over the pretreatment approach.

We recommend that plans to solve problems of combined sewer overflows and storm water overflows be implemented as soon as possible. The municipalities have plans to construct detention lagoons and increase the capacity of sewers and treatment plants. Until these facilities are constructed, bathing beaches and water intakes in the Calumet area will continue to be polluted.

Plans to increase capacity of overloaded municipal treatment plants and to add AWT should be implemented as soon as possible. Funding of these construction plans should be given a higher priority. This applies to the smaller plants in the eastern Calumet region, as well as to East Chicago, Gary and Hammond.

We recommend that some of the industrial and municipal effluent load allocations be lowered to allow water quality standards to be met in Lake Michigan, as well as in the Grand Calumet River/IHC system. We recommend a reduction of a factor of 7.7 in present loadings of ammonia-nitrogen. These reductions should be accomplished in such a way as to prevent the present harmful effects on ammonia on the operation of municipal sewage treatment plants. Phenol load allocations should be reduced to reflect the present improved phenol levels, to prevent degradation of phenol levels back to earlier conditions. We recommend that either the oil loads, or the BOD_5 allocations be reduced as a means to require the steel mills to drastically reduce the amount of oil they discharge to the IHC.

We recommend that efforts to control phosphorus effluents, which have shown some success, be continued, so that phosphorus effluents can be further reduced to the levels recommended by the Phosphorus Technical Committee (1972). This will require completion of some sewage treatment projects, monitoring of operation of sewage treatment plants, and control of combined sewer overflows, as discussed above. It may also require further control efforts by adjacent states to achieve the recommended reductions.

We also recommend that a further study be undertaken to determine the impact of IHC effluents on water quality over a wider area than can be determined by tracing the IHC plume. This would include a study of residence time of pollutants in the Calumet area of Lake Michigan, as well as a study of the movement of pollutants in a somewhat wider area using modern instrumentation. The objective would be to determine whether the NH_3-N and P levels observed are entirely due to local sources, or whether more distant sources can also contribute.

2. DESCRIPTION OF AREA AND WATERSHED

The area included in this project extends from the 68th St. Chicago water intake crib to Burns Harbor in Indiana, and the tributary streams between these limits. The flow pattern in these rivers is somewhat complicated, and only the portions flowing into Lake Michigan are included. These are discussed below.

Three streams connect directly with the Lake. These are the Indiana Harbor Ship Canal (IHC), the Calumet River, and Burns Ditch. See Figure 2.1.

The IHC normally flows toward the Lake, and it carries the largest quantities of pollutants. The Calumet River is also polluted, but its flow is reversed so that it does not normally drain to Lake Michigan. Flow in the Calumet River is controlled by the O'Brien Lock and is directed to the Cal-Sag Channel except during periods of heavy flooding or very low lake levels. Outward flow can also occur if effluent from Lever Bros. through Wolf Lake exceeds the flow through O'Brien Locks. Just at the mouth of the Calumet River the flow is usually outward, because U.S. Steel Co. discharges water from the Lake into the south slip just inside the River mouth (Technical Committee 1970).

There are two streams that run parallel to the shore. They are the Grand Calumet River and the Little Calumet River. The directions of flow are indicated by arrows on Figure 2.1. The west end of the Grand Calumet River flows to Illinois through the Cal-Sag Channel, and is not included in this study; however, the Grand Calumet River also connects to the Indiana Harbor Canal. The east portion of this river flows outward to the Lake through this canal, and is included. The east branch originates at the east edge of the U.S. Steel Company property in Gary as seepage from fresh water lagoons. The west branch is divided into two segments which are normally separated by a natural divide located near the east edge of the Hammond municipal sewage treatment

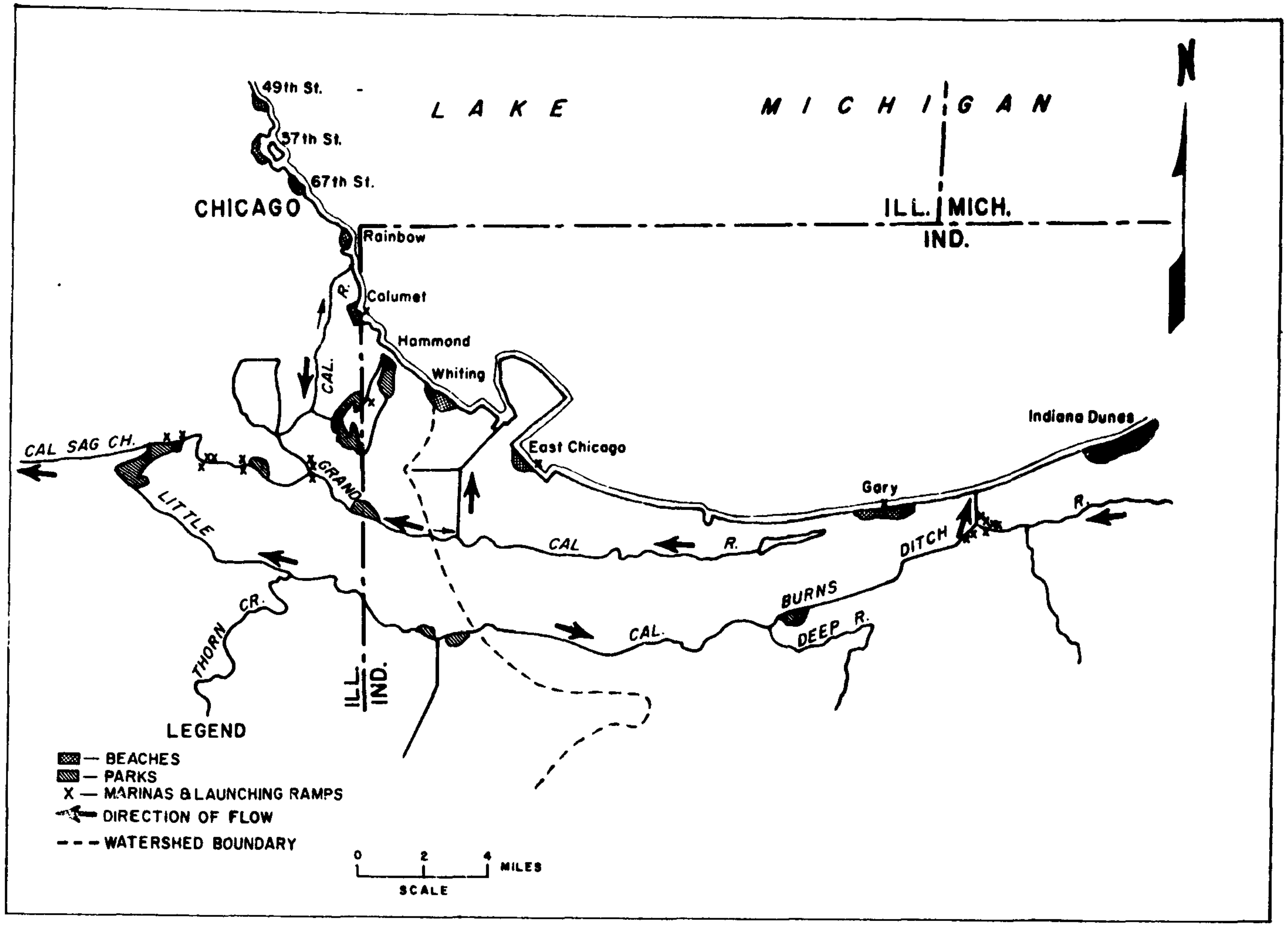

Figure 2.1

CALUMET AREA OF LAKE MICHIGAN BASIN
SHOWING STREAM FLOW DIRECTIONS
(Technical Committee on Water Quality 1970)

plant grounds. Water in the east segment of the west branch normally joins the east branch to form the IHC.

The Illinois segment of the west branch normally flows westward into Illinois; however, the entire flow in the Indiana portion of the stream is usually to Lake Michigan via the IHC. Flow into Illinois is possible on occasions, as a result of weather conditions on Lake Michigan. We have not seen this happen, though it is mentioned by the Technical Committee (1970).

The Grand Calumet River and the IHC drainage system constitute the largest source of pollutants to the Lake in the area (Figure 2.1). These streams, which have a combined length of approximately 13 miles, drain an area which contains a population approaching one-half million and one of the most concentrated steel and petroleum manufacturing complexes in the nation. In excess of 90% of the water flowing in these streams enters via sewers as treated waste water, cooling water or as storm water overflow. This description is from the Indiana Stream Pollution Control Board (1973).

The IHC has been dredged to a 28-ft depth as far as Columbus Drive, and its sides are quite steep. Water level is essentially at base level with Lake Michigan. Flow in the Canal is normally to the Lake, because of the large rate at which Lake water is pumped into the IHC via the Grand Calumet River by U.S. Steel Gary Works.

The Grand Calumet River is a shallow stream, which in most areas is bordered by 20 to 50 ft of cattail marsh. The bottom of the stream is covered with a mixture of organic debris, mud and sludge. Although the velocity of flow in the stream is generally slow enough to permit deposition, after locally heavy rains the velocity is increased to the point that bottom deposits may be resuspended.

Further inland is the Little Calumet River. The portion of this river west of Hart ditch generally flows west to the Cal-Sag

Channel, and it is excluded from this study. Hart ditch is just east of the Illinois-Indiana boundary (see Figure 2.2); however, the headwaters of the Little Calumet River and its tributaries, which drain the eastern portion of the basin, enter Lake Michigan via Burns Waterway, a man-made outlet, and are included.

In general then, the area included is the Lake itself between 68th St. in Chicago and Burns Harbor, and the eastern portion of the drainage basin outlined by a heavy dashed line in Figure 2.2.

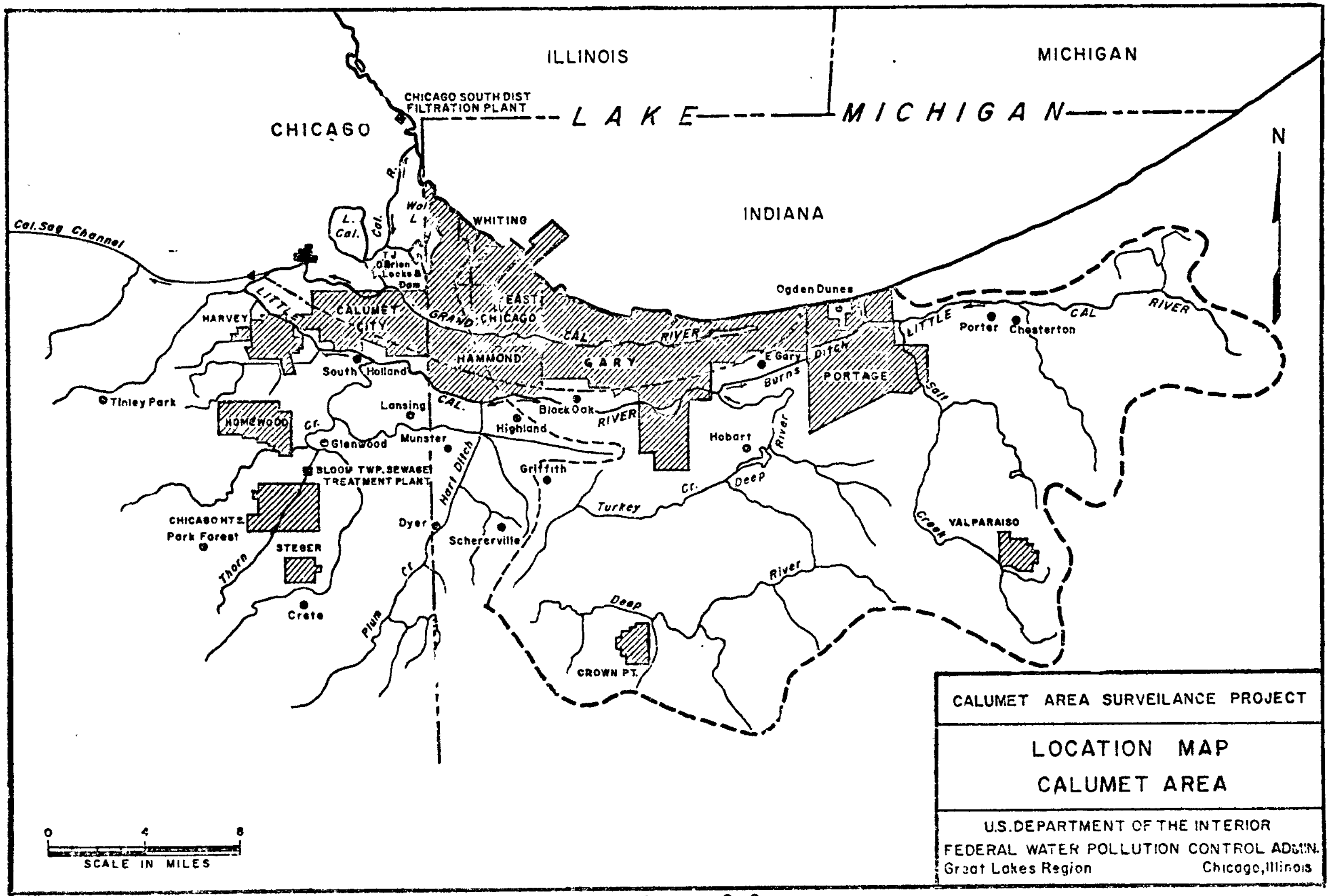

Figure 2.2

DRAINAGE BASIN OF CALUMET AREA TRIBUTARY STREAMS

3. FLOW DATA OF TRIBUTARY STREAMS

It is important to know the flow rates of tributary streams, to relate the effluent loads (lb/day) to concentrations in the streams. This information would then allow one to determine the reductions in loads necessary to achieve a given stream water quality. This is the approach that was taken by Combinatorics (1974) for the Grand Calumet River/IHC system.

Our main concern is with the water quality in Lake Michigan, as discussed in Chapter 1. We need flow data so that we can use measurements of pollutant concentrations in the streams to check the effluent load data from permit applications. The result of this checking process is a better estimate of the actual loads of effluents impacting the near-shore waters of the Lake. Our main concern is with the Grand Calumet/IHC system, because these tributaries have the largest sources of effluents in the Calumet area. We also obtained some flow data on other streams.

The Grand Calumet River is not an ordinary drainage stream, and its flow does not present the usual seasonal highs and lows that result from natural drainage. Most of the flow that enters the Grand Calumet River and the IHC comes from industrial or municipal discharges, and this water is taken from Lake Michigan. This situation is further described by Combinatorics (1974) and is made clear by the data presented below.

3.1 Flow Data

The most extensive data are those measurements made by the U.S. Geological Survey (1964). Figures 3.1a and 3.1b show gaging locations of the Geological Survey, and Figure 3.1c shows the flows they measured. The flow at stations 5B and 7 measure the contribution from the east branch of the Grand Calumet River, mostly coming from U.S. Steel Gary works and the Gary STP. It varies from 600 to 1000 cfs. The flow at Dickey Rd. includes most of the industrial effluents into the IHC except

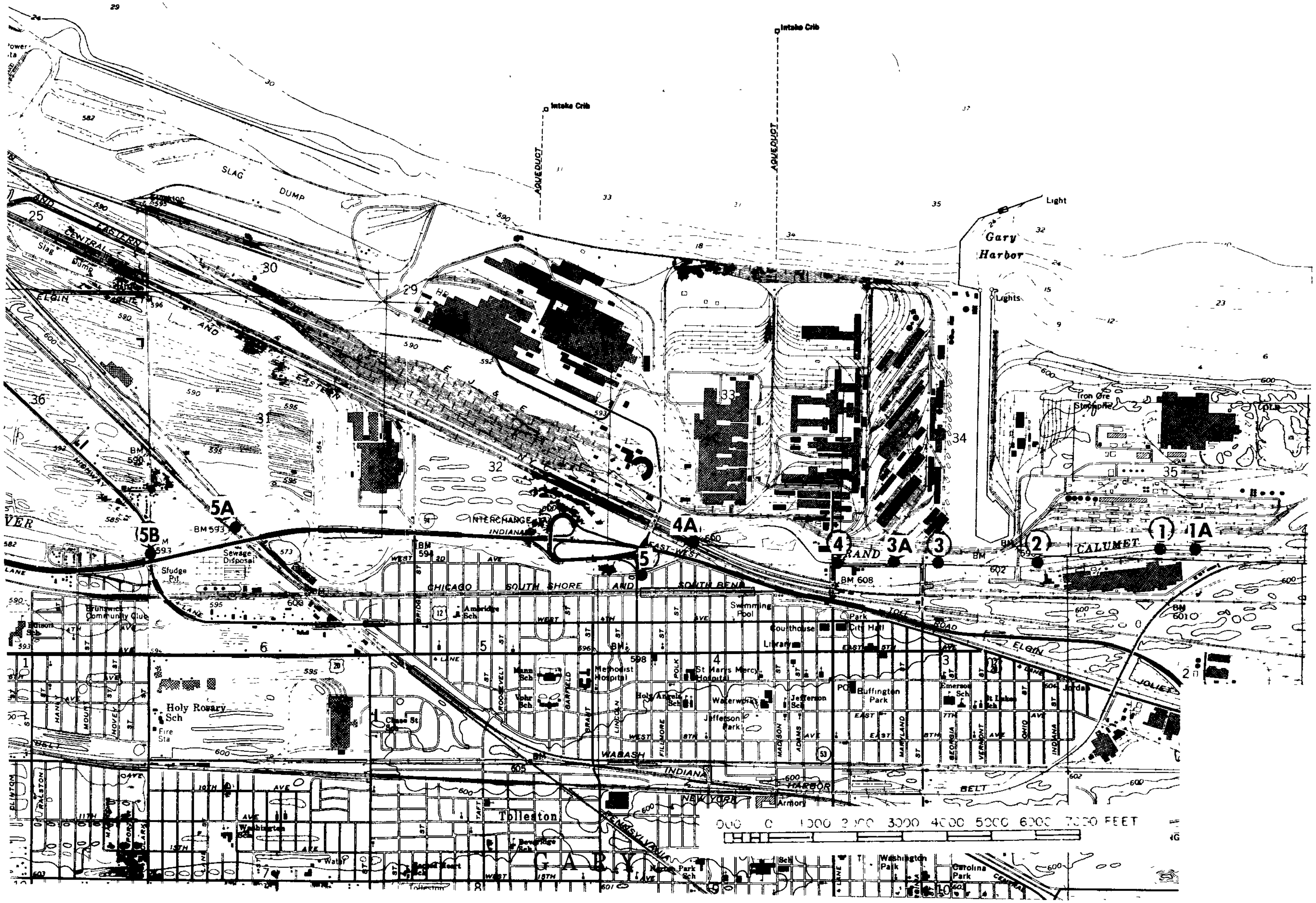

Figure 3.1a

GRAND CALUMET RIVER INFLOW INVESTIGATION
Water Resources Division
U.S. Geological Survey

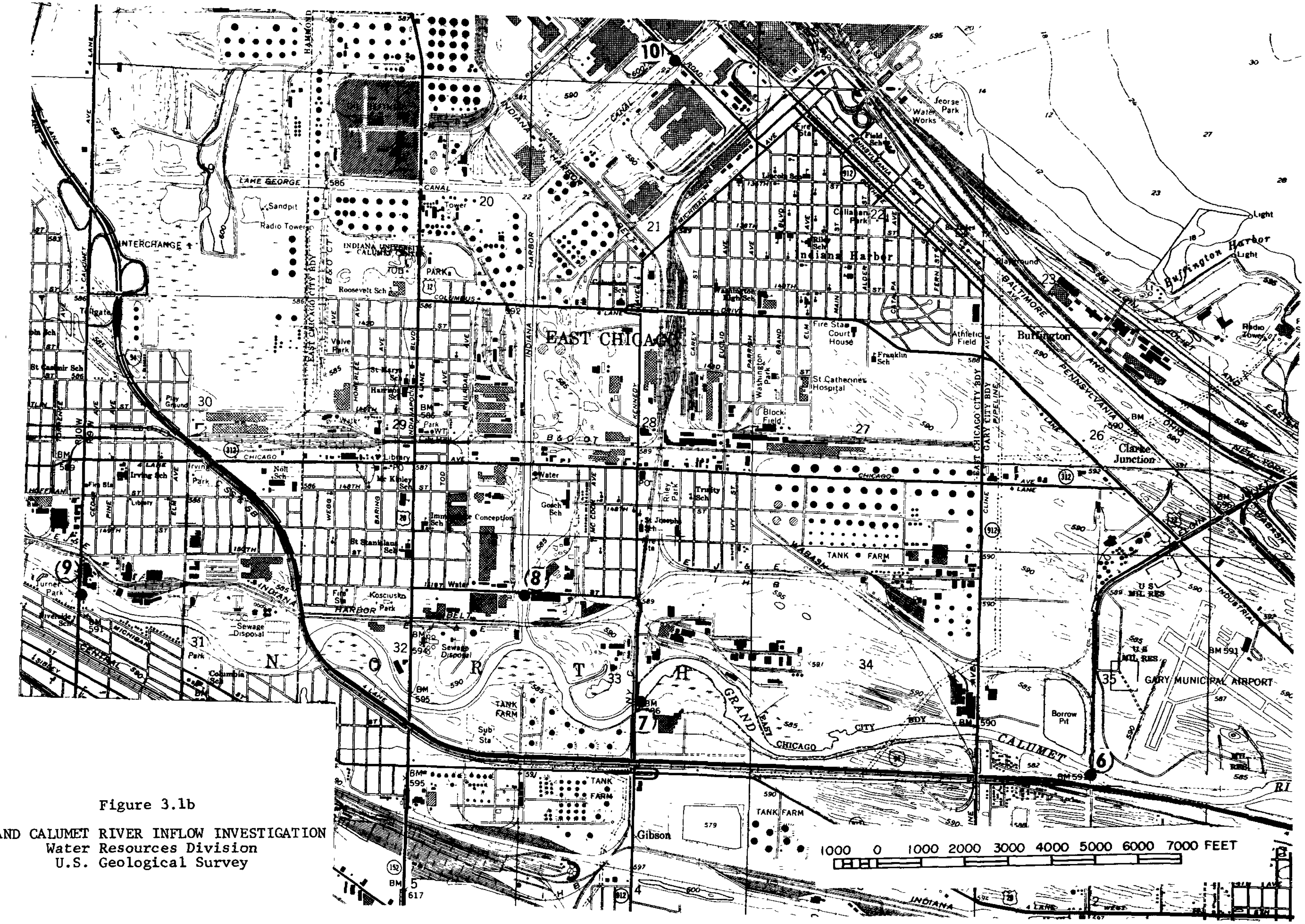

Figure 3.1b

GRAND CALUMET RIVER INFLOW INVESTIGATION
Water Resources Division
U.S. Geological Survey

Flow in Cubic Feet per Second

Site No.	Nov. 1954	May 1955	Aug. 1955	Sept. 1955	Mar. 1956	Mar. 1964	Location
1A	-	31.3	-	-	-	-	
1	52.2	69.0	-	-	-	-	
2	89.5	104	-	-	-	-	
3	265	256	329	-	225	297	Virginia Street
3A	-	344	-	-	-	-	
4	512	491	591	565	490	507	Broadway Street
4A	-	559	-	587	-	-	
5	564	582	723	640	492	657	Buchanan Street
5A	-	649	769	735	609	749	
5B	-	725	810	824	722	718	U.S. Highway 12
6	734	-	783	813	653	848	
6	-	-	-	-	-	808	
7	870	726	1010	844	806	894	Kennedy Avenue
8	785	657	977	933	855	1010	151st Street
9	117	181	209	57.1	58.0	20.1	Calumet Avenue
10	-	-	-	1040	1128	1450	Dickey Road
11	-	-	-	-	-	16.0	Burnham Avenue
	581.68	581.50	581.21	580.70	579.67	577.4 *	Monthly mean levels of Lake Michigan-Datum 1929

* Approximate elevation.

Figure 3.1c

GRAND CALUMET RIVER INFLOW INVESTIGATION
Water Resources Division
U.S. Geological Survey

for some outfalls of Inland and Youngstown Steel Cos. It amounts to 1000 to 1500 cfs.

More recent data from other sources give similar or slightly higher flows. Flows were measured by U.S. EPA in 1971 and 1972 (Table 3.1). The measurements at Kennedy Avenue represent the contribution of the east branch of the Grand Calumet River. The flow is between 900 and 1100 cfs, and is almost the same as the flow in the IHC at 151st St. The flow near the mouth of the IHC was not measured. The flow in the west branch of the Grand Calumet River was measured at Indianapolis Blvd., but this does not include the outflow from the East Chicago STP.

Table 3.2 locates the gaging stations used by Combinatorics (1974) in early October 1973. Their average measurements are given in Figure 3.2. Although there is some variation from point to point, the flow in the east branch of the Grand Calumet River is about 800 cfs. In the IHC it is about 900 to 1400 cfs. Flows from the permit data amount to about 900 cfs, but of course actual flows can vary from this depending on industrial operations at the time. The flow near the mouth of the IHC is higher, amounting to 2290 cfs. This includes some but not all of the inputs from Inland and Youngstown.

IITRI also measured the flow at two points on the IHC in November and December 1973. The methods of measurement are described in Chapter 11. The measurements at Columbus Drive are given in Table 4.4, Chapter 4. They range from 880 to 2200 cfs. There were no substantial rainfalls during the measurements. A representative flow would be about 1200 cfs. These variations could represent changes in industrial pumping rates, or reactions to fluctuations in level. Combinatorics (1974) also noticed that flow measurements varied in the IHC.

Level fluctuations occur in the dredged portion of the IHC, and even in its source, the Grand Calumet River. Continuous level monitoring records taken at Chicago Avenue on the IHC (Bowden 1974) show a fluctuation of the IHC water level of 1 ft with a

Table 3.1

CALUMET AREA SURVEILLANCE STREAM FLOW DATA
Q = Discharge in Cubic Feet Per Second
V = Velocity in Feet Per Second
(U.S. EPA, Region V, ILDO
January 8, 1973)

Date	Grand Calumet River @ Penn RR	Grand Calumet River @ Kennedy Ave.	Grand Calumet River @ Indianapolis Blvd *	Grand Calumet River @ Hohman Ave.	Indiana Harbor Canal @ 151st St.
	Q V	Q V	Q V	Q V	Q V
8/6/71	420, 1.5				
8/12/71	650, 2.2				
8/18/71	760, 2.3				760, 0.97
8/24/71	780, 2.3			44, 1.5	
8/30/71	710, 2.2				730, 0.95
9/1/71		910, 1.2	21W, 0.08		720, 0.88
9/8/71	760, 2.3			40, 1.5	890, 1.2
9/20/71	690, 2.0	900, 1.2			670, 0.84
9/21/71					940, 1.2
9/22/71	770, 2.3	870, 1.2		41, 1.4	
9/23/71		840, 1.2			440, 0.54
9/24/71	740, 2.3			37, 1.4	900, 1.2
9/27/71			70W, 0.32	44, 1.4	
9/28/71	730, 2.2	890, 1.2			850, 1.2
11/3/71		990, 1.6			830, 1.2
12/28/71			0.0, 0.0		980, 1.4
4/4/72			67E, 0.36		
4/11/72		980, 1.4	6E, 0.03		970, 1.4
4/17/72			56E, 0.27		920, 1.3
5/9/72	730, 2.2	1,000, 1.3	17E, 0.06		1,100, 1.4
5/10/72	720, 2.3	1,000, 1.4	49E, 0.20	59, 1.7	1,100, 1.4
5/11/72				54, 1.7	
10/11/72					1,200, 1.6
10/12/72		1,100, 1.3			
10/27/72	810, 2.4	1,100, 1.4			870, 1.1
10/31/72	770, 2.3				890, 1.1
11/3/72		920, 1.1			880, [illegible]
11/13/72	790, 2.3	740, 0.88			720, 0.83
11/17/72		920, 1.2	30W, 0.24		900, 1.1
Number of Measurements	15	14	9	7	21
Mean	720, 2.2	940, 1.3	-	46, 1.5	870, 1.1
Maximum	810, 2.4	1,100, 1.4	-	59, 1.7	1,200, 1.6
Minimum	420, 1.5	740, 0.88	-	37, 1.4	440, 0.54

* Flow can be to east or west.
Flows on 4/11/72, 5/9/72, and 11/17/72 are net flows; portion of stream flowed to east, portion to west.

Table 3.2

VELOCITY AND FLOW SURVEY OF OCTOBER 1-4, 1973
(Combinatorics 1974)

East Leg Grand Calumet River

Station	Cross-section, ft^2	Mile	Description of Location
CRE-1		5.97	200 ft. U.S. of Bridge St.
CRE-2		4.65	600 ft. D.S. of Penn Central R.R. Bridge near Gary S.T.P.
CRE-3		4.19	1,000 ft. D.S. of Industrial Highway (U.S. 12)
CRE-4		2.62	200 ft. U.S. of Cline Ave.
CRE-5	555	.63	200 ft. D.S. of Kennedy Ave.

West Leg of Grand Calumet River

Station	Cross-section, ft^2	Mile	Description of Location
CRW-1		2.00	At culvert crossing of Columbia Ave. (tentative)
CRW-2	352	1.42	900 ft. west of Toll Road.
DRW-3	249	.50	600 ft. east of Indianapolis Blvd.

Indiana Harbor Canal

Station	Cross-section, ft^2	Mile	Description of Location
HCX-1		3.86	100 ft. U.S. of 151st Street
HCX-2		3.10	200 ft. D.S. of B&O Railroad
HCX-3		2.35	1,032 ft. D.S. of Columbus Drive, between first and second Shell tanks nearest west bank.
HCX-4		1.94	300 ft. U.S. of Harbor Belt R.R.
HCX-5		1.25	300 ft. U.S. of Dickey Road
HCX-6		.60	Canal entrance, 500 ft. D.S. from last of triple railroad bridges.

Lake George Canal

Station	Cross-section, ft^2	Mile	Description of Location
LG-1		.5	100 ft. U.S. of Indianapolis Blvd.

U.S. = Upstream

D.S. = Downstream

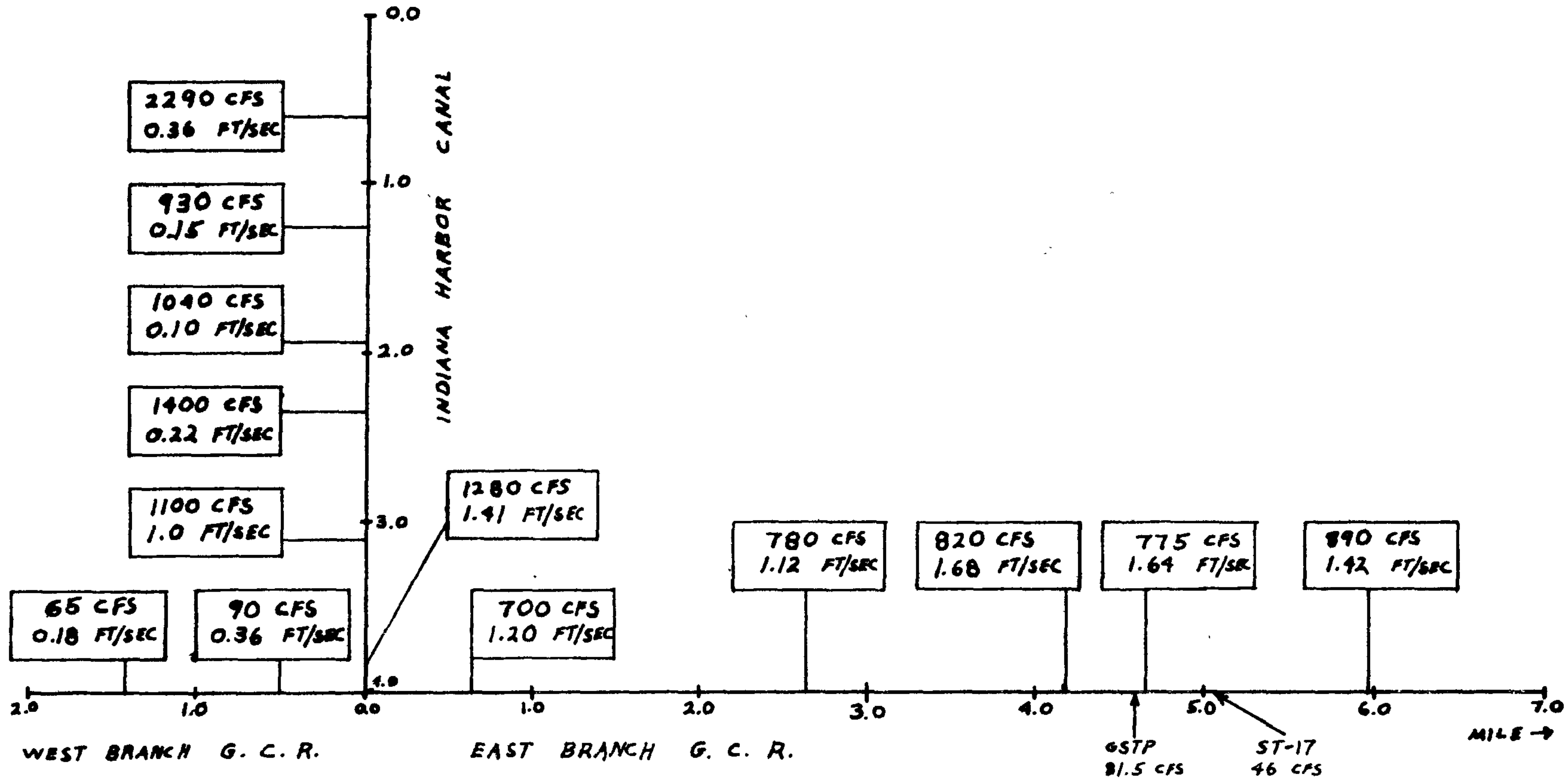

Figure 3.2

FLOW SURVEY OF OCTOBER 1-4, 1973
(Combinatorics 1974)

period of 1 hr. This appears to be due to natural resonance of the IHC geometry. The level is affected a few inches as far upstream as the Grand Calumet River. The level records also show a fluctuation with a period of 12 hr, which is the same period as north/south Lake Michigan oscillations (Mortimer 1968). The calculated volume of water associated with a level fluctuation of 1 ft is sufficient to explain the variations in flow rate that we measured at Columbus Drive, as shown in Table 4.4. Unfortunately we did not fully appreciate the nature of the flow fluctuations at that time, and did not measure the IHC level simultaneously with the flow measurements. Nevertheless the average flow data in Table 4.4 should be valid, and can be used for the purpose of checking the average effluent loads.

Changes of level as much as 3 ft are said to occur occasionally (Winters 1973; Bowden 1974). Such a change could result in a sudden outflow from the IHC; this could flush a slug of polluted water into the Lake, and produce concentrations higher than the usual plume. We did not observe any noticeable changes in the level of the IHC, but we believe they could occur.

IITRI also measured the flow on three days at the mouth of the IHC, at station CAL06. These are the only measurements we know of at this point. The measurements were made with a current meter by the method described in Chapter 11. The results are given in Chapter 12, Tables 12.1 and 12.2. At this point, the flow comes largely from upstream sources, including outfalls from Inland and Youngstown Steel Cos. below Dickey Road. The outflow also includes some Lake water that intrudes in a colder layer under the outflowing surface layer, as is described in Chapter 12.

3.2 Conclusions

Table 3.3 summarizes the flow data from all the data sources described above. The range of values given represents the range of usual values given in each report. The typical value is our own estimate. It is a rough average of the measured values. The typical values given in the table are in reasonable agreement

Table 3.3

SUMMARY OF FLOW DATA IHC AND GRAND CALUMET RIVER
(data from various sources)

Location	Flow, cfs		Flow, m^3/sec
	Typical value	Range	Typical value
Grand Calumet River, east branch	800	600 to 900	23
Grand Calumet River, west branch	70	-- 40 to 90	2.0
IHC, Columbus Drive	1200	800 to 2200	34.
IHC, Dickey Rd.	1500	-	42.
IHC mouth, upstream sources	2200	1500 to 3800	62.
IHC mouth, total	3500	3150 to 4200	100.

with the flow data from permit applications. These are compared in Chapter 4. Our typical values are slightly higher than those estimated by Combinatorics (1974). We feel that the permit data may not be as reliable as the stream measurements, and we put more reliance on the stream measurements than Combinatorics (1974) did.

3.3 Other Stream Flows

Figure 3.3 presents the flow measurements in streams near the Burns Harbor area in Indiana. For historical background, the stream flow data for some years in earlier decades are shown in Table 3.4.

The flow in the Calumet River was qualitatively described in Chapter 2. During our field sampling program we observed that there is usually a sluggish flow from the Calumet River into Calumet Harbor. We have not measured the flow, nor do we know of measurements (except an observation in Appendix D, Section 9). From available information it is reasonable to assume that the effluent from South Works goes into the Lake, and effluents from sources further inland normally go westward to the Cal-Sag channel (Technical Committee 1970).

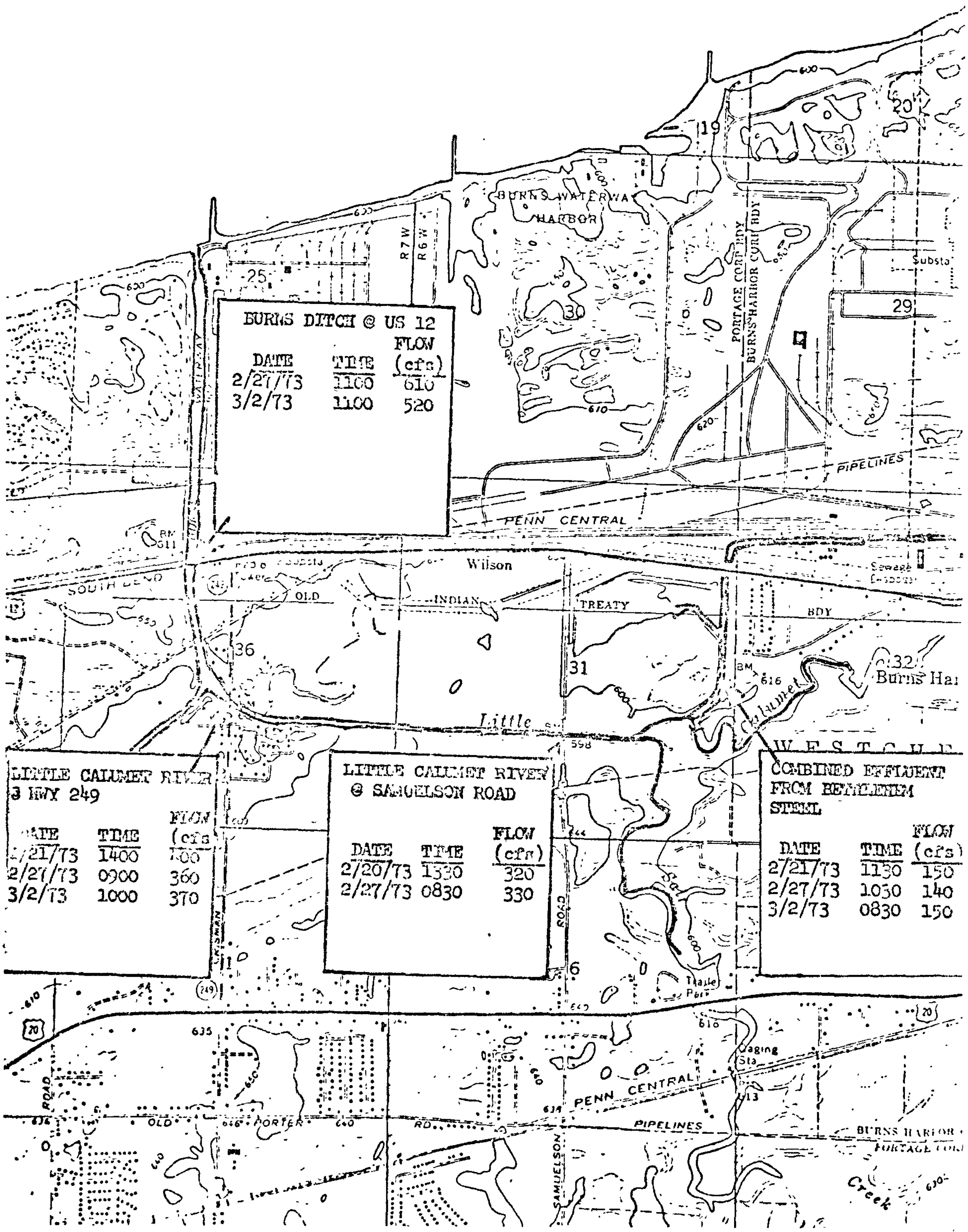

Figure 3.3

FLOW MEASUREMENTS NEAR BURNS HARBOR, INDIANA with the flow data from permit applications. These are compared in Chapter 4. Our typical values are slightly higher than those estimated by Combinatorics (1974). We feel that the permit data may not be as reliable as the stream measurements, and we put more reliance on the stream measurements than Combinatorics (1974) did.

3.3 Other Stream Flows

Figure 3.3 presents the flow measurements in streams near the Burns Harbor area in Indiana. For historical background, the stream flow data for some years in earlier decades are shown in Table 3.4.

The flow in the Calumet River was qualitatively described in Chapter 2. During our field sampling program we observed that there is usually a sluggish flow from the Calumet River into Calumet Harbor. We have not measured the flow, nor do we know of measurements (except an observation in Appendix D, Section 9). From available information it is reasonable to assume that the effluent from South Works goes into the Lake, and effluents from sources further inland normally go westward to the Cal-Sag channel (Technical Committee 1970).

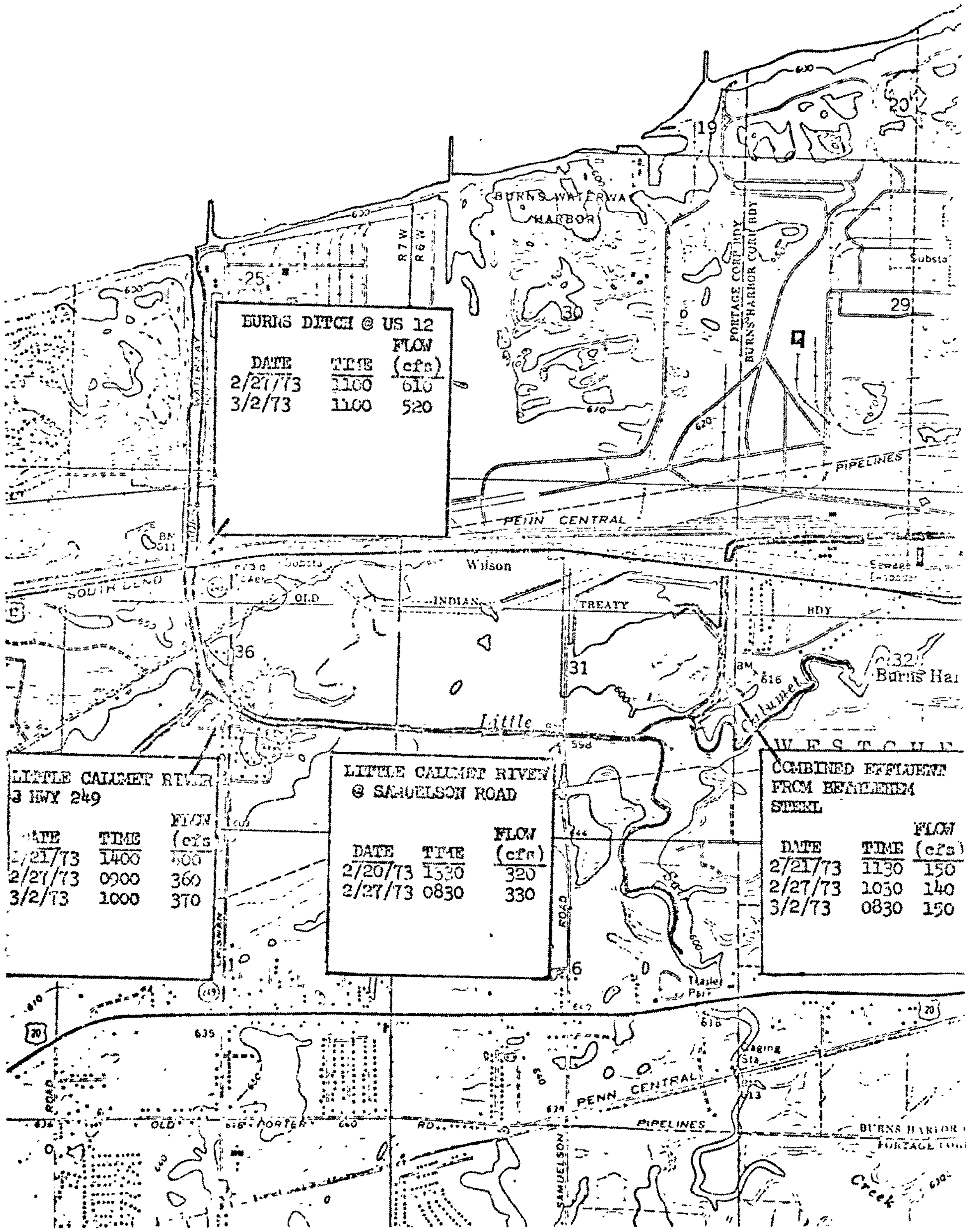

Figure 3.3

FLOW MEASUREMENTS NEAR BURNS HARBOR, INDIANA

Table 3.4

SELECTED LOW FLOW AND OTHER DATA FOR STREAM GAGING STATIONS[1]

River	Station location	Drainage area, sq. miles	Gage datum above M.S.L., ft	Bankful stage, ft	7-day 10-yr low flow, cfs	Min. day flow, cfs	Comments	Records since, yr
Lake Michigan Basin		-	-	-				
Little Calumet	Munster	-	-	-	3.7	2.0		-
Little Calumet	Gary	-	-	-	0.0	0.0		-
Little Calumet	Porter	62.9	603.48	7.0	19.9	18.0		1945
Burns Ditch	Gary	160.0	577.04	-	5.6	2.6	Above confluence with Little Cal.	1944
Hart Ditch	Muncster	69.2	591.27	7.0	3.2	2.8		1943
Deep River	Lake George Outlet	125.0	-	-	4.9	4.2		1947
Salt Creek	McCool	78.7	594.10	10.0	21.0	19.0		1945

[1]Source: "Low Flow Characteristics of Indiana Streams" U.S.G.S. and State of Indiana, 1961.

Second Source: Lake Porter Regional Transportation and Planning Commission Report: "Water and waste water, a component of the regional plan."

4. INDUSTRIAL WASTE SOURCES, OUTFALLS AND EFFLUENT DATA

4.1 Description

The major population centers in the area are East Chicago, Gary, Hammond and Whiting, in Indiana; and a part of the south side of Chicago in Illinois. The area is highly industrialized. There are ten major steel mills including the United States Steel Corporation's Gary Works, Gary Sheet and Tin Mill, Youngstown Sheet and Tube Company, and Inland Steel Company in Indiana and United States Steel's South Works in Illinois. There are four petroleum refineries including the American Oil Company, the Cities Service Refinery (now closed), the Mobil Oil Company, and the Arco Refinery, in Indiana. Other industries include Lever Brothers, Union Carbide Chemicals, E.I. DuPont, Blaw Knox, American Maize and a large number of smaller concerns.

These industries are located in four major groups. One group is concentrated along the Calumet River in Illinois. Of these, only U.S. Steel discharges to the Lake under normal conditions. Another is along the Indiana Harbor Canal (IHC). The third is in Gary, Indiana, and discharges to the headwaters of the Grand Calumet River and to the Lake via the IHC. A fourth includes several steel mills, municipalities and smaller industries in the Burns Harbor basin. These groups make the Calumet area one of the most important industrial centers in the nation.

The largest sources of pollution are industries along the IHC. There are currently seven major industries discharging into the Grand Calumet River and IHC, and several other industries with minor discharges. These are mainly steel mills, oil refineries, a chemical company, and municipal sewage treatment plants. The main pollutants are ammonia, oil, iron sediments, BOD, fecal bacteria, phenol, cyanide, and some heavy metals. The amounts of these effluents are assessed in this chapter, and detailed analyses of individual parameters are given in Chapters 13 to 18. All of the major discharges currently provide some treatment to their waste water, but in some cases current treatment is inadequate. Law suits are pending against several steel mills to force them to provide better treatment.

There are some outfalls along the Lake shore, primarily from American Oil Co. in the Whiting area, and from U.S. Steel Co. at Gary. There are also a number of combined storm-sewage overflow outfalls, both along the Lake and in tributary streams. Plans to treat these overflows are scheduled for 1977.

The Indiana Stream Pollution Control Board has reported to the Lake Michigan Enforcement Conference that a number of industries on the Little Calumet River are meeting Indiana effluent requirements. The Conference Proceedings (1970) lists these sources, the flow volumes, and the type of treatment used. In the Burns Harbor area are two steel companies that have new effluent treatment facilities. Permit and water quality data for these sources are discussed in Appendix C.

4.2 Identification of Outfalls

Figure 4.1a and 4.1b present a location map of the various important industries and sewage treatment plants in the Calumet area which are the principal sources of wastes. Detailed maps showing the locations of outfalls are given in Appendix C. A listing of the outfalls is given in Table 4.1.

The sources for developing the outfall identification maps are NPDES Permit applications, Indiana State Pollution Control Board 24-hr effluents sampling program data and site visits by the personnel of Citizens for a Better Environment (CBE) and Businessmen and Professionals in the Public Interest (BPI). CBE was our subcontractor for this part of the work, and information was taken from a previous study by Businessmen in the Public Interest (1972). Data were current as of fall 1973.

Appendix C contains a description of each of the industries that discharge in the area, with additional information about the discharges.

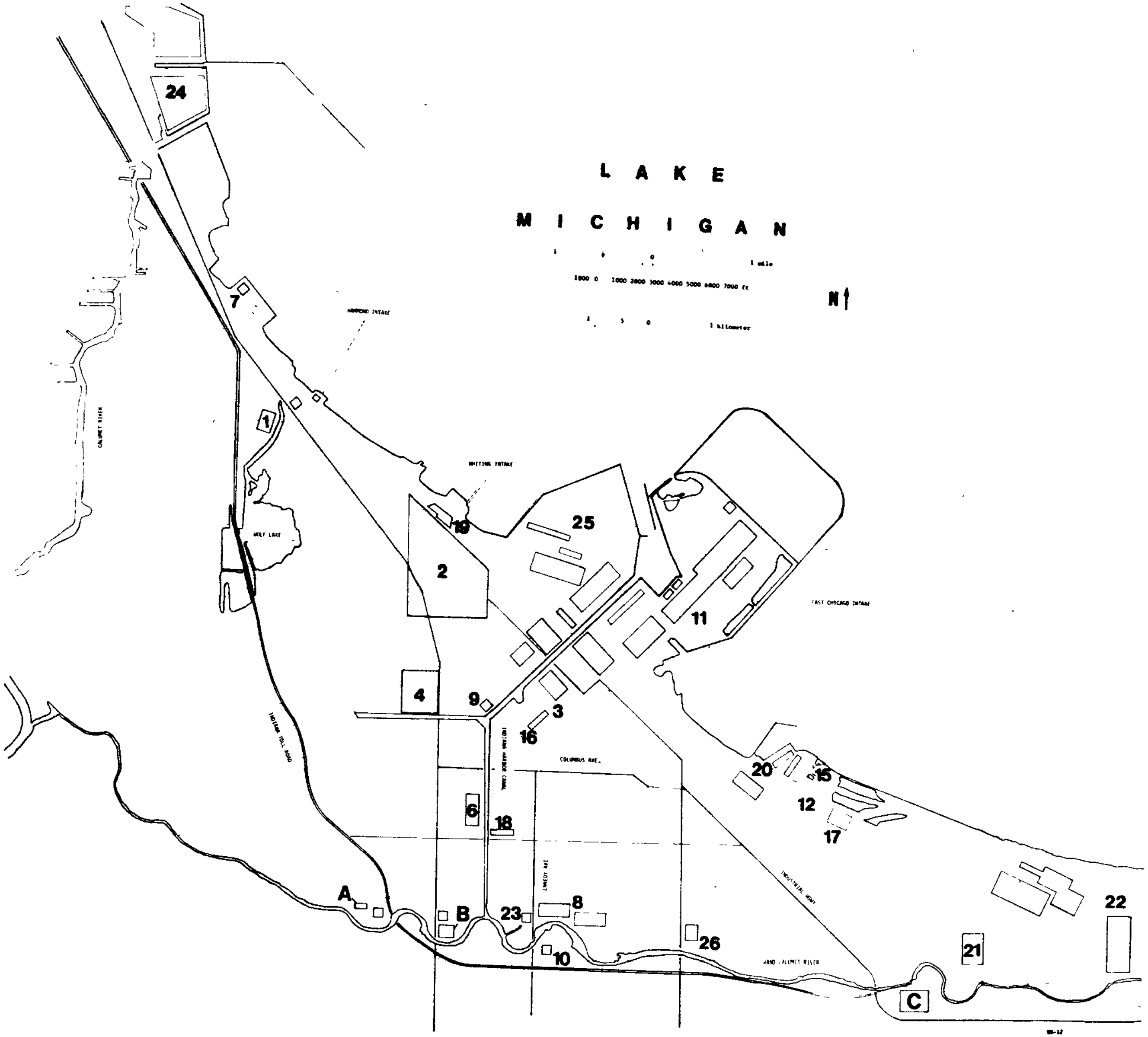

Figure 4.1a

LOCATION MAP SHOWING MAJOR INDUSTRIAL AND MUNICIPAL PLANTS
IN THE CALUMET AREA

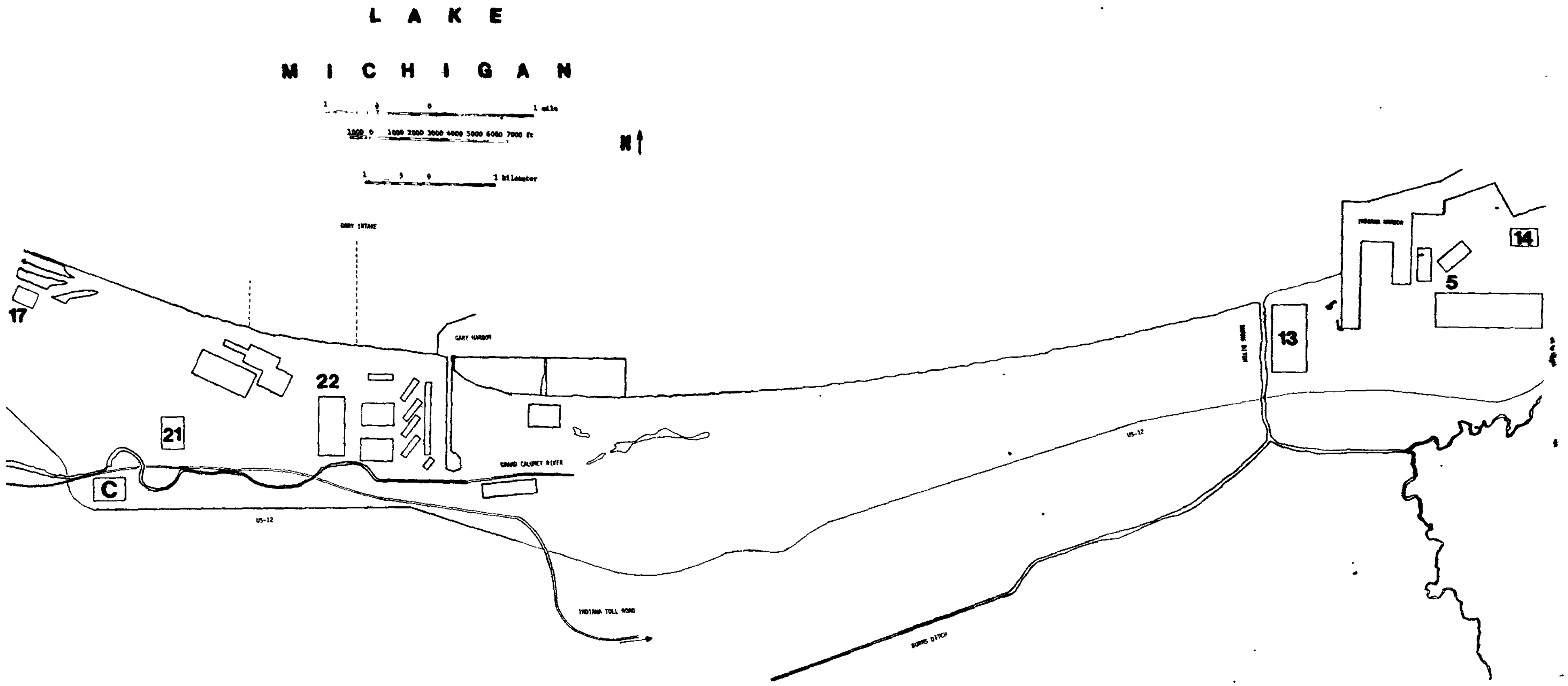

Figure 4.1b

LOCATION MAP CONTINUED

Table 4.1

LISTING OF INDUSTRIAL EFFLUENT SOURCES IN CALUMET AREA

BASIN	NAME OF COMPANY	DATE	NPDS #	MAJOR	PERMIT	# OUTFALLS	FLOW	TYPE OF WASTE
Lake Michigan	US Steel - South Works	6-18-71	2720612	Yes	No	6	241.24 MGD	Cooling water
Lake Michigan	Commonwealth Edison - State Line	7-1-71	2720443	Yes	No	1	1000 MGD	Cooling water
Lake Michigan	American Maize	6-22-71	2720034	Yes	No	1	9.7 MGD	Process water
Lake Michigan	American Oil	6-7-71	2720170	Yes	No	2	130 MGD	Process &cooling water
Lake Michigan	Union Carbide - Whiting	6-4-71	2720011	Yes	No	1	47.54 MGD	Cooling water
Lake Michigan	Universal Atlas Cement Division US Steel			Two possible unreported discharges				
Lake Michigan	NIPSCO - Mitchell Station	6-30-71	2720201	Yes	No	1	457 MGD	Cooling water
Lake Michigan	Marblehead Lime Co.		2720485	No	No	2	130,000 GPD	Water runoff
Lake Michigan	Union Carbide T-1200 Linde Division	6-18-71	2720042	Yes	No	1	100 MGD	Cooling water
Lake Michigan	US Steel - Gary	7-1-71	2720608	Yes	No	5	251.5 MGD	Cooling & process water
Lake Michigan	Midwest Steel Burns Ditch	6-30-71	2720355	Yes	No	5	11.923 MGD	Cooling & process water
Lake Michigan	Bethlehem Steel - Burns Harbor	8-25-71	2720246	Yes	No	1	104 MGD	Treated process water
Lake Michigan	NIPSCO Bailey Station	6-30-71	2720202	Yes	No	1	456 MGD	Cooling water
Little Calumet	Bethlehem Steel	8-25-71	2720246	Yes	No	1	154 MGD	Treated process water

Table 4.1 (cont.)

LISTING OF INDUSTRIAL EFFLUENT SOURCES
CALUMET STUDY AREA

BASIN	NAME OF COMPANY	DATE	NPDES #	PERMIT	MAJOR	# OUTFALLS	FLOW	TYPE OF WASTE
Grand Calumet River	US Steel - Gary	7-1-71	2720608	No	Yes	34		Process & cooling
Grand Calumet River	US Lead Refinery	6-30-71	2720393	No	?		150,000 CPD	Cooling water very high temp.
Grand Calumet River	US Steel - American Bridge			Two possible unreported discharges				
Grand Calumet River	E.I. DuPont de Nemours	4-17-72	2720889	No	Yes	9	9850 GPM	3 Outfalls proposed at flow
Grand Calumet River	Harrison-Walker Refractories	6-14-71	2720462	No	No	1	140,000 GPD	Non-contact cooling
Indiana Harbor Canal	Blaw-Knox	6- -71	2720710	No	NO	2	207 MGD	2 Outfalls - storm drainage only
Indiana Harbor Canal	Union Carbide-Linde Air Products	6-15-71	2720043	No	Yes	1	150,750 GPD	Process water
Indiana Harbor Canal	General Transportation Corp.	6-28-71	2722502	No	No	1	30,000 GPD	Process water
Indiana Harbor Canal	Atlantic Richfield	6-25-71	2720045	No	Yes	1	4.75 MGD	Submerged outfall data rev. 7-16-73
Indiana Harbor Canal	Phillips Pipeline	6-30-71	2720563	No	No	1	48,000 GPD	Process water
Indiana Harbor Canal	American Steel Corp.	6-25-71	2720242	No	No	1	230,000 GPD	Contact-cooling quench water for heat-treated steel castings
Indiana Harbor Canal	Union Carbide - Whiting	6-4-71	2720011	No	Yes	1	216,000 GPD	Process water
Indiana Harbor Canal	Inland Steel	6-21-71	2720129	No	Yes	18	865 MGD	Process & cooling water
Indiana Harbor Canal	Youngstown Steel	7-1-71	2720319	No	Yes	11	290 MGD	Process & cooling water

4.3 Effluent Loads Other Than via IHC

Table 4.2 gives a more detailed list of outfalls to Lake Michigan (other than those entering via the IHC). The table also gives the flows, concentrations and loads of the most important pollutants. This information is taken primarily from permit applications. In Appendix C additional information is given, comparing the permit data with data from Indiana 24-hr sampling of the industry outfalls. The sampling was done on February 2-3, 1973, and June 19-20, 1973. The State of Indiana also obtains daily operating reports on a monthly basis from major industries. The data from these three sources of information are compared in Appendix C; the conclusion is reached that most of the permit data are of the correct order of magnitude, although numerous discrepancies are pointed out.

Most RAPP documents were submitted in the summer of 1971, and data included could represent analysis taken as much as one year previously. Some industries have installed pollution control equipment and made other changes in their processes. Most of these have been reflected in changes in the permit application data in U.S. EPA files. Appendix C represents the available data in December 1973. In the case of DuPont and U.S. Steel South Works, the information in the Appendix has been updated based on court decrees.

4.4 Effluent Loads to Lake Michigan via IHC

The sources that discharge into the Grand Calumet River and the IHC were investigated by Combinatorics (1974). Their information is partly from permit applications, partly from data in Indiana files, and partly from information supplied to Combinatorics by industry. A descripton of the status of each industry in this group is also given in the Combinatorics (1974) report, together with projections for the future.

A list of the major outfalls in this group is given in Table 4.3. The flow rates, concentrations of each pollutant and

Table 4.2

EFFLUENT CONCENTRATIONS AND LOADS FROM INDUSTRIES IN CALUMET AREA
DRAINING INTO LAKE MICHIGAN DIRECTLY
OR VIA LITTLE CALUMET RIVER AND BURNS DITCH
Average values (maximum values in parenthesis)
Source: NPDES data compiled by Citizens for a Better Environment
as of December 1973

	Flow		Chloride		Ammonia-Nitrogen		Total organic carbon		Fluoride	
Source and outfall	mgd	m^3/sec	mg/ℓ	lb/day	mg/ℓ	lb/day	mg/ℓ	lb/day	mg/l	lb/day
NIPSCO Bailly	Cooling									
001	456	20.	8	30,448	-	-	-	-	-	-
			(8)	(31,220)	(0.03)	(117)	-	-	-	-
Bethlehem Steel	treated process									
001	104	4.6	30	25,821	0.1	86	-	-	0.43	370
			(140)	(199,864)	(1.4)	(1,998)	-	-	(1.42)	(2,027)
002	154	6.7	8	10,219	0.1	127	-	-	0.13	166
			16	(23,665)	(1.4)	(2,070)	-	-	1.0	(1,479)
Midwest Steel										
001	0.023	0.001	-	-	0.65	<1	-	-	-	-
			-	-	(0.65)	(0.271)	-	-	-	-
002/003	Cooling									
	4.76	0.2	-	-	-	-	-	-	-	-
004	9.06	0.40	20	1,512	0.0185	1.4	-	-	1.00	76
			(25)	(2,168)	(0.035)	(2.64)	-	-	(3.0)	(260)
005	Cooling									
	1.08	0.047	-	-	-	-	-	-	-	-
006/STP	0.0007	-	-	- -	-	-	-	-	-	-
U.S. Steel Gary										
035	76.8	3.36	12	7,686	0.3	192	-	-	0.2	128
036	28.2	1.24	11	2,587	-	-	-	-	0.2	47
037	7.0	0.307	11	642	0.2	12	-	-	-	-
038	10	0.44	Recently became operational; no data available							
039	71.3	3.12	12	7,136	0.3	178	-	-	-	-
Marblehead Lime										
007	0.07	0.003	-	-	0.05	small	-	-	-	-
008	0.06	0.003	-	-	-	-	-	-	-	-

Table 4.2 (cont.)

Source and outfall	Total iron mg/ℓ	Total iron lb/day	Total solids mg/ℓ	Total solids lb/day	Total suspended solids mg/ℓ	Total suspended solids lb/day	Total phosphorus mg/ℓ	Total phosphorus lb/day	Total coli mg/ℓ	Total coli lb/day
NIPSCO Bailly										
001	-	-	182	692,692	20	76,120	-	-	642	24.2×10^6
	-	-	(165)	(643,919)	(3)	(11,708)	(0.27)	(1,054)	(642)	-
Bethlehem Steel										
001	2.358	2,030	286	246,163	16	13,771	0.37	318	-	-
	(9.6)	(13,705)	(450)	(656,696)	(74)	(105,642)	(3.0)	(4,282)	60	-
002	1.339	1,710	214	273,357	16	20,437	0,21	268	-	-
	7.0	(10,353)	(300)	(443,718)	(209)	(309,123)	(2.0)	(2,958)	-	-
Midwest Steel										
001	-	-	170	32	-	-	0.15	<1	-	-
	-	-	(170)	(71)	(3)	(11,708)	(0.15)	(0.063)	-	-
002/003	-	-	-	-	-	-	-	-	-	-
004	0.5	38	957	72,350	10.7	809	0.1	8	-	-
	(0.7)	(60.67)	(823)	(62,233)	(11.0)	(833)	(0.1)	(7.55)	(540)	-
005	-	-	-	-	-	-	-	-	-	-
006/STP	-	-	-	-	7.7	small	-	-	-	-
U.S. Steel Gary										
035	-	-	156	99,920	3	1,192	0.42	12.8	-	-
036	0.1	9	168	39,512	10	2,352	0.02	4.7	-	-
037	1.1	64	165	9,633	6	350	0.02	1.2	-	-
038	-	-	-	-	-	-	-	-	-	-
039	1.8	64	226	134,389	21	12,487	0.01	6.4	-	-
Marblehead Lime										
007	-	-	952	556	0	0	0.6	small	-	-
008	-	-	987	494	0	0	-	-	-	-

Table 4.2 (cont.)

Source and outfall	Flow mgd	Flow m³/sec	Chloride mg/ℓ	Chloride lb/day	Ammonia-Nitrogen mg/ℓ	Ammonia-Nitrogen lb/day	Total organic carbons mg/ℓ	Total organic carbons lb/day	Fluoride mg/ℓ	Fluoride lb/day
NIPSCO Mitchell	Cooling 457	20.	-	-	0.04	152	-	-	-	-
			(8.5)	(43,921)	(0.04)	(207)	-	-	-	-
Amoco										
001	29.17	1.28	44	10,672	5.43	1,319	36	8,748	-	-
			(54)	(13,121)	(20.0)	(4,665)	(44)	(10,692)	-	-
002	Cooling 99	4.3	5.3	4,327	0.06	48	20	16,327	-	-
Union Carbide Whiting										
001	47.54	2.1	8	3,174	-	-	392	15,562	0.15	60
			(12)	(22)	-	-	-	-	-	-
American Maize	Process 9.7	0.43	11	890	1.57	127	13	1,052	-	-
			(12)	(971)	(1.96)	(245)	(14)	(1,133)	-	-
Com. EDI Stateline	Cooling 1000	4.4	11	91,806	0.11	0 (net)	-	-	-	-
			-	-	-	-	-	-	-	-
U.S. Steel S. Works										
001	110.9	4.9	11	10,181	-	-	2.1	1,944	0.2	185
002	12.96	0.57	13	1,406	0.3	32	8.5	919	0.4	43
003	16.56	0.73	-	-	0.4	55	2.6	359	-	-
004	Stream overflow		-	-	-	-	-	-	-	-
005	3.74	0.16	12	375	1.5	47	9.8	306	0.3	9
006	97.36	4.3	14	11,374	0.09	73	8.0	6,500	0.5	406

Table 4.2 (cont.)

Source and outfall	Total iron mg/ℓ	Total iron lb/day	Total solids mg/ℓ	Total solids lb/day	Total suspended solids mg/ℓ	Total suspended solids lb/day	Total phosphorus mg/ℓ	Total phosphorus lb/day	Total coli mg/ℓ	Total coli lb/day
NIPSCO Mitchell	-	-	208	793,312	10	38,140	0.14	723	546	$2x10^7$
	(274)	(1,416)	(208)	(1,074,782)	(10)	(51,672)	(0.14)	(723)	-	-
Amoco										
001	0.357	87	360	87,475	20	4,860	0.03	3	-	-
	(580)	(141)	(406)	(101,459)	(78)	(19,472)	(0.22)	(56.8)	-	-
002	0.230	190	208	171,185	12	9,876	0.01	8	-	-
Union Carbide Whiting										
001	0.2	80	2.4	950	-	-	0.05	small	-	-
	(0.45)		(17.3)	(31.1)	(17.3)	(31.1)	(0.19)	(0.33)	-	-
American Maize	-	-	285	23,056	23	1,860	0.52	41	0	0
	-	-	(718)	(89,822)	(76)	(9,508)	(0.73)	(91)	-	-
Com. EDI Stateline	0.097	810	175	1,460,550	6	50,076	0.10	41,793	-	-
	(0.58)	-	(2)	(670)	0	-	(0.07)	(2.81)	-	-
U.S. Steel S. Works										
001	4.0	3,702	184	170,305	6	5,553	0.03	28	-	-
002	1.6	173	206	22,281	14	1,514	0.04	4	-	-
003	1.1	152	194	26,813	14	1,934	0.02	3	-	-
004	-	-	-	-	-	-	-	-	-	-
005	2.6	81	203	6,336	33	1,030	0.05	2	-	-
006	20	1,625	320	259,968	28	22,747	0.05	41	-	-

Table 4.3

LOCATION AND DESCRIPTION OF DISCHARGES TO GRAND CALUMET RIVER AND IHC
Source: Combinatorics (1974)

Discharge Designation	NPDES Permit Design.	Location (River Mile)	Description of Discharge
U.S. Steel		East Branch	
GW-1	002	9.30	Process water from tube operation; non-contact water from coke plant.
GW-2	007	9.20	Non-contact water from distillation plant; misc.
GW-2A	009	9.08	Process water from blast furnaces.
GW-3	010	8.83	Non-contact water from No. 1 battery air compressor; misc.
GW-3A	011	8.73	Process water from blast furnaces.
GW-4	015	8.50	Non-contact water from No. 3 sinter plant.
GW-5	017	8.35	Process water from blast furnaces.
GW-6	018	8.31	Non-contact water from blast furnaces, No. 2 sinter plant, and No. 4 boiler house.
GW-7	019	8.21	Non-contact water from No. 2 sinter plant, No. 4 boiler house.
GW-7A	020	8.07	Non-contact water from No. 1 Basic Oxygen Process (BOP) shop and No. 4 boiler house.
GW-9	021	7.94	Non-contact water from No. 3 and No. 4 open hearth operations.
GW-10A	028	7.78	Process water from bar mills, wheel mill, billet mill, rail mill, blooming mills, slabbing mill, and plate mill. Non-contact water from bar mills and rail mill.
GW-11A	030	7.36	Same as 10A.
GW-13	032	7.30	Non-contact water from bar mill.

Table 4.3 (cont.)

Discharge Designation	NPDES Permit Design.	Location (River Mile)	Description of Discharge
ST-14	033	6.50	Non-contact water from atmosphere gas plant.
ST-17	034	5.04	Process water and non-contact water from galvanizing line, hot strip mills, pickle lines, CR mills, CA lines, tin mills, and annealing operations.
Gary			
GSTP-1	N/A	4.60	Gary's wastewater treatment facility discharge.
E.I. duPont			
001	001	1.40	Process and non-contact cooling water from the production of inorganic chemicals.
002-004	002-004	1.38	Same.
005	005	1.16	Same.
007-010	007-010	.85	Same.
U.S.S. Refinery Inc.			
USL-1	001	.25	Non-contact cooling water discharge from blast furnace and casting mold.
Hammond		West Branch	
HSTP-1	N/A	1.90	Hammond's wastewater treatment facility discharge.
East Chicago			
ECSTP	N/A	.55	East Chicago's wastewater treatment facility discharge.

Table 4.3 (cont.)

Discharge Designation	NPDES Permit Design.	Location (River Mile)	Description of Discharge
Atlantic Richfield Oil Company		Lake George Branch	
ARCO	001	1.00	Oil refinery discharge.
Union Carbide Linde Division		IHS Canal	
UC-1	001	2.65	Process and cooling discharge from production of industrial gases.
Youngstown			
YS-20	001	1.81	Process water from continuous pickling, cold rolling and finishing operations.
American Steel Foundries			
AS-1	001	1.70	Process and cooling waters from a foundry.
Inland			
IE-2	001	1.50	Process and cooling water from an electric furnace steel shop and bar mill.
Youngstown			
YS-2	002	1.20	Cooling water from cold rolling and finishing operations.
YS-4	003	1.16	Cooling water from finishing operations at No. 1 tin mill.
YS-8	004	1.00	Cooling water from cold rolling operation at No. 1 tin mill.
YS-11	005	1.00	Cooling water from continuous pickling operation at No. 1 tin mill.
Inland			
4E-1	002	1.00	Process water, contact and non-contact cooling water from blast furnace; non-contact cooling water from a coke plant; and power house cooling water.

Table 4.3 (cont.)

Discharge Designation	NPDES Permit Design.	Location (River Mile)	Description of Discharge
5E-1	003	.95	Process water and non-contact cooling water from a plate mill, spike mill and continuous hot dip galvanizing lines.
5E-2	004	.94	Process and non-contact cooling water from a spike mill.
Youngstown			
YS-12	006	.90	Cooling and process water from a coke plant operation.
Inland			
5E-3	005	.87	Process and non-contact cooling water from a bar mill and blooming mill.
Youngstown			
YS-13	007	.83	Cooling and process water from a coke plant operation.
Inland			
6E-1	006	.78	Discharge from auto tunnel sump-pumps.
Youngstown			
YS-22	008	.78	Cooling and process water from a coke plant operation.
YS-14	009	.65	Power house and sinter plant cooling water.
Inland			
7E-1	007	.64	Non-contact and contact cooling water from blast furnaces.
Youngstown			
YS-15	010	.63	Power house and blast furnace cooling water.
Inland			
10E-1	008	.20	Non-contact condenser cooling water from power house.

Table 4.3 (cont.)

Discharge Designation	NPDES Permit Design.	Location (River Mile)	Description of Discharge
Youngstown			
YS-18A	011	Harbor West Side	Process water and cooling water from blooming, hot strip, billet, bar, and buttweld mills; process and cooling water from boiler house, open hearths, and basic oxygen furnace; cooling water from blast furnace.
Inland			
13G-1	011	Harbor East Side	Non-contact and contact cooling water from blast furnaces; non-contact cooling water from sintering plant and power house.
13H-1	012	Harbor East Side	Gas scrubber water from blast furnaces, cooling water from coke plant and open hearth and a sanitary sewage plant effluent.
14H-TT	013	Harbor East Side	Process water from a coke plant, hot rolling mills, and cold rolling mills; coil picklers rinse water.
15H-TT	014	Harbor East Side	Process water from a coke plant, hot rolling mills, and cold rolling mills; coil picklers rinse water.
16H-1	015	Harbor East Side	Non-contact cooling water from an open hearth furnace and a small sanitary sewage plant effluent.
16H-2	016	Harbor East Side	Non-contact cooling water from an open hearth furnace and mold foundry operation.
16H-3	017	Harbor East Side	Process water from hot and cold rolling mills. Non-contact cooling water from hot strip rolling mills, cold rolling mills, and coil picklers.
16F-1	018	Harbor East Side	Grit water from basic oxygen furnace. Contact and non-contact cooling water from basic oxygen furnace; power house cooling water.

loads are not given in this table; instead, separate tables for each pollutant are given in Chapters 13 to 18.

A check of the accuracy of the load data for this group of industries is given by instream measurements done by IITRI during our field sampling program. The field sampling program is described in Chapter 11. The measured concentrations, measured stream flows, and calculated loads are presented in Tables 4.4 and 4.5. The data in Table 4.4 at the Columbus Drive bridge measure the loads of pollutants from sources upstream of this point. Also given in the table are the sums of the average loads from outfalls above this point estimated by Combinatorics (1974). Similarly, the data in Table 4.5 measure the loads from all outfalls on the IHC/Grand Calumet River system. The Combinatorics estimates tend to be at the low end of the measured range. The loads of many of the pollutants vary from day to day by a factor of about 3. The best measure of the actual effluent loads at this time (November to December 1973) would be an average of the measured loads in Tables 4.4 and 4.5.

Combinatorics (1974) reported effluent loads for some parameters in addition to those shown in Tables 4.4 and 4.5. These parameters are BOD, phenol, and cyanide.

4.5 Conclusions and Recommendations

This chapter summarizes the industrial effluent sources and loads; but the impact of particular pollutants on water quality in Lake Michigan is assessed in Chapters 13 to 18. These chapters conclude that substantial quantities of pollutants are going into Lake Michigan from industrial sources on the IHC; and that the present inadequate municipal sewage treatment is in large part due to overloading of municipal sewage treatment plants by industrial effluents to municipal sewers.

A few industrial companies have substantially reduced their effluents, as a result of settlement of court suits. These include U.S. Steel Corp. South Works, where decreased effluents

Table 4.4

MEASURED EFFLUENT CONCENTRATIONS AND LOAD PER DAY
IN INDIANA HARBOR CANAL AT COLUMBUS DRIVE BRIDGE (STATION IHC3S)
IITRI data

Date	Measured flow (IITRI) cfs	mgd	m^3/sec	Chloride Concentration, mg/l	Load, lb/day	Ammonia-Nitrogen Concentration, mg/l	Load, lb/day	Total organic carbon Concentration, mg/l	Load, lb/day	Fluoride Concentration mg/l	Load, lb/day
11/12/73	-	-	-	55	-	5.3	-	-	--	0.87	-
11/13/73	1409	906	40	65	491,496	4.6	34,783	15.0	113,422	0.76	5,476
11/14/73	1051	679	30	59	334,349	4.5	25,501	14.5	82,170	0.86	4,874
11/15/73	-	-		54	-	5.2	-	12.0	--	1.00	-
11/16/73	-	-		65	-	5.4	-	15.5	--	1.30	-
11/17/73	2200	1422	62	84	999,913	6.8	80,702	17.0	201,756	1.07	12,699
11/18/73	2200	1422	62	46	545,928	3.7	43,912	10.0	118,680	1.00	11,868
11/19/73	880	569	25	72	341,919	5.7	27,069	14.5	68,859	0.93	4,416
11/20/73	880	569	25	45	213,699	3.4	16,146	11.0	52,238	0.78	3,704
11/29/73	1100	711	31	70	415,380	4.8	28,483	18.0	106,812	1.07	6,349
11/30/73	1035	669	29	60	335,008	4.3	24,010	13.0	72,585	1.02	5,695
12/07/73	1470	950	42	71	562,938	6.3	49,951	18.5	146,680	1.34	10,624
12/08/73	-	-		76	-	6.7	-	15.0	--	0.68	-
Combinatorics (1974) estimate:	962.5	622	27		202,603		23,561				4,087

Date	Total iron Concentration, mg/l	Load, lb/day	Total solids Concentration, mg/l	Load, lb/day	Total phosphorus Concentration, mg/l	Load, lb/day	Total coliform Coli/100 ml	Total No.	Suspended solids Concentration, mg/l	Load, lb/day
11/12/73	1.30	-	-	-	-	-			19.8	-
11/13/73	1.32	9,981	-	-	-	-			20.7	-
11/14/73	1.00	5,667	-	-	-	-	$24x10^4$	$6.2x10^{15}$	16.2	91,804
11/15/73	0.86	-	297	-	0.18	-			14.3	-
11/16/73	0.78	-	312	-	0.25	-			12.9	-
11/17/73	0.98	11,631	376	4,462,372	0.24	2,848			13.5	160,218
11/18/73			261	3,097,551	0.18	2,136			10.6	125,800
11/19/73	0.58	2,754	283	1,343,931	0.16	760	$22x10^4$	$4.9x10^{15}$	9.4	44,639
11/20/73	1.47	6,981	215	1,030,506	0.14	665			18.5	87,854
11/29/73	0.88	5,222	246	1,459,765	0.23	1,365			19.9	118,086
11/30/73	0.77	4,299	344	1,920,715	0.25	1,396			11.7	65,327
12/07/73	0.74	5,869	374	2,965,334	0.18	1,427	$19x10^4$	$10.8x10^{15}$	15.7	124,480
12/08/73	0.66	-	287	-	0.15	-			14.6	-
Combinatorics (1974) estimate		7,431				209				127,668

Table 4.5

MEASURED EFFLUENT CONCENTRATIONS AND CALCULATED LOADS
AT MOUTH OF INDIANA HARBOR CANAL (STATION CAL06)
IITRI data

Date	Measured flow (IITRI) cfs	mgd	m^3/sec	Chloride Concentration, mg/l	Load lb/day	Ammonia-Nitrogen Concentration, mg/l	Load, lb/day	Total organic carbon Concentration, mg/l	Load, lb/day	Fluoride Concentration, mg/l	Load, lb/day
11/14/73	3153	2057	90	31	526,584	2.7	45,900	10.0	170,002	0.48	8,159
11/19/73	3591	2320	102	40	774,508	2.8	54,218	11.5	222,681	0.61	11,810
12/07/73	4226	2731	120	28	638,201	1.5	34,191	9.5	216,544	0.30	6,838
Combinatorics (1974) estimate:	1395	902	40		393,537		33,271				6,477

Date	Total iron Concentration, mg/l	Load, lb/day	Total solids Concentration, mg/l	Load, lb/day	Total phosphorus Concentration, mg/l	Load, lb/day	Total coliform Coli/100 ml	Total No.	Suspended solids Concentration, mg/l	Load, lb/day
11/14/73	0.67	11,365	165	2,805,504	-	-	26×10^3	2.0×10^{15}	7.8	133,908
11/19/73	0.48	9,245	208	4,027,630	0.06	1,161	30×10^3	2.6×10^{15}	8.1	156,838
12/07/73	0.98	22,338	226	5,151,480	0.07	1,596	4.8×10^3	5.0×10^{15}	9.6	218,812
Combinatorics (1974) estimate		22,343				389				382,795

indicated in Appendix C have improved the parameters at the Calumet River mouth as indicated in Chapters 13 to 18. Effluents from DuPont Co. on the IHC are also improving as a result of a settlement of a suit, as indicated in Appendix C. A few other companies on or near the IHC are believed to have improved their effluents, although an evaluation of the waste treatment programs of industrial companies was beyond the scope of this project, and our efforts were limited to examination of permit data. An industrial parameter in the IHC that has improved substantially since the Technical Committee (1970) report is phenol (Chapter 14). Some observers have stated that the amount of floating oil on the IHC has also decreased, and the load data in Chapter 15 indicate a 50% effluent decrease. Water quality measurements do not show a trend, perhaps due to the difficulty of sampling and measuring oil. Other parameters in effluents of the major industires in the IHC area have shown little improvement. The major change has been a shifting of effluents to the municipal sewage treatment plants, where it has caused new problems. Enforcement action is needed to decrease the loads of specific pollutants, as indicated in Chapters 13 to 18.

5. MUNICIPAL SOURCES AND COMBINED SEWER OV[illegible]

The three main municipal sources are the sanitary districts of Gary, East Chicago, and Hammond. There are numerous smaller sources in the eastern part of the Lake Michigan [illegible] as well. Appendix D describes these facilities and gives data on their effluent concentrations and loads. Effluents from these main sources discharge to the Grand Calumet River, [illegible] flow to Lake Michigan via the IHC. The locations [illegible] waste treatment plants of these municipalities are shown in Figure 4.1. Effluents from the smaller municipalities in the eastern portion of the basin discharge to the Little Calumet River, Deep River, Salt Creek, and flow to the Lake via Burns Ditch. Some information is presented on these smaller municipalities, but most of our effort is concentrated on the larger municipalities.

Appendix D describes the treatment process in use at each municipal plant, as well as the status on January 1, 1974, of plans to upgrade these plants. Two of the plants (Gary and East Chicago) have installed phosphorus precipitation processes. Plans for further improvements to reduce effluent loadings include advanced waste treatment, but these plans have been delayed primarily due to lack of funding. A major pro[illegible] all three plants, but especially that of East Chicago [illegible] overloading by industrial effluents going to municipal sewers. This situation is documented in Chapters 13, 16 and 17 as well as Appendix D. Pretreatment guidelines of the U.S. EPA (1974) [illegible] that industries discharging to municipal sewers must pretreat their wastes so as not to interfere with municipal treatment plant operation, and we recommend that such pretreatment be required. It might be feasible for the municipalities to accept the industrial wastes on a charge basis if they expand the municipal treatment plants and include the necessary processes [illegible] the increasing loads. If this were to be seriously considered, a study would be needed of the technology and economics of these two alternatives, including an estimate of the time delay to fund the municipal plant construction.

Another major problem concerns the pollution entering the Lake from combined sewer and storm water overflows. Locations of these overflows are shown in a map in Appendix D, Figure D-2. Only Hammond measures these overflows; the indications are that this source of pollution amounts to half of the treatment plant effluents. Evidence presented in Chapter 16 shows that three outfalls directly to the Lake in Whiting and Hammond are responsible for some of the very high coliform counts at the Whiting water intake. The municipalities have plans to solve the overflow problems by constructing detention lagoons and increasing the capacity of sewers and treatment plants. A few of these projects have actually been constructed, but most are planned for completion in 1977.

There are a number of smaller waste treatment plants in the eastern portion of the Lake Michigan basin, and their effluents enter the Lake via the Little Calumet River and Burns Ditch. The operating reports of these plants are summarized in Appendix D. In general, the effluent levels of these plants are high enough to cause very poor water quality conditions in the receiving streams. This is also indicated by benthic studies in Appendix A; however, the loads are small enough so that the effect on Lake Michigan is moderate. Some plans to improve these plants by adding AWT and phosphorus precipitation are summarized in Appendix D.

Recommendations for improving the effluents from municipal plants include requiring pretreatment of industrial effluents; hastening the funding of treatment plant improvements, which are behind schedule; hastening construction of sewer and detention lagoon projects; and improving operation and monitoring of treatment plants.

6. WATER QUALITY DATA

6.1 Availability of Data

Extensive water quality data are contained in reports included in the proceedings of both the Lake Michigan Enforcement Conference and the Conference on the Interstate Waters of the Calumet Area. A report to the Conference of the Technical Committee on Water Quality, issued September 1970, contains extensive tables of water quality parameters at the sampling points located on Figure 6.1 and Table 6.1. Data taken by the U.S. EPA through 1973 are available through Storet. In addition, Illinois has a water quality network. Computer print-outs are available for recent years through 1972. Indiana has a reasonably extensive water quality monitoring program. The data are available at Indianapolis, and data through 1971 are in Storet.

In addition to the water monitoring stations, there have been several field data programs conducted to sample bottom sediments and analyze them.

The following sections discuss the individual data sources and point out the gaps in the data insofar as the present project is concerned, in order to plan supplemental sampling program for the purpose of filling those gaps.

6.2 U.S. EPA - Generated Data

The major internally generated U.S. EPA water quality data consist of measurements at sampling stations designated as CAL01 through CAL17 in the Calumet area. (See Figure 6.1 and Table 6.1 for station positions.) These are located along the Grand Calumet River, Little Calumet River, Wolf Lake and some near-shore areas of the southern part of Lake Michigan. These data are available for the years 1965 through 1973 and are in Storet. The most extensive EPA measurements were conducted from 1966 through 1969. Since then sampling has been done only during

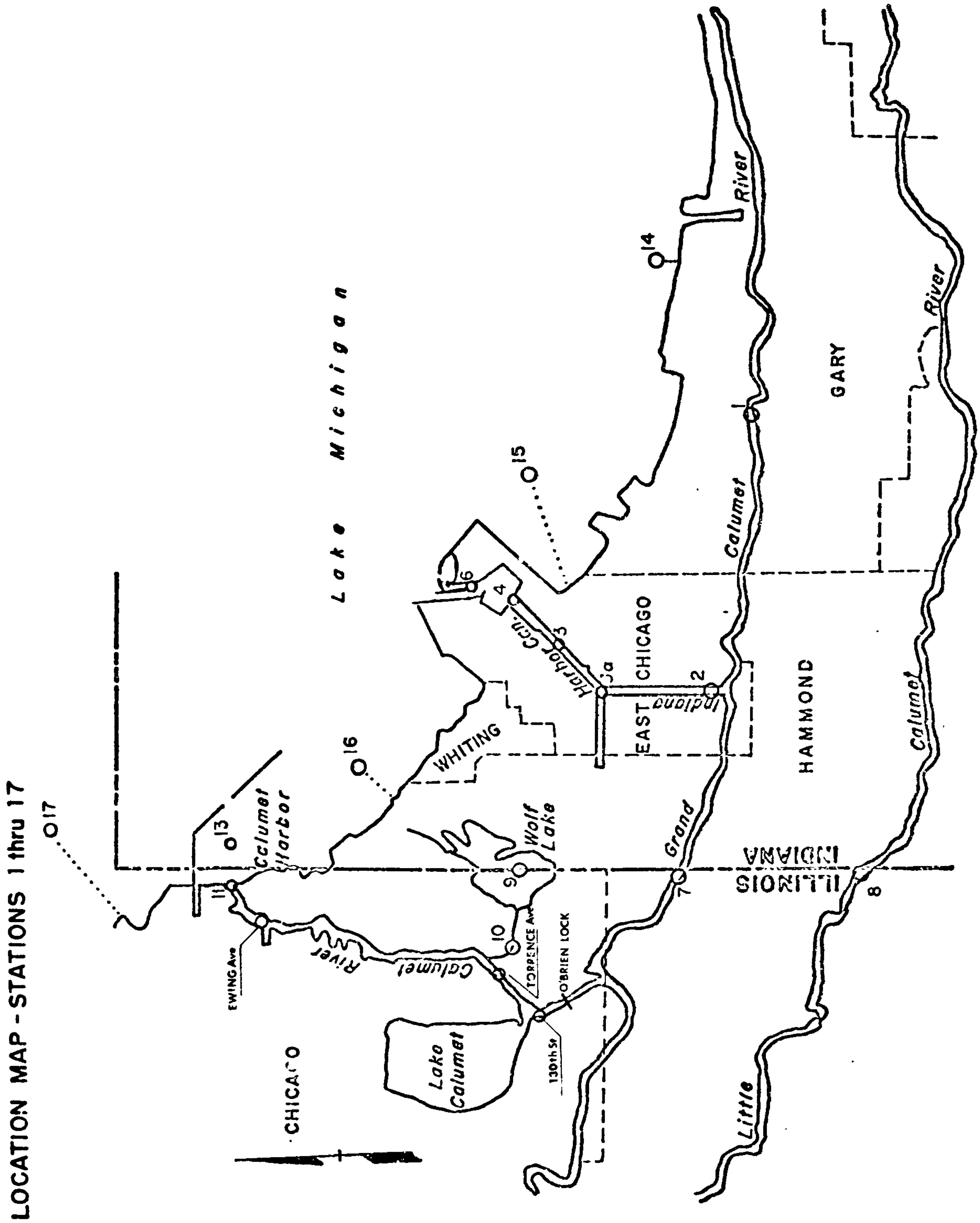

Figure 6.1

LOCATION MAP EPA WATER QUALITY SAMPLING STATIONS CAL01-CAL17

Table 6.1

U.S. EPA WATER QUALITY MONITORING STATIONS IN CALUMET AREA

Station No.		Station location
CAL 01	(170 141)	Grand Calumet River & Penn-Central R.R.
CAL 02	(170 160)	Indiana Harbor Canal & 151st St.
CAL 03*	(170 149)	Indiana Harbor Canal & Dickey Road
CAL 03A	(170 153)	Mouth of Lake George Branch, Indiana Harbor Canal
CAL 04	(170 150)	Indiana Harbor Canal Mouth pier Head Light
CAL 05	(170 152)	Indiana Harbor breakwater Inner Lights
CAL 06	(170 198)	Indiana Harbor Breakwater Inner N-E Light
CAL 07	(160 177)	Grand Calumet Control Park Indiana Harbor Belt R.R.
CAL 08	(160 147)	Little Calumet Point & Wentworth Avenue
CAL 09**	(160 189)	Wolf Lake Control State Line Culvert
CAL 10	(160 188)	Wolf Lake Channel at Carondolet Avenue
CAL 11	(160 178)	Calumet Harbor Mouth North Pier Light
CAL 12	(160 141)	Calumet Harbor Mouth of River
CAL 13	(170 197)	Calumet Harbor Midchannel Outer
CAL 14	(170 117)	Gary-West Water Plant Intake
CAL 15	(170 201)	East Chicago Water Plant Intake
CAL 16	(170 200)	Hammond Water Plant Intake
CAL 17	(160 650)	Chicago South Water Plant Intake

Note: U.S. EPA Agency No. is 1115G050 for Storet

*CAL 03 corresponds to Indiana Station IHC-1, Agency No. 21 IND for Storet

**CAL 09 corresponds to Indiana Station W6-SL Agency No. 21 Ind for Storet.

brief periods in each season. Plots of these data through 1973 have been obtained and are presented in Chapters 13 through 18.

Our main use of the Storet plots was to help relate the pollutant concentrations in the Lake waters to the corresponding concentrations flowing from the major input source, which is the Indiana Harbor Canal.

A predecessor to the U.S. EPA was the U.S. Public Health Service and the Federal Water Pollution Control Administration. Extensive surveys of the quality of Lake Michigan waters were contained in Physical and Chemical Quality Conditions (FWPCA 1968), and in Report on Water Quality of Lower Lake Michigan (FWPCA 1966), as well as published summaries by Risley and Fuller (1965, 1966).

Also in Storet are water quality data obtained in 1963 for more than 150 stations located in open water near the shore of the southern part of Lake Michigan. We were not able to relate these data to flow of effluents from IHC or other sources.

6.3 Indiana Water Quality Data

In 1957, the State of Indiana initiated a water quality monitoring program. The original sampling network included two stations on Lake Michigan. At the present time, there are 16 sampling stations located on tributaries to Lake Michigan. In addition, five water treatment plant intakes on Lake Michigan are sampled as part of the program (Table 6.2 and Figure 6.2). These data are in Storet through 1971 and applicable plots are included in Chapters 13 to 18. This sampling program provides data that are used to measure general characteristics of Indiana waters in the Lake Michigan Basin at important locations and to record trends in water quality. No other data are available for the eastern portion of the Calumet area.

The Indiana program has been expanded to include the collection of samples from various industrial outfalls and run-off from landfills. For the most part, these samples are collected during

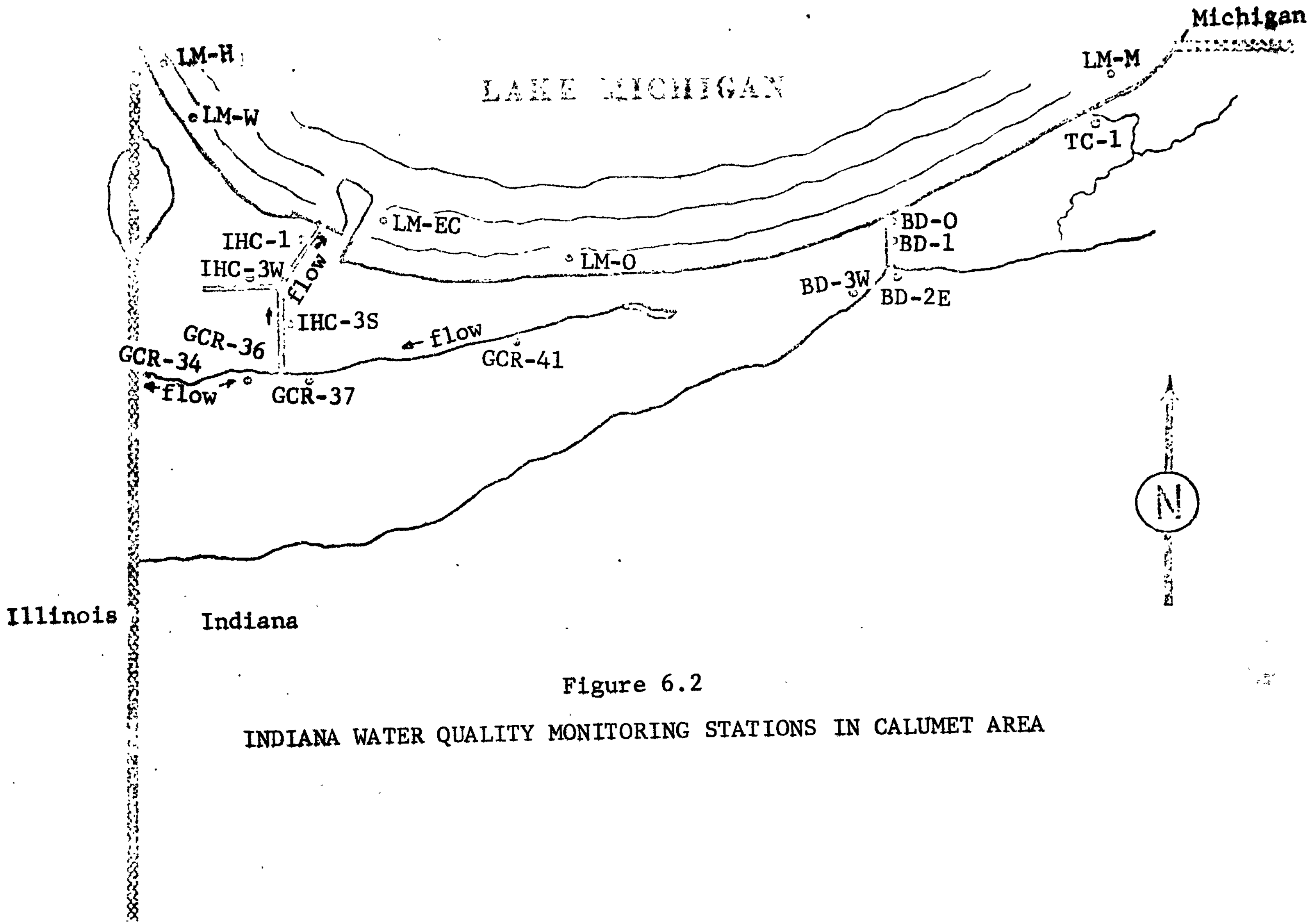

Figure 6.2

INDIANA WATER QUALITY MONITORING STATIONS IN CALUMET AREA

Table 6.2

INDIANA WATER QUALITY MONITORING STATIONS
Great Lakes Drainage Basin
Sampling Frequency: Biweekly

Station No.	Station location
BD 0	Burns Ditch at Mouth (Midwest Steel Co. Catwalk)
BD 1	Burns Ditch at Midwest Steel Truck Bridge
BD 2E	Burns Ditch East Branch at Chrisman Road
BD 3W	Burns Ditch West Branch at Portage Boat Yard
GCR 34	Grand Calumet River in Hammond
GCR 36	Grand Calumet River in East Chicago at Indianapolis Blvd.
GCR 37	Grand Calumet River in East Chicago at Kennedy Avenue
GCR 41	Grand Calumet River at U.S. 12 in Gary
IHC 1	Indiana Harbor Canal at Dickey Road in East Chicago
IHC 3S	Indiana Harbor Canal, South Branch at Columbus Drive in East Chicago
IHC 3W	Indiana Harbor Canal, West Branch at Indianapolis Blvd
LRC 39	Little Calumet River, East leg at SR 149 in Porter
LM EC	Lake Michigan at East Chicago water intake
LM G	Lake Michigan at Gary water intake
LM H	Lake Michigan at Hammond water intake
LM M	Lake Michigan at Michigan City water intake
LM W	Lake Michigan at Whiting water intake

comprehensive 24-hr surveys of point discharges. These data are available at Indianapolis, and were used by CBE to check permit application data (Appendix C), but are not yet available through Storet. Water quality data and effluent loads in the Grand Calumet River/IHC system were recently compiled for the State of Indiana by Combinatorics (1974), including Indiana State data.

6.4 The Metropolitan Sanitary District of Greater Chicago Data

The Metropolitan Sanitary District of Greater Chicago (MSDGC) has conducted several studies of water quality, sediments and benthic organisms in Calumet Harbor and the IHC and the adjacent Lake since 1967, but the data are mostly not available to this project. The measurements were made in support of lawsuits that are still pending against several steel companies in the area, primarily Inland, Youngstown, and U.S. Steel. Samplings comprise 24-hr composite effluent samples, water quality samples and bottom sediment analyses.

6.5 Chicago City Raw Water Data

The city of Chicago has conducted intake water analysis since 1880, and detailed records of the raw water quality are available from 1945. The data include detailed daily analyses of raw water from both the south and central water intake cribs. Extensive data are also available for samples taken from the Hammond water intake on a daily basis from 1967 through 1971, and less frequently since then; and from samples taken about weekly from East Chicago and Gary during the same period. These data are in the Chicago Water Department library; aside from examining them to determine that they show pollutant peaks similar to those exhibited by Storet plots, we were not able to make as much use of them as they deserved, due to their sheer magnitude. The South Water Intake data are the most extensive, and have been plotted over a period of years. We updated the available plots, and used them in Chapters 13 to 18 to establish trends of water quality in the Lake.

Since 1966 the Chicago Water Dept. has had a program of water sampling from a boat. The four surveys are called the North Shore Survey, the South Shore Survey, the Central WFP Radial Survey and the South WFP Radial Survey. The South WFP Radial Survey stations are shown on Figure 6.3. We made extensive use of the two south surveys, and plotted much of these data to show that peaks of pollutant concentrations in the Lake could be related to likely locations of the plume from IHC (Chapters 13 to 18). Not all the peaks or unusual high values can be definitely tied to particular sources because data are not available to determine the motion of the plume from IHC or other sources. Furthermore the concentrations and flow of the IHC were not measured on the same days as the Lake surveys. (On a few days the reports of these surveys contain sketches showing observations of the plume. Some reports contain wind observations.) The annual reports of these surveys are in the Chicago Water Dept. Library.

The Chicago Water Dept. also conducts weekly samplings and analysis of stations in the tributary waters of the IHC, Grand Calumet River, and Calumet River. This is called the Calumet Area Industrial Survey. We used some of these points to measure the trends in water quality in these tributaries, and selected data are plotted in Chapters 13 to 18. Some of the other stations were of limited value because we could not relate them to effluent sources. In particular, flow data would be needed on the sampling dates to establish stream loadings. We have keypunched a few recent years of the Radial and Calumet Industrial Survey data for Storet, but mostly we relied on hand-generated plots of data averages.

6.6 State of Illinois Data

The State of Illinois has conducted a shore survey since 1970 (Illinois EPA, Lake Michigan Open Water and Lake Bed Survey, 1970, 1971, 1972). Beach water samples, bottom samples, and water samples taken one mile from shore were reported. Since most of the data lie outside the Calumet area, we made little use of these data except for comparison with Calumet area data. The

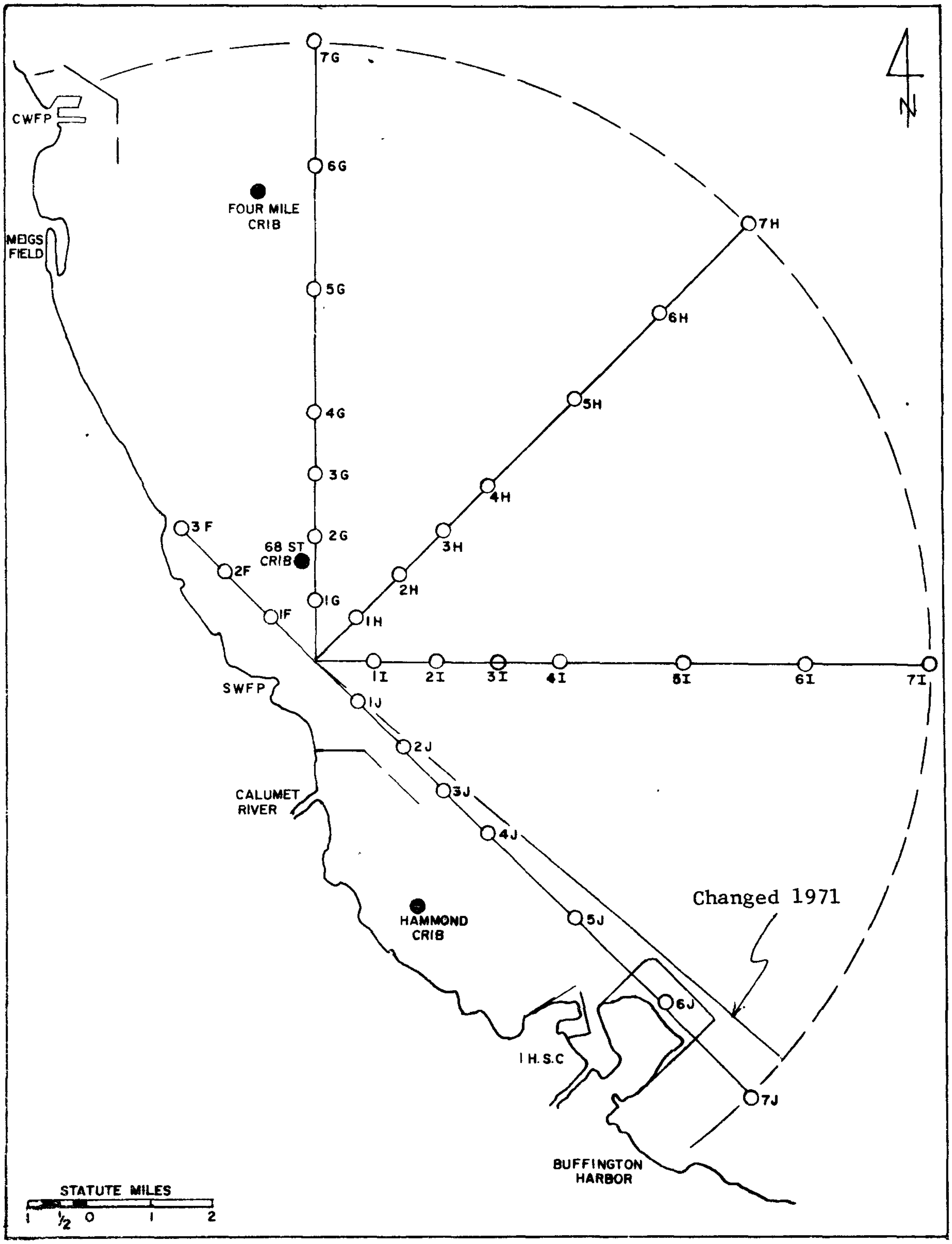

Figure 6.3

SOUTH WATER FILTRATION PLANT RADIAL SURVEY

Illinois water quality network is a computer print-out of measurements in inland streams (available from Illinois Environmental Institute Library). It contains practically no data applicable to the Calumet area of Lake Michigan.

6.7 Additional Data Sources Surveyed

Table 6.3 lists organizations that were contacted either by IITRI or CBE with requests for available data. Most of these supplied some information in the form of reports and other documents. The applicable information is either summarized in this report or mentioned in the list of references.

Table 6.3

LISTING OF DATA SOURCES SURVEYED

U.S. Army Corps of Engineers, Chicago District
U.S. Department of the Interior - EROS Data Center
U.S. Environmental Protection Agency - Region V Laboratory
Illinois Environmental Protection Agency
Illinois Water Survey
Illinois Natural History Survey
City of Chicago - Department of Water and Sewers
Metropolitan Sanitary District of Greater Chicago

Businessmen for the Public Interest
Lake Michigan Federation

Great Lakes Research Division, University of Michigan
Great Lakes Basin Commission
Great Lakes Commission
Great Lakes Fishery Laboratory, U.S. Buruea Sports Fisheries & Wildlife
Center for Great Lakes Studies, University of Wisconsin-Milwaukee
Environmental Research Institute of Michigan, University of Michigan

Indiana Stream Pollution Control Board
Indiana State Board of Health
Regional Transportation and Planning Commission (Indiana)

Industrial Bio-Test Laboratories, Inc.
Combinatorics, Inc.
Commonwealth Edison Company
Northeastern Indiana Public Service Company

United States Steel Corp.
Youngstown Sheet and Tube Company
Inland Steel
Bethlehem Steel
Midwest Steel
Union Carbide
E. I. DuPont de Nemours and Company
Mobil Oil
Shell Oil
Atlantic Richfield

Illinois Geological Survey

7. SEDIMENT POLLUTION AND BENTHIC ORGANISMS

Sediments play a role both in carrying pollutants from the tributary rivers into the Lake, and in the exchange of pollutants from the near-shore waters to the bottom.

Suspended solids in the tributaries can come from steel mills in the form of iron particles or precipitates, from sewage treatment plants in the form of organic particles or from soil erosion in the form of minerals. These particulates can be combined with oil from steel mills and refineries.

Polluted sediments affect the aquatic life in the water, and studies of benthic organisms can be used to measure pollution. These subjects are discussed in the following, as well as in Appendix A.

7.1 Transport of Sediments in IHC

Not all of the pollutants which enter the Grand Calumet River and IHC are carried directly to the Lake. Some of them are deposited on the bottom; this is evident from the fact that the Corps of Engineers finds it necessary to dredge the navigation channel of the IHC about every two years. The next dredging is planned for 1974 (Corps of Engineers, impact statement, 1973).

There are two questions to be answered with regard to sediments in the present study. One is whether the deposition of sediments is important enough to affect our assessment of effluent loads. The other is whether the deposited sediments can be resuspended during heavy rainfall periods, resulting in peak pollution loads to the Lake that may not have been measured by previous sampling programs.

Concerning the first question, Table 4.4 in Chapter 4 shows that the suspended solids load measured by IITRI at Columbus Drive is in reasonable agreement with Combinatorics (1974) load estimates. On the other hand, the composition of the sediments reported in the Corps of Engineers (1968) study (Appendix A25-V) indicates that the sediments are primarily of clay or other materials originating from soil erosion; it would therefore be difficult to use a sedimental material balance to check the point source effluents. The quantity of sediments dredged in 1967 was estimated at 72,000 cubic yards (Appendix A25-V). The composition of the sediments discussed in the next section indicates that they do contain appreciable amounts of various industrial pollutants, particularly oil and grease. It was also estimated (Corps of Engineers 1968, p. 103) that the dredging company removed 1750 tons of oil and grease contained in dredging spoils.

To answer the second question would require a very detailed study of flows and sediment compositions during dry and wet weather; however, since the flow in the IHC comes mainly from industrial water pumped from Lake Michigan, we might expect rainfall to have less effect than it does in other natural streams. We made one measurement at 8 PM on December 4, 1973, after a rainfall of 1.19 in. as recorded at Midway Airport. The measured flow was 1570 cfs at station IHC3S; this value is within the normal range of flow for dry weather. The turbidity of a sample was 23, which is above the normal range of 9 to 15 shown in Table 11.3 for IHC3S. This suggests that resuspension is not an overpowering effect. Also, the Corps of Engineers (1968) study generally concluded that resuspension of sediments during dumping in landfill lagoons produced less effluents than were contained in the IHC plume.

7.2 Composition of Suspended Solids and Sediments from IHC

Some data on the composition of suspended solids from IHC3S can be found in Table 11.3. Suspended solids range from 10 to 20 mg/ℓ. About half of the suspended solids is volatile on ignition, and less than 19% of the solids is iron. Three samples from station CAL06 show lower concentrations due to dilution, but show similar ratios of these components.

Table 7.1 summarizes sediment composition data from the Corps of Engineers (1969) study. The composition is not unlike that of the suspended solids just mentioned, except that the nonvolatile

Table 7.1

COMPOSITION OF SEDIMENTS DREDGED FROM INDIANA HARBOR
Source: Corps of Engineers (1969), Vol. I., p. 6.45

Parameter	Lake George branch[b]	Grand Calumet River branch[b]	Main Canal Penn RR Bridge Station numbers 21[b]	I-5[c]	Harbor Channel Outer Light Station numbers 18[b]	12-0[a]	I-1[c]
Total solids, %	42.5	40.9	73.6	47.5	60.5	37.9	45.0
Volatile solids, %	20.7	15.2	9.0	16.1	6.1	6.6	6.1
Oil and grease, %	14.2	5.92	-	-	0.32	2.79	-
BOD, mg/ℓ	6.24	4.17	5.25	-	1.13	-	-
COD, mg/ℓ	-	-	-	461	-	261.5	117
NH_3-N, mg/ℓ	-	-	-	0.07	-	0.26	0.09
Organic - N, mg/ℓ	-	-	-	2.98	-	0.76	1.68
Phosphorus - P, mg/ℓ	-	-	-	1.05	-	0.79	0.48

[a]FWPCA 1967 data, Appendix A7, Appendix A.

[b]Lake Survey 1967 data, Appendix A25, Table 3, all values are averages.

[c]University of Wisconsin data, Appendix C5, Tables A-21 and A-25.

portion is somewhat higher.

Howmiller (Appendix A) reviewed data on the composition of sediments, both in the IHC and in the Lake. IHC sediments were reported to have oil and grease contents ranging from 3 to 17%. Some data on the composition of sediments in the inner harbor are shown in Figure A-10 of Appendix A.

Howmiller (Appendix A, p. A-33) reviewed evidence that the sediments of IHC and Calumet harbors are toxic to certain organisms. The data are given in more detail by Gannon (Appendix B). It was concluded that these sediments are so toxic that dredging spoils should not be dumped into the open Lake. Oil appeared to be the component in largest concentration, but it has not been established what substance or combination of substances is most toxic in the sediments.

7.3 Relation to Dredging

The Corps of Engineers (1973) is required to dredge the navigation channel of the IHC as far upstream as Columbus Drive. Dredging can have both harmful and beneficial effects as far as Lake pollution is concerned.

During the actual dredging operations, stirring up of the sediments can resuspend pollutants and cause peak loads into the Lake. Even more important over the long term is the method of disposing of the dredging spoils. The disposal can result in another pollution source.

On the other hand, by removing polluted material from the channel, dredging can be considered as a way of ridding the tributaries of polluted matter that might eventually reach the Lake. This is no substitute for effluent controls, but it might be a way of purging the river of polluted sediments after effluent loads have been reduced.

The proposed method of disposing of spoils (Corps of Engineers 1973) is by barging it to a landfill constructed in the Lake by Inland Steel Co. This fill is 1 mile by 2 miles in size, and is presently filled with water enclosed by a revetment. The revetment is made of cells constructed of steel piling filled with slag and capped with concrete (Santina and Bochantin, personal communication 1974). It is not completely impermeable, especially to fluctuations in Lake level. The amount of exchange with Lake water is not known.

The Corps of Engineers (1969) study showed that there was some exchange of polluted water from the lagoon during deposition of spoils, although the impact on the Lake was less than that of the plume from the IHC. The effluents from the lagoon were substantially less after deposition of spoils was completed.

Investigations are underway at the Waterways Experiment Station (Corps of Engineers, WES Newsletter, 1973, 1974) to determine better ways of disposing of spoils and to assess their pollutional impact.

7.4 Lake Michigan Sediments and Relation to Pollution

Sediments in southern Lake Michigan are surveyed by Howmiller (Appendix A). Figure A7 shows that the coarser sands and gravels tend to lie in the shallower areas near shore, especially in the southwestern corner of the Lake. Fine sand particles lie along the eastern shore, while fines and silt are found in the deeper central region. Sediment transport is known to occur, and to have built the dunes in the southern and eastern shores of the Lake.

Shimp and coworkers (1970, 1971) sampled and analyzed the bottom sediments over the whole southern basin of Lake Michigan. Few of their samples were taken in the Calumet area. Shimp (personal communication, 1973) suggested that Lake currents have a size-classifying action, depositing silts in the central region (See Figure A7, Appendix A). Presumably the finely-divided pollutant silts are eventually deposited here as well.

The turbidity of near-shore waters of the Lake increases noticeably after a storm, indicating that bottom sediments have been resuspended. Some data showing this effect are given in Table 17. 6, Chapter 17.

Suspended solids in the Lake include phytoplankton, as well as solids from the rivers. The role of phytoplankton in extracting dissolved nutrients from the water has been discussed by Robertson and Powers (1965). As the phytoplankton die, they settle to the bottom, carrying the phosphorus and nitrogen to the bottom sediments. Mortimer (1971) discussed the exchange of chemicals between sediments and water in the Great Lakes. The release of nutrients from sediments is expected to be small, so long as dissolved oxygen content at the sediment surface does not fall below 1 to 2 mg/ℓ. In Lake Michigan the dissolved oxygen content usually does not fall to low values even in the hypolimnion.

A number of studies have shown that burrowing benthic invertebrates can have important effects upon the structure of sediments and upon exchange of materials between sediments and water. Howmiller (Appendix A, p. A61) mentions such effects including mechanical overturn of sediments, chemical transformation of sediment within the gut of the animal, or irrigation of burrows with consequent changes in the stratification of redox potential. Laboratory experiments with Lake Michigan sediments showed that benthic organisms promoted release of phosphorus from sediments. Research has been insufficient to allow quantitative estimates of exchange rates under actual Lake conditions.

7.5 Sediment Pollution from IHC and Other Sources

Studies done in 1967 of the distribution of polluted sediments in the Calumet area (Appendix A, Figure A10) indicated that the Calumet River and the IHC were the major sources of polluted sediment in the area. The most recent studies have not been released for publication, but improvements in steel mill effluents from the Calumet River are likely to leave the IHC as the major source polluting the bottom sediments.

The types and species of benthic organisms have been used to measure the state of pollution in the Calumet area. Howmiller reviews in detail the available data on the distribution of benthos (Appendix A, p. A35). Studies based on absolute counts of various types such as clams or worms generally indicate that the near-shore areas are particularly polluted, especially those areas that are close to major effluents, such as the Calumet area; however, attempts to assess environmental quality through numbers of organisms of major groups are limited in sensitivity and scope, because other affects besides pollution have an influence. Instead, Howmiller (Appendix A, p. A43) shows that by measuring ratios of the numbers of species within one type, one can rate the pollutional level of the area sampled. This procedure normalizes out other factors that affect absolute population numbers, e.g., type of substrate, scouring of bottom by currents, etc. Several types of organisms could be considered, but Howmiller considers that Oligochaete worms appear to offer particular promise for the bioassessment of environmental quality in Lake

Michigan. He ranks the species of the oligochaetes according to their tolerance of enrichment or pollution of the environment in Table A2 (Appendix A). A few studies have been done to assess the condition of parts of the Calumet area. These are summarized by Howmiller (Appendix A, p. A49).

Sediments from the Little Calumet River and Burns ditch showed highly polluted sediments, with paucity of benthos. This condition appears to be related to the inadequate municipal sewage treatment reported in Appendix D. In shallow water in the nearby Lake at Bailly, benthic organisms were found which are tolerant of pollution. It was concluded that the bottom fauna of this in-shore region was dominated by forms characteristic of eutrophic regions of the Great Lakes, but not of highly polluted regions.

The oligachaete fauna of the Calumet and IHC harbors were examined by Howmiller in 1967 and 1968. Table A4 (Appendix A) indicates that this inner harbor region is dominated by a species that is tolerant of extreme pollution. The composition of the worm fauna in this region is much like that found in lower Green Bay, an area which vies with the Calumet area for the distinction of being the most severely degraded portion of Lake Michigan. The distribution pattern of benthos clearly reflects the importance of the IHC as a source of pollution in this part of the Lake. Any changes in status since 1968 are not known at present. Howmiller (Appendix A) proposes additional measurements, including sampling further out into the Lake to gain information on the extent of the IHC effect.

8. IMPACT OF POLLUTANTS ON QUALITY AND USE OF WATER

The presence of a Great Lake is an accident of nature that makes life more pleasant for millions of people that live along its shore. The kinds of water-related activities are documented in a report by the FWPCA (1966), and by the Corps of Engineers (1969).

The Lake Michigan Basin is abundantly endowed with natural terrain making it one of the major water oriented recreation areas in the nation. The preservation and improvement of the water quality within the Basin is imperative to maintain this status. The United States Bureau of Outdoor Recreation (1965) report "Water Oriented Outdoor Recreation - Lake Michigan Basin," presents most of the facilities that are available, the problems that are developing, and the action that must be taken to preserve this natural heritage. There are a total of 625 public recreation areas in the Basin. Of these, 536 are water oriented. There are 74 recreational harbors on Lake Michigan. Recreational areas are scattered throughout the Basin, although the major concentration of population is in the southern portion. This, combined with the closing of some facilities due to pollution, has resulted in crowding of the facilities in the southern portion of the Basin.

In 1960, there were a total of 82 million activity days of water-oriented recreation and 94 million activity days of water-related recreational activities. It is estimated that the demand for water-oriented activities could increase to 247 million activity days by the year 2010, if adequate facilities are provided. The largest activity is swimming. For this purpose, the waters in the Calumet area are already too polluted, and the Whiting and Calumet beaches are closed. The problems are caused by excessive coliform counts from inadequately treated sewage, and combined sewer overflows. Chicago beaches are polluted with algal growths. The over-fertilization of the Lake results in algal growth which makes the water objectionable for body contact.

Sport fishing is the second largest form of water-oriented recreation. The Fish and Wildlife Service (1966) estimates 19 million angler days per year are spent in the Lake Michigan Basin, and expects this number to triple by 2010. The quality and species of fish depend on the quality of the waters. In addition, pollution can impair the spawning grounds of fish.

Perhaps the most important use of Lake water is for municipal water supplies of cities along the shore. The increasing problems of treating Lake water to overcome effects of pollution are well documented by reports of Vaughn (1969) and Vaughn and Reed (1972), and of course these treatments do not restore the water to its unpolluted state, and residual tastes remain.

The FWPCA Report (1966) continues: "The value of the Lake Michigan Basin for recreation and plain aesthetic enjoyment, which is part of most recreational uses, is difficult to measure. It is, however, recognized as a significant portion of the economy of the basin. One only has to look at the premium prices paid for purchases and rental of apartments or cottages with a lake view or observe the number of people who will go out of their way to take a lake shore drive, as opposed to a more direct route, to get an indication of the esthetic value of Lake Michigan. A more indirect way of measuring its value is by the amount that is spent annually for recreation in the basin -- for lodging, food and recreational equipment such as boats and fishing tackle. There is no detailed tabulation on this available, but one need only visit several of the prime recreation areas in the Basin to see the investment in recreational facilities."

8.1 Water Pollution Problems

The National Academy of Sciences (1969) defines eutrophication as a state of increased nutrient supply. Lake Michigan is now exhibiting some eutrophication of the near-shore waters, as evidenced by excessive algal growth. The accompanying changes in zooplankton and benthic organisms are reviewed in subsequent sections of this report (Chapter 9, Appendix A, B).

Evidence for recent changes in species of algae are reviewed in Appendix A. These may be early hints that the Lake is being abused by man. Of more direct concern is the excessive growth of a particular algae, Cladophora, which grows on rocks, breaks up by wave action, and washes ashore to litter the beaches in slimy windrows. Cladophora clogs water intake screens and makes swimming unpleasant. When it decays it produces a putrid odor and provides a breeding place for flies. These effects are documented in the FWPCA Report (1966).

8.2 Phosphorus Pollution

Many experiments have demonstrated that the growth of algae can be controlled by limiting the phosphorus nutrient in the water (Thomas 1972; Schindler 1974). Chapter 17 is devoted to phosphorus pollution.

The report of the Phosphorus Technical Committee (1972) analyzes the available data concerning excessive phosphorus concentrations in near-shore waters and suggests that 0.02 mg/ℓ total P might be a desirable goal for shore waters. This amount has been exceeded frequently in measurements near the Calumet area (Chapter 17).

The most feasible direct action that can be taken is to prevent the escape of phosphorus from municipal treatment plants. These are the main sources of phosphorus in the Calumet area. Indiana has agreed to an effluent limitation of 1 mg/ℓ, which would reduce P effluents by 90%. Chapter 5 documents the progress of municipal treatment plants to achieve this reduction. In addition, Indiana has set limits on phosphorus in detergents. Chicago's experience with this approach proved that it is effective (personal communication, MSDGC Stickney plant personnel 1972). Chapter 17 shows that there has been a 40% reduction in P effluents in the IHC in the past four years, and the 15-year upward trend at Chicago SWFP crib appears to have reversed, with a 20% decrease in the last two years.

8.3 Bacterial Pollution

The coliform bacteria counts in the IHC are generally at the level of 100,000 to 1,000,000 per 100 mℓ, a level which makes it similar to an open sewer and dangerous to health. A major reason is that the NH_3-N loads on the East Chicago STP from steel mill discharges are so high that adequate chlorination of the effluent from the plant would require an excessively costly amount of chlorine. (See Chapters 5 and 16.) Another reason is that several of the sewage treatment plants are operating above capacity and plant improvements have been delayed. Combined sewer overflows also contribute, especially in the Whiting area.

The Report of the Technical Committee on Water Quality (1970) documents the closing of the beach at Hammond, Indiana, for many years, and the frequent occurrences of excessive bacterial counts at all of the Calumet area beaches at least as far as Rainbow Beach at 77th St. in Chicago. More recent criteria violations are presented in Chapter 16.

8.4 Safety of Water Supplies

The reason for concern over coliform bacterial pollution is that it is an indicator that other sewage pathogens may be expected. Data are also given in Chapter 16 on the presence of other sewage bacteria, such as fecal streptococcus and salmonella. In addition, if parameters such as bacteria, NH_3-N, and oily odor indicate the presence of sewage and industrial effluents, then there is more likelihood of the presence of other toxic materials such as PCB's and heavy metals, which were not specifically investigated in this project.

It is generally assumed that municipal water treatment plants can be completely relied on to eliminate bacteria and other dangers that may come from drinking water. An article by Harris and Brecher (1974) reviews U.S. Public Health Service reports and indicates that some of these plants are not adequately funded, especially by the smaller municipalities, and are not completely reliable. We repeatedly visited the five municipal water plants in the area, and in general, were favorably impressed. The plants in this area use three treatment methods: coagulation and filtration to remove suspended solids; chlorination or ozonation to sterilize, and carbon treatment to remove tastes and odors. We did notice that the amount of monitoring of plant performance, especially during off-hours does seem to depend on the size of the plant. For safety's sake it would seem best to have more than one line of defense, and cleaning up the effluents to which the plants are exposed would be very desirable from this point of view.

8.5 Chemical Pollution

The sources of chemical pollution in the Calumet area are primarily the steel mills, the oil refineries, and the chemicals, food, and miscellaneous mineral industries in the area. The sources and major quantities of chemicals were identified in Chapter 4. A major source is waste pickle liquor from the steel mills. This contains iron, both in suspension and solution, either sulfate or chloride, and large quantities of oil. The iron forms sediments in the Canal. Phenolic compounds, ammonia, and cyanides come from coke manufacture by the steel mills. They are washed into the water from coke quenching and water used for scrubbing air pollution.

The cyanide level in the IHC is harmful to aquatic life, but it is quickly diluted in the Lake. Phenols, however, have a deleterious effect on water quality for municipal use, and Vaughn (1969) has demonstrated the effect of phenols and refinery odors (which might include oil) in water at the Chicago 68th St. crib. See Chapter 14.

Fluoride concentrations in the Canal are high, but concentrations in the Lake usually do not exceed standards.

The Canal regularly has slicks of oil, although the amount of oil is said to be decreased. Some of this oil comes from present or past oil refining operations. Oil slicks are frequently seen in the Lake waters outside the harbor. A rain of coal dust from inefficient coking operations and blast furnaces regularly occurs over land or water, contributing unknown quantities of organic matter to the Lake. In addition, oil spills by cargo ships are still being observed, in spite of police action.

The oil pollution directly affects boating in the Harbor area, but its further effects are hard to document; however, oil is organically biodegradable, and must stimulate the growth of bacteria and lower forms of aquatic life that feed on polluted conditions. Heavy metals are also present, which likely come from industrial sources, including airborne sources. Coal is a known source of heavy metals, and coal is used in large quantities by the steel mills. Other parameters are summarized in Table 8.1.

8.6 Oxygen Depletion

Whenever organic pollutants are dumped into a stream, such as thousands of pounds of oil per day, the effect is usually to stimulate growth of organisms that thrive on pollutants, and deplete the oxygen level of the stream. Oxygen depletion kills fish and eliminates desirable species. Examination of Storet data indicates that there are days when the oxygen content of Indiana Harbor Canal is essentially zero, but there are also days when it is close to saturation. This subject is further analyzed by Combinatorics (1974). Indiana data show pronounced improvements in dissolved oxygen.

Howmiller (Appendix A, Table A- 3) indicates that bottom studies in the IHC in 1965 and 1966 found a paucity of benthic organisms, and at some stations none at all. (More organisms are found in the turning basin, because the bottom there is overlain by less polluted Lake water, as shown in Chapter 12.) Apparently the conditions in the IHC are highly toxic to most kinds of life, except bacteria (Chapter 16). Whether occasional days of oxygen depletion cause the paucity of life, or whether there are other causes, has not been determined. In any case,

Table 8.1

SUMMARY OF WATER QUALITY MEASUREMENTS
STATION 6 INDIANA HARBOR AT EAST BREAKWALL INNER LIGHT

Parameter	Dec 1965			Jan-Dec 1966			Jan-Dec 1967			Jan-Dec 1968			Jan-June 1969			Jan 1971-Jan 1973			Criteria*		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max	Min	Mean	Max.	Min.	Mean
Temp. °C	10	9	9	29	6	16	24	3	16	27	9	18.6	21	5	13	24	3	14.0	32.3	-	4
Total Coli.No./100ml	22M	1M	11M	350M	1M	33M	510M	300	55M	800M	400	122M	180M	1800	32M		-		5000	-	2000
Fec.Strep. "	530	310	360	1600	10	130	875	20	200	900	10	200	1600	10	260		-		100	-	-
Fec.Coli. "	-	-	-	23M	10	2900	97M	100	12M	110M	40	9300	6300	300	1700		-		-	-	-
pH	6.9	6.7	6.8	8.0	6.6	-	8.0	6.0	-	8.2	6.5	7.4	8.5	7.0	7.4	7.8	6.8	7.4	9.0	7.0	7.5-8.5
DO mg/l	7.7	7.0	7.5	8.0	1.1	5.9	9.1	0.1	7.1	9.3	1.8	5.8	10.0	3.9	6.8		--		-	2.0	4.0
BOD "	3.4	2.9	3.1	13	1.2	3.7	8.8	1.3	4.5	11	1.6	3.6	9.1	2.8	4.7		-		-	-	-
COD "	131	13	87	72	4	16	34	6	11	220	1.5	22	100	3	22	21	2	9.1	-	-	-
Chlorides "	-	-	-	35	9	21	40	11	24	39	15	23(1)	34	21	28(1)	50	12	25.6	35	-	25
Sulfate "	69	56	64	77	22	51	79	11	43	61	21	37	48	15	32	58	31	39.2	75	-	60
NH_3-N "	1.7	1.5	1.6	2.8	.19	1.7	4.1	.34	1.7	2.5	1.1	1.5(1)	2.9	1.1	2.2(1)	27	0.6	2.8	1.5	-	1.0
NO_2-NO_3-N "	.60	.30	.46	.80	.10	.45	.65	.09	.32	0.8	.24	.45(1)	0.4	0.1	0.3(1)		-		-	-	-
Org.Nitrogen "	0.5	0.2	0.4	2.7	0	0.6	6.4	0	1.2	0.6	0.2	0.4(1)	0.6	0.3	0.4(1)		-		-	-	-
Total Phos. "	.120	.026	.062	.456	.026	.065	8.15	.033	.244	.491	.025	.136	2.19	.06	.23		-		.033	-	.016
Sol.Phos. "	.059	.033	.036	.098	.003	.023	3.26	.006	.096	.055	.006	.024(1)	-	-	-		-		-	-	-
Dis.Iron "	-	-	-	-	-	-	-	-	-	.38	0	.13	.45	.06	.17		-		0.30	-	0.15
Total Iron "	3.1	1.5	2.2	15	1.1	3.4	7.7	.76	2.8	9.0	.83	2.18	7.8	.94	2.3		-		-	-	-
Phenol ug/l	24	18	21	422	1.4	21	675	0	53	33	0	7.4	34	7	15	39	1	8.2	10	-	5
Oil&Grease mg/l	-	-	-	-	-	-	3.3	0.5	1.4	13	0	2.7	15.8	0	4.6	13	5	5.8	-	-	-
Cyanide "	0.18	0	0.06	.35	0	.08	.36	0	.10	.23	0	.06	.79	0	.15	0.31	0.01	0.096	0.10	-	-
Susp.Solids "	28	10	17	119	7	23	28	2	14	34	1	12	106	2	19	20	6	18.1	-	-	-
Dis.Solids "	225	210	220	266	128	225	274	164	228	267	158	223	323	200	247	270	170	209	275	-	-
Conductivity umho/cm	420	390	400	470	310	372	500	275	366	420	300	340	470	309	388	670	295	514	-	-	-
MBAS mg/l	-	-	-	.35	.05	.15	.26	.05	.17	.46	.08	.15(1)	.21	.10	.17(1)		-		0.5	-	0.3
Color units	-	-	-	-	-	-	7	0	3	8	0	2	25	0	4.1		-		30	-	10
Turbidity "	-	-	-	55	1.6	16	25	0.2	12	19	.15	7.3	7.8	.2	2.0		-		-	-	-
Number of Samples		3			51			42			37			25			20				

(1) 6 samples (Jan-Dec 1968)

(1) 6 samples (Jan-June 1969)

*Indiana Regulation SPC-7

one can not rely on the dissolved oxygen measurements to indicate the state of life in the IHC, as can be done in a stream where BOD is the main form of pollution.

The loading of organic pollutants from the Canal into the Lake should also result in a decrease of oxygen content of the near-shore waters due to BOD. Storet data at water intake cribs does not indicate oxygen depletion, but measurements closer to the mouth of the Canal might do so. Oxygen depletion near the polluted bottom sediments is another possible effect. Normally Lake Michigan does not become anaerobic, even at the bottom in winter (FWPCA 1968).

8.7 Thermal Pollution

Thermal pollution is not a main subject of this study, because there are other programs studying thermal pollution of Lake Michigan; however, there are thermal effects in the Calumet area. The IHC water is taken from the Lake for industrial and municipal uses, and is heated by an increment of up to $10^{\circ}C$ when it is returned at the Canal mouth. The resulting buoyancy of the warmer Canal water affects the motion of the heated plume. See Chapter 12, where the mechanism of gravity spreading is discussed. The increased temperature should also increase the rate of biological activities in the IHC. Temperature measurements in the plume were conducted during our field sampling program, and are presented in Chapter 11.

In addition to the IHC, there is also a thermal plume from the State Line power plant of Commonwealth Edison Co. A few measurements of the thermal plume from this plant were documented by Frigo and Frye (1972). A thermal plume is also produced by cooling water emissions from the U.S. Steel South Works at the mouth of the Calumet River. The plant takes cooling water from a slip just inside the breakwater on the Lake shore, and discharges it into the river close to its mouth and also directly to the Lake. Other cooling water uses in the area are at Burns Ditch, from Bethlehem Steel and Midwest Steel Companies. The Bailly nuclear power plant planned at Burns Harbor proposes to use a cooling tower, and will cause a small thermal plume in the Lake (AEC Environmental Statement 1973). The existing Bailly fossil plant causes a somewhat larger thermal plume.

9. BIOLOGICAL INDICATORS OF WATER QUALITY

Because the biota of lakes and rivers changes gradually with increasing pollution and eutrophication, it is possible to assess the quality of the aquatic environment through a study of the biota. Much publicity is currently being given to constant monitoring apparatus for chemical parameters. Biologists have made use of a natural integrating monitoring system for many years, viz: the community of plants and animals living in the water.

This chapter summarizes reviews of phytoplankton and zooplankton communities in Lake Michigan in general and the Calumet area in particular. The summaries are based on the more detailed reviews by Howmiller and Gannon given in Appendices A and B.

Chapter 7 contains a summary of the benthic organisms, again based on the Appendix by Howmiller. Chapter 16 contains a brief summary of the bacterial flora of Lake Michigan, based on Howmiller's review in the Appendix. It also contains an assessment of bacterial pollution from sources in the Calumet area.

9.1 Phytoplankton

Howmiller (Appendix A) reviews the trends in quantity and composition of algae in Lake Michigan. Several maps (Figures A2 to A4) show that the abundance of algae is substantially greater in the near-shore waters than in the main body of the Lake, especially near large sources of pollution. The Calumet area is one of these. Furthermore, the total plankton counts at the Chicago water intake has been increasing regularly as shown in Figure A5 from 1926 to 1958. Further increases since then have been reported by Vaughn (1969). This is a further indication that the nutrient level of this area has been increasing.

Further evidence of deterioration is shown by changes in the dominant species and types of flora. There are definite differences between the in-shore and off-shore species, which are related to abundance of nutrients in the in-shore waters. There are changes in the composition of the diatom population as well as increases in the proportion of blue-green algae to diatom. Species of diatoms which are favored by eutrophic conditions have increased in relative abundance in recent years. Changes in the diatom flora of the Lake appeared first in near-shore waters and virtually all near-shore waters now have a flora radically different from that indicated by the earliest samples taken 90 years ago. Collections from the Chicago area in 1876-1881 contained most of the species which now are found exclusively in the open Lake, although some of the species which are now characteristic of in-shore waters were also present. This pattern, of new introductions to the flora appearing first in near-shore waters and later spreading to the open Lake, was taken as evidence that the changes are caused by nutrient pollution and not natural phenomena. (See Appendix A.)

There is also recent evidence that silica is sometimes limiting the growth of diatoms in Lake Michigan. This is due to added amounts of phosphorus, presumably the usual limiting nutrient at most times in the past, allowing diatoms to use up the available silica. Thus, it can be expected that the composition of the planktonic flora will shift from near complete dominance of diatoms to a greater proportion of the less desirable nonsiliceous green and blue-green algae. Major changes appear to be happening first in the southwestern section of the Lake. Abundant plankters of certain taxa have caused problems for water supply around southern Lake Michigan. Problems include fishy odors and filter clogging, and even carbonate turbidity.

Howmiller (Appendix A) also reviews the problems resulting from increased growth of macroscopic algae. These green filamentaceous algae grow on rocks, then break off and are washed up on beaches. Among these the most prevalent is Cladophora. Its distribution is correlated with nutrient-rich water. Phosphorus is considered to be the limiting nutrient in most situations. We can expect continuing problem growths of Cladophora in direct proportion of the input of nutrients, especially phosphorus.

9.2 Zooplankton

Gannon (Appendix B) has reviewed available information on the ecology of Lake Michigan zooplankton. These tiny animals are part of the food chain, since they feed on phytoplankton, and are themselves food for fish. These fauna can be used as indicators of pollution and nutrient enrichment; however, they have been inadequately investigated in Lake Michigan as a whole, and investigations in the Calumet area are even more rare. There is enough information to observe some general trends, and to confirm other indicators of pollution in the Calumet area.

Extreme reduction or absence of zooplankters in a given area will be a good indication of toxic pollutants. On the other hand, numbers of a few species in a certain region will be a good indication of nutrient enrichment (Appendix B, p. 48).

9.2.1 Lake-Wide Effects

To obtain a general picture of the zooplankton, Gannon consider studies throughout the Lake. Comparative studies over a long period of time would show long-term trends in pollution, but early studies are incomplete. Some extensive studies (Appendix B, p. 7) were done in 1955. Later studies in 1966 and 1968 showed changes, but these could be due to alewife predation as well as to pollution occurring in the meantime.

Another comparison is between in-shore and mid-Lake (or off-shore) waters. In general (Appendix B, p. 12) it was noted that oligatrophic off-shore waters of Lake Michigan contain high ratios of calanoid copepods relative to cladocerans and rotifers, and the opposite is true for the more eutrophic in-shore waters. In the Milwaukee harbor region (Appendix B, p. 8, 16) it was noted that higher numbers of zooplankton reflect a response to nutrient enrichment of the near-shore waters by the discharge of municipal sewage, industrial wastes, and storm water run-off from the Milwaukee River watershed. Green Bay represents another polluted area, which may indicate the pattern of changes likely to occur in the Calumet area. The large biomass of zooplankton in Green Bay is partly attributed to nutrient-laden waters from the Fox River, and partly to zooplankters that are carried into the Lake by the River. This last effect is very unlikely in the vicinity of the IHC, because the IHC has not been reported to harbor any zooplankton life.

The most extensive data on plankton in the Calumet area are those of the Chicago Water Dept. Measurements were made as far back as 1879, and have been made regularly since 1926. Unfortunately, zooplankton were not usually separated from phytoplankton. If zooplankters are mentioned at all, only data for the most common genera of rotifera, copepoda, and clodocera are mentioned. Although these data have been adequate for purposes of water filtration plant operations, they are not adequate for detecting long-term changes in zooplankton species composition and abundance commensurate with changes in water quality. Nevertheless, examination of the raw data might be a worthwhile project.

9.2.2 Calumet Area

A few Lake-wide studies (Appendix B, p. 24) include measurements in the Calumet area, including Gary and Michigan City. The abundance of zooplankton at all stations in Indiana waters were considerably higher than values reported for elsewhere in Lake Michigan. In fact, the biomass in 1972 was ten times higher than values reported elsewhere. Comparable numbers have been reported only in Milwaukee harbor and in Green Bay (Appendix B, p. 31). The zooplankton crustacea community in the Indiana waters was characterized by low numbers of calanoid copepods relative to cyclopoid copepods and cladocerans. A number of bar graphs showing these ratios are included in the Appendix. These ratios indicate a response by the zooplankton community to nutrient enrichment of the Indiana waters of Lake Michigan. A similar response by rotifers is reported (Appendix B, p. 40).

The question may be asked why we should be concerned if one form of zooplankton supplants another due to increasing pollution of the water by man. One reason is that we can use these changes to measure the general level of pollution in an area such as the Calumet, both over time and in relation to cleaner portions of the Lake. Another reason is that the plankton serve as food for fish (Appendix B, p. 18). Changes in the composition of the plankton population are known to result in changes in fish populations. This has not been a part of the present study, but it would be of concern to the many people who make use of the Lake for sport fishing. Another concern is that toxic materials may be carried along the food chain and be concentrated in fish. The Calumet effluents have not been implicated as an important source of toxic materials in fish, but the subject has not been studied to our knowledge. The bottom sediments of the IHC area have been shown to be toxic to zooplankton, however (Appendix B, p. 42).

Gannon (Appendix B) concludes that our knowledge of the zooplankton ecology of the Calumet area is woefully incomplete. To estimate general patterns, it is necessary to reason by analogy with similar waters elsewhere. There is insufficient data on zooplankton in the Calumet area to demonstrate water quality degradation. Gannon (Appendix B, p. 49) recommends field studies to analyze zooplankton community structure, including taxonomic identification to the species level. He also recommends laboratory bioassay studies using zooplankton to determine response to effluents in the Calumet area.

10. LAKE CURRENTS

The currents in Lake Michigan have been extensively studied. They are complex, and a number of controversies persist; yet the major outlines are known. These are set forth in reports by FWPCA (1967), by Mortimer (1968, 1971), and by Noble, Huang and Saylor (1968). Although we are concerned primarily with the southern tip of Lake Michigan, most of the work describes the main body of the Lake. In fact, little is known about the currents in the southern tip.

10.1 Thermal Structure

The seasonal structure of temperatures underlies the current behavior (Noble, Huang and Saylor 1968). During summer the Lake is stratified; the depth of the warmer epilimnion increases with the season. The thermocline is a density barrier that prevents mixing (except for up-welling) with the winter-cooled water below. In September the surface begins to cool, and by late autumn the thermocline becomes so weak that vertical mixing is possible. Temperatures become uniform near 4°C, the temperature of maximum density. In winter, the surface falls close to 0°C, but the smaller winter density gradient is a less effective barrier to mixing.

The warming process, beginning in April-May, is most noticeable near the shore. The shore heating results in a cellular convection effect that has been named the "thermal bar." The shore water, heated above 4°C, meets very cold surface water further out; at some distance from shore, this produces a mixture at 4°C. This maximum density water sinks, setting up a warm convection cell near the shore, and a cold one over the remaining stratified surface water. There is no vertical stratification to prevent mixing; the shore water leads the rest of the lake in temperature, and there are vertical isotherms. Eventually, the bar extends to mid-lake. As summer approaches, the surface waters are again heated, and the strong summer thermocline develops over the whole Lake.

10.2 Causes of Lake Currents

There are several major forces that result in Lake currents (Mortimer 1971). The first of these is thermal convection, resulting from the greater rate of temperature rise of near-shore water. The second is the surface stress of wind acting on the water. The third is the Coriolis force, or the inertial effect of water currents resisting change of direction resulting from the earth's rotation. A fourth results from the flow-through from tributaries to the outlet at Lake Huron, but this is negligible.

In addition to these forces, the currents are dominated by boundary effects due to the shores, the thermocline, and topographical features. A persistent feature is the strong currents that flow along both eastern and western shores (Ayers 1959).

Convection currents of warmer shore waters flow outward in spring, but the Coriolis effect turns Lake currents to the right (Mortimer 1971; 1959). The amount of deflection due to the Coriolis effect is a function of the boundary stress, i.e., depth. Consequently, the deflection may approach 45° in deep waters, be closer to 30° in moderately shallow water, and there may be little or no deflection in shallow areas (Beeton 1974). Thus convection can cause currents along the shore. Huang (in Ayers, Huang and Saylor 1968) proposed a mathematical model including these effects, but excluding wind stress. This model explains many persistent features of currents, but it cannot explain the daily changes in current pattern that are observed. To explain these, one must invoke wind stress.

Mortimer (1968, 1971) has given the best picture of currents including wind effects. Wind tends to blow warm water off one shore toward the other. Because of the Coriolis effect, winds from the north and east move warmer water to the western shore; those from south and west move water to the eastern shore. Extensive bathythermograph data by Mortimer (1968) show that such winds tip the thermocline, and if winds are strong enough they cause upwelling of cold bottom water to the left of the wind direction. Another effect is the piling up or "set-up" of wind-driven water on the opposite shore. There may be downwelling, as well as flow along the shore toward the end of the Lake.

10.3 Current Data and Trends

In the south basin the shore set-up results in a characteristic gyre (Ayers et al. 1958; Ayers 1959), which can give rise to one or two large eddies, driven like gears in the Calumet region. Likewise typical eddy patterns arise in the north basin as a result of its special shape. These shore and eddy currents can go in directions opposite to the wind, but Ayers (1971) claims to be able to explain the primary currents in terms of the wind vector modified by the Coriolis angle, plus the shoreline set-up. Very close to the shore, inside of these major currents, there is often a local current that follows the normal wind direction along the shore, opposite to the direction of the larger gyre or eddy further out (Ayers 1959).

Several experimental techniques have been used to gather current data. Drift bottles containing a return postal card were used by Harrington (1895), Van Oosten (1963) and Johnson (1960). These studies showed the persistent northward current along the east shore, and are consistent with the picture of gyres and shore currents described above. Mortimer (1968) described bathythermograph data obtained from rail ferry crossings in 1964. Ayers (1959) carried out extensive similar measurements using eight boats to make simultaneous crossings. These gave a picture of the thermocline and its tilt due to winds.

Noble et al. (1968) also deduced the currents from the thermal data. The method is based on a plot of geopotential, or dynamic height. A region of colder, higher density water near the surface is like a local hill, and must indicate flow away from this point. Although the data are indirect, Ayers et al. (1958) used it to construct current charts that agree reasonably well with those prepared by other methods.

FWPCA (1967) set a grid of water current meters at numerous depths in the Lake (but not in the top 10 m). These meters recorded local currents over a period of months including winter. The most prominent features were the cyclic and rotating currents representing the passage of internal waves on the thermocline, with periods of 2 to 17 hr. These waves are a separate subject that have only secondary effects for our purposes. They complicate the interpretation of current meter data as well as data from vessel traverses. FWPCA (1967) used time-series methods to average out the wave effects. The report presents maps that show currents averaged over several months in summer and winter with N/E winds or S/W winds. These are valuable because they represent true average data, not generalizations from a few cases; however, they do not show the variations that occur in the currents, although this information was undoubtedly recorded. Also, only a few current meters were located in the Calumet area of interest to us, and these were considerably off-shore. Therefore, the maps do not reveal local conditions in the Calumet area.

10.4 Summary of Currents

From the above discussion, we can conclude a thermocline should seldom be formed in the Calumet area of Lake Michigan, because it is too shallow, being only 7-15 m depth out to a distance of 10 km. Currents can be either north or south along the shore. They will tend to be as indicated on the FWPCA (1967) maps, but can be in any direction. Flow out from the shore has even been observed at Chicago, and may be possible in the Calumet area. A wind-driven current close to shore can even move in a direction opposed to a larger gyre several km out from shore.

Current velocities of 5 to 15 cm/sec (0.2 to 0.5 ft/min) are typical in Lake currents. Fifty cm/sec currents have been recorded, and near-zero velocities occur as well. Saylor (1968) reported currents off Calumet Harbor of 18 and 15 cm/sec.

10.5 Diffusion Coefficients

A few measurements have been made of turbulent diffusion coefficients in Lake Michigan. Huang (in Noble, Huang and Saylor 1968) reported experiments on the dispersion of rhodamine red dye off Benton Harbor, which gave diffusion coefficients around 500 cm/sec^2 in the horizontal direction. Coefficients in the vertical direction are expected to be 1/100 to 1/1000 as large. Unfortunately the weather and current regime at the time of the test was not reported. It should be clear that wind and currents will lead to rapid mixing, or a high diffusion coefficient; other conditions such as thermal stratification tend to prevent mixing. Conditions of very slow currents will result in little mixing. Conditions of high shear, where one current deflects from another or from the shore, or conditions of cellular convection, should give rapid mixing. Since there are few data on diffusion coefficients and wide variations are possible, one should try a range of diffusion coefficients in our model that are consistent with expected or known current conditions.

10.6 Current Measurements During This Program

Currents were measured for a period of one month at two locations as part of our field study. The methods of measurement and the resulting data are presented in Chapter 11. The conclusion was reached that the currents near shore do not follow the same rules as for currents far out in the Lake, because of the influence of the shore. Generally the currents travel along the shore either in a northerly direction, or in a southerly direction. The direction depends on the wind, but is not necessarily in the wind direction; any wind to the north will tend to cause a current to flow to the north. When the wind is to the north east there may be a slight off-shore component of the current, but this is difficult to determine because of the possible effect of the Calumet harbor breakwater. The current at 19 ft depth is in nearly the same direction as the current at 9 ft.

On November 14 and 19 the current was measured vs depth at 68th St. crib (see Table 10.1). The data check the moored current meter. The data for November 19 show only slight variation of direction with depth. The data of November 14 show larger variation with depth; this may be related to the observation that the current was changing direction at that time.

The current generally drops to zero speed when it changes direction in response to a wind direction change. On a few occasions the current was observed to travel directly off-shore for a few hours, and this occurred at a time when the current was shifting direction. The observed direction of the plume of effluents from IHC was the same as the direction indicated by the current meters.

In general, the currents in the Calumet area appear to mainly follow the shore, in the general direction of the wind.

Table 10.1

CURRENT METER MEASUREMENTS
AT 68th ST. CRIB (CAL17)

Depth, m	Speed, knots	Direction,* degrees
	November 14, 1973 9:40 A.M.	
1	0.1	330
2	0.11	315
3	0.09	320
4	0.06	305
6	0.09	290
8	0.10	270
10	0.08	270
	November 19, 1973 9:15 A.M.	
1	0.1	170
2	0.1	190
3	0.1	170
4	0.07	180
6	0.07	180
8	0.03	160
10	0.01	160

*Direction parallel to shore is 335° or 155°

11. IITRI FIELD SAMPLING PROGRAM AND DATA

11.1 Objectives and General Plan

During the period from November 5, 1973 to December 8, 1973, IITRI conducted a program of field sampling in the Calumet area of Lake Michigan. The purpose was to obtain data on near-shore water quality, simultaneously measuring currents and locating the plume from the Indiana Harbor Canal. This allowed us to relate the water quality to the Canal effluents, and thus fill a gap in the data.

It was apparent that a comprehensive file of water quality data was already available from other agencies, and the objective was not merely to add to it. In analyzing available data via Storet, we found it difficult to relate the near-shore water quality to the known effluent sources, because hydrodynamic conditions in the Lake were not measured simultaneously with the water quality. Consider for example the region near Indiana Harbor, where the main source is the Indiana Harbor Canal. On any particular sampling day the Lake currents could carry the plume from this canal either up-shore toward Chicago, or down toward Gary, or even out into the Lake. Without knowing the direction of movement of the plume, it is difficult to say whether data measured at some station represents pollution coming directly from the Canal, or from some other source such as the Calumet Harbor, or even represents the general level of the near-shore waters built up over time from a number of sources.

We also noted that available measurements of water quality in the Lake were often not combined with measurements of the flow and quality of water into the Lake at the mouth of major tributaries. This information was needed to relate water quality to effluent loadings.

In addition, there is a lack of direct measurements of currents and dispersion parameters needed for any model of pollution dispersion in the near-shore Calumet area. Only a few current measurements are reported by Saylor (1968). Otherwise, one must extrapolate from measurements made further out in the Lake, for example by FWPCA (1967). Our objective was to obtain as much data as possible to tie together these effects of water quality, effluents, and Lake currents or dispersion, within the available budget.

It appears that there is also a gap in the biological data, in that the species have not been analyzed to indicate the state of pollution in the area. Biological sampling was planned at the same time as chemical sampling, to give an independent measure of the state of pollution. This was not done because we were not able to arrange for a suitable boat for biological sampling.

Our objective was not merely to add data to the comprehensive data file already obtained by other agencies, or being obtained. We did not attempt to measure all parameters, but concentrated our efforts on a few representative parameters of each type. We included types that would have different dispersion behavior, such as dissolved, suspended, biologically active and inert; and also tried to include pollutants most important for their effects on the Lake.

The study area includes several streams tributary to the Lake, as well as the southern part of the Lake from the 68th St. Chicago water intake crib to Burns Harbor, Indiana. Sampling of these tributary streams was currently being done by the State of Indiana, more extensively than we could do. In addition, the U.S. EPA takes samples at infrequent intervals. Therefore, we did not plan detailed sampling at points along the streams.

The objectives of the program are related to the importance of the various portions of the waters in the region. Some of the streams are of very poor quality, with high bacteria counts and conditions toxic to life. Their improvement to reasonable aesthetic quality is very important; however, these streams are limited in extent, and are not so important as the Lake itself. The alarming deterioration of the Lake, especially its near-shore waters, is documented in a report of the U.S. FWQA (1968). For these reasons, it is important to determine the response of the near-shore waters to immediate pollution sources, both by modelling and by sampling. This will help the EPA and the State of Indiana to determine either effluent limitations, or water quality requirements in the Indiana Harbor Canal that will lead to restored Lake conditions.

In planning the field studies, we received excellent advice and cooperation from personnel of the Argonne National Laboratory, who worked for us on a subcontract relating to the field sampling. (See Acknowledgments.) Various means for measuring the IHC plume were considered, such as dye injection, drogue measurements, and continuous monitoring at the mouth of the IHC. We finally selected the following methods: (1) sampling of water at predetermined Lake stations from a boat, (2) in-situ measurements at various depths at the same locations, (3) sampling from public water supply intakes in the area, (4) visual and photographic observations of the plumes from an airplane, and (5) measurement of currents in the Lake by installing current meters at two locations.

11.2 Water Sampling and Boat Measurements

11.2.1 Location of Sampling

Our plan was to concentrate our efforts on the effluents from the IHC, and its impact on the near-shore waters of Lake Michigan. Therefore, most of our measurements were made in the Lake in the region where the plume was expected. See Figures 11.1, 11.2 and Table 11.1 for sampling station locations. Some stations were

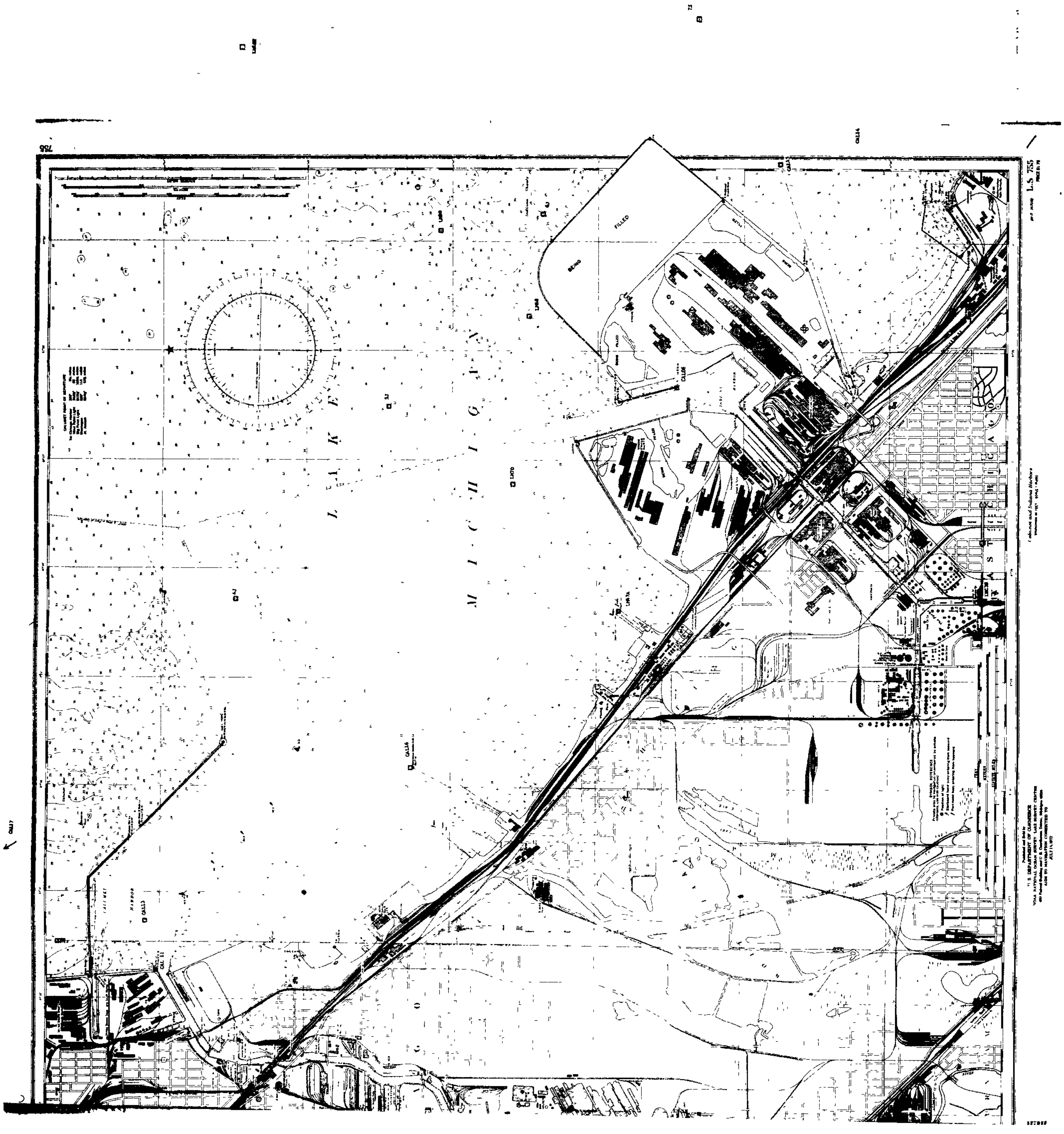

Figure 11.1

DETAILED MAP OF STATIONS FOR IITRI FIELD SAMPLING

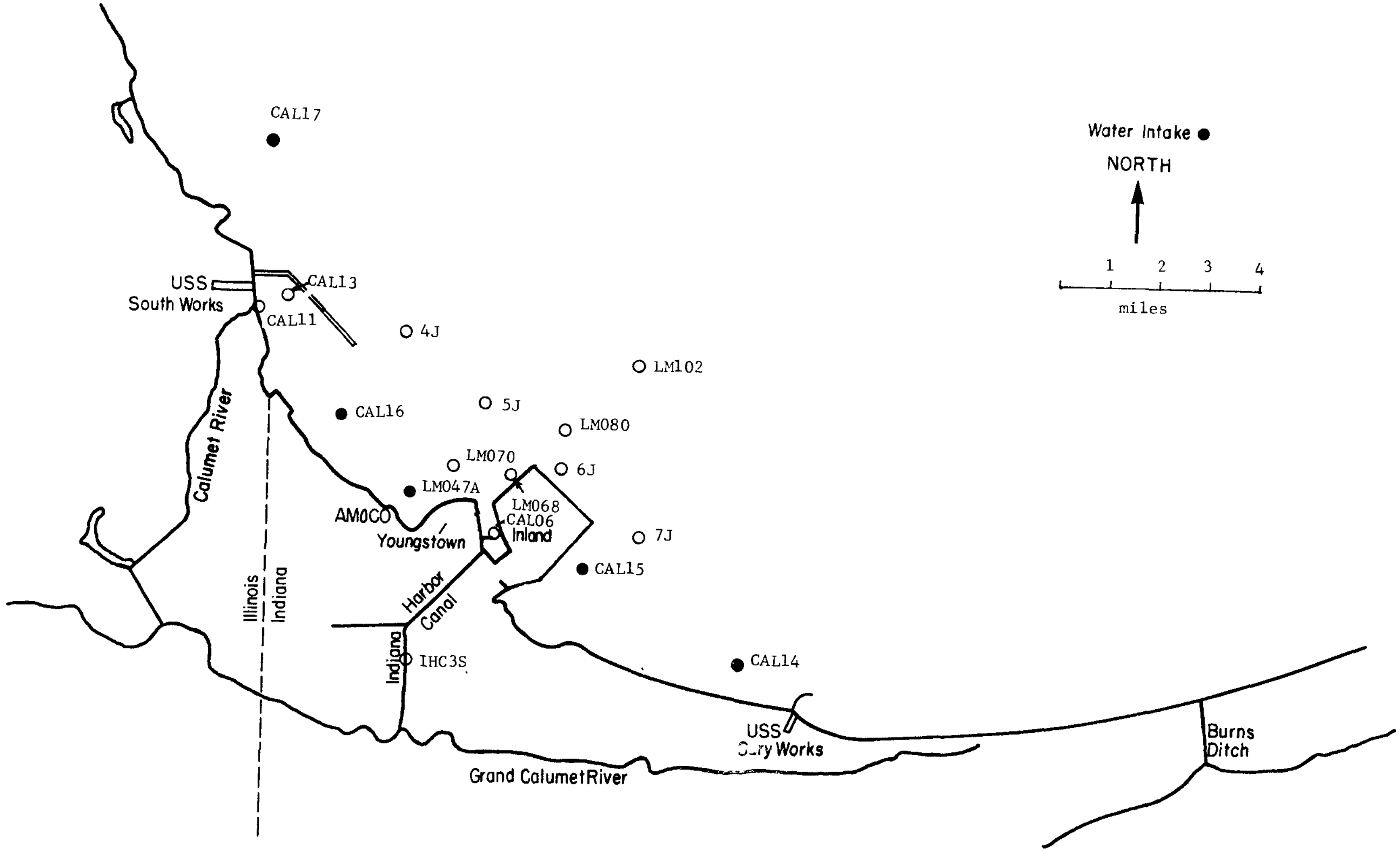

Figure 11.2

MAP OF STATIONS FOR IITRI FIELD SAMPLING

Table 11.1

WATER SAMPLING STATIONS - CALUMET AREA

Station		Location	Latitude	Longitude
CAL	17	68th St. Crib	41 41 11	87 32 22.5
CAL	13	Calumet Harbor	41 44 06	87 31 16
CAL	11	Calumet R. mouth, north pier head light	41 44 02	87 31 45
CAL	06	Indiana Harbor breakwater inner NE light	41 40 28	87 26 20
CAL	16	Hammond water intake	41 42 14	87 29 49
CAL	15	East Chicago water intake	41 39 45	87 24 18
CAL	14	Gary West water intake	41 38 27	87 20 28
LM	47A	Whiting water intake (American Oil intake)	41 40 50	87 28 22
SWFP	4J	Chicago Water Dept. open Lake	41 43 28	87 28 17
SWFP	5J		41 42 26	87 26 31
SWFP	6J		41 41 23	87 24 45
SWFP	7J		41 40 21	87 23 00
LM	70	EPA open Lake stations	41 41 35	87 27 15
LM	68		41 41 28	87 25 42
LM	80		41 42 5	87 24 55
LM	102		41 43 25	87 23 15
IHC	3S	Indiana Harbor Canal at Columbus Drive	41 38 20.7	87 28 16.8
		Current meter near Inland landfill	41 42 14	87 24 34
		Current meter near 68th St. crib	41 46 81	87 31 84

also located where they would measure the influence of other sources, such as the Calumet River. Measurements were also made at the mouth of the IHC and the Calumet River, to determine the total amounts of effluents entering the Lake from these sources and to check the information on loads obtained from the permit applications. Measurements were also made at Columbus Drive on the IHC, to measure the load of effluents from sources above this point, particularly on the Grand Calumet River.

Most of the Lake samples were obtained from a boat. At this time of year, the weather limits access to the Lake in a small boat, and in fact there were only three suitable days in a one-month period. So that we could have a more continuous record of water quality, the boat samplings were supplemented by samples obtained from five public water supply intakes in the area. These are indicated on Figure 11.2 as

CAL17	Chicago SWFP
CAL16	Hammond WFP
LM047A	Whiting WFP
CAL15	East Chicago WFP
CAL14	Gary WFP (Hobart Water Co.)

In each of these plants there is a tap, from which a sample can be drawn of the raw water from the intake crib. We drew the samples, and analyzed them.

In addition to taking samples from the boat, a Hydrolab instrument was used for in-situ measurements. This instrument permitted us to measure a few water quality parameters at various depths, in addition to the more extensive measurements made on a sample taken at 1-meter depth. The in-situ measurements were temperature, pH, dissolved oxygen, conductivity, and chloride ion concentration. The conductivity and chloride measurements made in this way were calibrated by comparison with measurements made in the laboratory on samples from 1-m at each station. The dissolved oxygen probe was calibrated against air-saturated water.

All water samples were taken in 2.5-gal cubitainers. Because the water was cold at this time of year,and the samples were analyzed within a few hours, no attempt was made to preserve them except to keep them in the dark.

11.2.2 On-Board Instrumentation

The Argonne boat used has a cathedral hull, is 18 ft long, with two 25-hp motors. Position is determined by a Motorola Miniranger. Two transponders were mounted at known points on shore. Sampling positions were within 30 m of the station location. Wind speed and direction were determined from the boat. Also available was a Bendix Q15 current meter. This was used to measure current vs depth at 68th St. crib, and also at the mouth of the IHC.

11.2.3 Shore Sample Treatment

On-shore filtration and analysis of samples was done in space provided by the Hammond Water Treatment Plant laboratory by IITRI personnel (see Acknowledgments).

At this laboratory the following measurements were made: pH, conductivity, turbidity, total coliform bacteria. Two portions of each water sample were also filtered here. The residue was analyzed at IITRI. Samples of the filtrate were preserved and analyzed at IITRI. An untreated water sample was also frozen and subsequently freeze-dried to determine total solids. Some of these samples were analyzed for phosophorus at IITRI, and they are preserved for later use.

11.2.4 Analytical Methods

Standard methods used for analyzing the samples are given in Table 11.2.

Table 11.2

ANALYTICAL METHODS FOR GENERAL ANALYSIS OF WATER SAMPLES

Parameter	Storet number	Units of measurement	Method of measurement: 13th Edition Standard Methods No.	Method of measurement: 1971 EPA-MCA pages	Instrument to be used	Sample preservation (if any)	Brief description of method	Comments or other reference
Temperature	00010	°C	162 p.348	296	thermisters	none needed - measure in situ	Thermisters mounted at various depths from the sampling boat up to 30 ft.	
Conductivity	00095	μmho/cm	154 p. 323	284 & 285	Hydrolab conductivity meter	none - in situ	Instrument standardized with KCl solution; values corrected to 25°C; the parameter is related to total concentration of ionized substances	ASTM Standard Methods D1125-64 (1970)
pH	00400	pH units	144A p. 276	230 & 231	Hydrolab pH meter	none - in situ	pH is the logarithm of the reciprocal of the hydrogen ion concentrations electrometrically measured.	ASTM Standard Methods D1293-65 (1970)
Turbidity	00075	Jackson units	163A p. 350	308	Hach model 2100A turbidimeter	none - measure on boat	Light-scattering is measured from a sample.	Sensitivity 0.01
Dissolved oxygen	00300	mg/l	218F p. 484 (tentative)	60 to 63	Hydrolab membrane electrode DO analyzer	none - in situ	The probe is dependent on electrochemical reactions. The current or potential is correlated with DO concentrations.	0.1 mg/l
Chloride	00940	mg/l	-	-	Hydrolab D6 with selective ion electrode	none - in situ check in lab	Specific chloride ion electrode will be used to measure porentiometrically chloride concentrations.	Sensitivity 0.27 mg/l
Fluoride	00950	mg/l	-	72 to 75	selective ion electrode	measure in Hammond, Indiana water dept. lab	Specific fluoride ions electrode will be used to measure potentiometrically floride concentrations.	Sensitivity 0.019 mg/l
Ammonia (NH_3)	00610	mg/l	-	-	selective ion electrode	filter & add NaOH - at Hammond	Gas sensing ammonia electrode will be used to measure ammonia present.	Sensitivity 0.017 mg/l

Table 11.2 (cont.)

Parameter	Storet number	Units of measurement	Method of measurement: 13th Edition Standard Methods No.	Method of measurement: 1971 EPA-MCA pages	Instrument to be used	Sample preservation (if any)	Brief description of method	Comments or other reference
Phosphorus (total)	00665	mg/l	223 p. 518	235 to 238	colorimetry	Freeze on same day	Freeze-dry 500-ml sample and analyze dry residue for total phosphorus — Robbins, Landstrom & Wahlgren, Proc. 15 Great Lakes Res. Conf., 270-290, 1972	Sensitivity 0.0005 mg/l with preconcentration
Total coliform	31501	MFIM ENDO/ 100 ml	408A p. 679	-	binocular widefield dissecting microscope	incubation at 35 + 0.5°C & 90% RH	Coliform membrane filter is used for filtration count the total coliforms and reports density/ 100 ml	
Total organic carbon	00680	mg/l		221 to 229	infrared analyzer	2 ml H_2SO_4/l (pH ≅ 2) 7 days if necessary	A 100-ml sample is injected into a catalytic combustion tube. CO_2 is measured and is directly proportional to carbonaceous material. Subtract inorganic blank.	Precision 1 mg/l
Nonfilterable residue (suspended solids)	00530	mg/l	p. 287	278 to 281	Gelman glass filter	filter 1-liter sample at Hammond on same day	Filter sample and dry to constant weight at 103-105°C	Unknown
Chlorophyll	-	mg/l	602A p. 746	-	spectro-fluorimeter (0.5-5 μm)	use residue from above	Extract chlorophyll in acetone from dried material retained on Gelman filter. Extract and determine chlorophyll.	Sensitivity 0.001 mg/l
Volatile solids	00505	mg/l	p. 538	282 to 283	ignition	use residue from above	Ignite at 550°C and determine weight loss	0.11 mg/l
Iron in suspension	00680 (total) 00681 (dissolved)	mg/l	129A p. 211	108 & 109	atomic absorption spectrophotometer	use residue from above	Dissolve ash in 10 ml 6N HCl.	

11.3 Chemical Results

The results of chemical sampling are presented in Table 11.3. The first six pages pertain to the three boat sampling days, November 14, November 19, and December 7. For each station the first line of data presents the laboratory analysis of samples taken at the indicated depth of 1 m. Below this are listed the results of Hydrolab measurements made at several depths as indicated. Some of the stations were located at water supply intakes. In this case the final line, identified with an * or S, gives the analysis of a sample which we took from the intake. The time at which each sample was taken is given after the data; the time was different for the boat and intake samples.

Pages 7 and 8 of Table 11.3 present results of samples taken from water intakes and the IHC station on the remaining days, when there were no boat samples.

11.4 Aerial Observations

On each day that weather permitted during the sampling period, one of the project personnel went up in a light airplane to observe evidence of water pollution. Records were kept by making logbook notes, making sketches on a map, and taking color slide photographs. A log listing of the slides was compiled later. The sketch maps have been redrawn by an artist, and are reproduced in Figures 11.3 to 11.12.

The usual flight path started at Gary Municipal Airport. The plane then flew along the Grand Calumet River until it was over the junction with the IHC. At this point, the direction of river flow could be seen by the streamlines of colored water. In every case the flow of both branches was toward the IHC. The plane then followed the IHC to Lake Michigan. Oily outfalls and oil spills were noted. The plane then circled over the environs of the IHC mouth, to observe the location of the plume in the Lake. Outfall plumes in the turning basin of the IHC were noted.

Table 11.3

WATER QUALITY DATA IN IHC AND CALUMET AREA OF LAKE MICHIGAN
MEASUREMENTS FROM IITRI FIELD SAMPLING PROGRAM
November 5 to December 8, 1973

Station	Year Month Day Hour	Depth, m	Dissolved oxygen, mg/ℓ	pH	Temperature, °C	Chloride, mg/ℓ	Conductivity, u mho/cm	Turbidity, JTU	Fluoride, mg/ℓ	NH_3-N, mg/ℓ	Total phosphorus, mg/ℓ	Total coliform MF, per 100 ml	Total organic carbon, mg/ℓ	Total solids, mg/ℓ	Suspended solids, mg/ℓ	Chlorophyll, μg/ℓ	Volatile suspended solids, mg/l	Total iron, ug/ℓ	Dissolved iron, ug/ℓ
CAL17	7311140940	1.0	11.4	8.2	8.5	7.5	195.0		0.100	0.03	.	18.0	8.0	.	1.80	1.90	0.5	40.0	20.0
CAL17	7311140940	3.0	11.4	8.2	8.4	6.0	194.0												
CAL17	7311140940	5.	8.4	8.2	8.4	5.4	[illegible]												
CAL17	7311140940	8.0	8.6	8.2	8.4	5.4	200.0												
SCAL17	7311140900	5.		9.1	10.0	7.[illegible]	225.0	3.0	0.120	0.07	.	100.0	8.0	.	3.10	2.20	0.3	70.0	20.0
SWFP4J	7311141030	1.0	11.7	[illegible]	.6	9.1	[illegible]		0.130	0.03	.	99.0	11.0	165.0	2.10	2.10	0.3	20.0	10.0
SWFP4J	7311141030	3.0	11.5	8.3	8.5	7.0	200.0												
SWFP4J	7311141030	5.0	11.[illegible]	8.2	8.4	7.4	[illegible]												
SWFP4J	7311141030	8.0	12.2	8.2	8.3	7.5	205.0												
SWFP5J	7311141100	1.0	11.2	.	8.3	9.1	[illegible]		[illegible]	[illegible]	.	1000.0	12.5	.	2.70	2.60	0.5	70.0	20.0
SWFP5J	7311141100	3.0	11.8	.	8.1	[illegible]	21[illegible]												
SWFP5J	7311141100	5.0	12.0	.	[illegible]	9.1	[illegible]												
SWFP5J	7311141100	8.0	12.6	.	[illegible]	9.7	205.[illegible]												
CAL11	7311141240	1.0	10.6	7.9	10.5	12.8	230.0		[illegible]	0.23	.	21[illegible]0.0	10.[illegible]	155.0	7.00	4.00	0.6	250.0	20.0
CAL11	7311141240	3.0	11.2	8.1	10.0	12.0	220.0												
CAL11	7311141240	5.0	11.6	8.[illegible]	9.4	11.2	215.												
CAL11	7311141240	8.0	12.2	8.1	9.0	10.4	21[illegible]												
CAL13	7311141300	1.0	10.4	8.2	9.1	9.1	[illegible]		0.150	0.15	.	66.0	13.0	171.0	4.70	5.50	0.7	90.0	20.0
CAL13	7311141300	3.0	11.6	8.2	[illegible]	9.1	[illegible]												
CAL13	7311141300	5.0	12.0	8.	8.9	[illegible]	[illegible]												
CAL13	7311141300	8.0	12.[illegible]	8.2	8.9	8.[illegible]	[illegible]												
CAL16	7311141215	1.0	11.1	8.7	8.7	7.[illegible]	195.[illegible]		0.12[illegible]	[illegible]	.	58.0	10.[illegible]	.	1.40	1.30	0.1	20.0	20.0
CAL16	7311141215	3.	11.[illegible]	8.5	8.5	7.3	[illegible]												
CAL16	7311141215	5.0	12.0	8.5	8.4	7.[illegible]	[illegible]												
CAL16	7311141215	7.	12.[illegible]	8.4	8.3	9.	200.												
*CAL16	7311141200	5.0		8.1	11.6	6.7	210.0	2.3	0.120	0.02	.	6.0	11.0	159.0	2.20	1.50	0.3	30.0	10.0
LM047A	7311141150	1.0	11.4	8.7	8.6	6.5	[illegible]		0.120	0.0[illegible]	.	35.0	8.0	144.0	1.50	1.30	0.3	20.0	10.0
LM047A	7311141150	3.0	11.3	8.5	8.5	[illegible]	200.0												
LM047A	7311141150	5.0	12.4	8.4	8.4	5.[illegible]	200.0												
LM047A	7311141150	7.0	12.2	8.4	8.[illegible]	6.	215.[illegible]												
*LM047A	7311141130	5.0		8.1	[illegible]	7.7	21[illegible]	2.5	0.111	[illegible]	.	40000.0	11.[illegible]	.	2.90	4.50	0.3	40.0	10.0
LM070	7311141120	1.0	11.4	8.4	[illegible]	9.3	200.0		0.110	0.11	.	58.0	9.0	175.0	2.30	1.90	0.5	30.0	10.0
LM070	7311141120	3.0	12.4	8.3	[illegible]	7.[illegible]	200.0												
LM070	7311141 0	5.0	12.4	8.2	7.9	7.[illegible]	200.0												
LM070	7311141120	8.0	12.[illegible]	8.2	7.0	7.[illegible]	200.0												

* CRIB S SHORE CRIB SWFP

Table 11.3 Page 2

Station	Y MD HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
IHC3S	7311141100	1.0		7.6	10.0	59.0	440.0	10.0	0.860	4.50	.	240000.0	14.5	0.	16.20	2.60	4.6	1000.0	30.0
CAL06	7311141400	1.0	7.0	7.3	14.9	31.0	315.0		0.480	2.70	.	26000.0	10.0	204.0	7.70	3.00	2.2	670.0	20.0
CAL06	7311141400	3.0	7.5	7.3	15.0	25.0	315.0												
CAL06	7311141400	5.0	9.4	7.4	12.5	23.0	300.0												
CAL06	7311141400	8.0	11.6	8.1	9.0	14.0	240.0												
LM068	7311141430	1.0	10.2	8.0	10.7	13.0	240.0		0.220	0.50	.	3800.0	11.5	138.0	4.20	3.20	0.6	200.0	20.0
LM068	7311141430	3.0	11.9	8.2	8.7	7.8	230.0												
LM068	7311141430	5.0	12.4	8.2	8.4	9.5	225.0												
LM068	7311141430	8.0	12.5	8.2	8.2	8.2	225.0												
LM068	7311141430	10.0	12.6	8.2	8.1	7.5	225.0												
LM080	7311141510	1.0	10.0	8.0	10.3	13.0	245.0		0.200	0.50	.	2900.0	10.5	172.0	3.70	5.40	1.1	140.0	20.0
LM080	7311141510	3.0	8.3	8.3	8.4	11.1	225.0												
LM080	7311141510	5.0	8.2	8.2	8.3	10.2	225.0												
LM080	7311141510	8.0	8.2	8.2	8.2	10.2	225.0												
LM080	7311141510	10.0	8.2	8.2	8.1	9.7	225.0												
LM102	7311141620	1.0	10.2	8.1	9.0	9.0	210.0		0.140	0.27	.	1000.0	8.0	162.0	2.90	11.90	.	90.0	10.0
LM102	7311141620	3.0	12.1	8.3	8.5	12.2	205.0												
LM102	7311141620	5.0	12.5	8.2	8.3	12.2	205.0												
LM102	7311141620	8.0	13.1	8.3	8.3	11.5	205.0												
LM102	7311141620	10.0	12.7	8.3	8.3	10.9	205.0												
SWFP6J	7311141450	1.0	10.4	8.0	9.8	10.0	240.0		.	.	.	4100.0	11.5	176.0					
SWFP6J	7311141450	3.0	11.2	8.0	9.5	9.3	240.0												
SWFP6J	7311141450	5.0	12.0	8.2	8.6	8.2	220.0												
SWFP6J	7311141450	7.0	12.2	8.2	8.5	8.1	220.0												
CAL15	7311141550	1.0	11.2	8.2	9.0	9.6	215.0		0.140	0.05	.	400.0	8.5	163.0	3.00	2.90	0.3	50.0	20.0
CAL15	7311141550	3.0	11.8	8.2	8.8	9.1	215.0												
CAL15	7311141550	5.0	12.2	8.2	8.5	8.6	220.0												
CAL15	7311141550	8.0	12.3	8.2	8.5	8.6	220.0												
CAL15	7311141550	10.0	12.1	8.2	8.4	8.5	225.0												
*CAL15	7311141030	9.0		8.1	11.0	7.9	220.0	2.7	0.040	0.04	.	16.0	11.0	.	2.70	2.10	0.2	40.0	20.0
SWFP7J	7311141530	1.0	11.1	8.4	8.7	9.0	210.0		0.130	0.11	.	22.0	10.5	142.0	2.40	2.10	0.5	40.0	20.0
SWFP7J	7311141530	3.0	11.8	8.3	8.5	8.2	210.0												
SWFP7J	7311141530	5.0	12.3	8.3	8.4	8.2	210.0												
SWFP7J	7311141530	8.1	12.8	8.3	8.4	7.4	210.0												
SWFP7J	7311141530	10.0	12.6	8.2	8.4	7.4	210.0												
*CAL14	7311141000	9.0		8.1	10.0	8.1	220.0	.	0.090	0.05	.	0.0	9.0	.	2.20	3.10	0.9	60.0	20.0

Table 11.3 Page 3

Station	Y MD HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
CAL17	7311190915	1.0	11.8	8.5	7.2	7.5	210.0	4.3	0.110	0.02	.	3.0	7.5	63.0	8.60	0.80	2.6	90.0	10.0
CAL17	7311190915	2.0	11.5	8.5	7.2	7.5	210.0												
CAL17	7311190915	3.0	11.0	8.5	7.0	7.2	210.0												
CAL17	7311190915	5.0	10.5	8.4	7.2	6.8	210.0												
CAL17	7311190915	8.0	9.5	6.4	7.2	6.7	210.0												
*CAL17	7311190900	6.0		8.2	9.5	8.1	220.0	5.3	0.120	0.03	.	11.0	7.0	140.0	6.20	1.30	2.2	100.0	10.0
SWFP4J	7311191000	1.0	12.1	8.6	7.6	8.9	210.0	4.1	0.120	0.03	.	31.0	8.0	136.0	7.20	0.50	2.1	130.0	20.0
SWFP4J	7311191000	3.0	12.4	8.6	7.6	8.9	210.0												
SWFP4J	7311191000	5.0	12.8	8.5	7.5	8.9	210.0												
SWFP4J	7311191000	8.0	12.3	8.5	7.5	8.6	210.0												
SWFP4J	7311191000	10.0	12.7	8.5	7.5	8.9	210.0												
SWFP5J	7311191415	1.0	11.3	8.3	7.7	6.7	190.0	3.9	0.130	0.04	.	9.0	7.5	131.0	5.10	2.30	1.4	40.0	20.0
SWFP5J	7311191415	3.0	12.5	8.3	7.5	6.1	190.0												
SWFP5J	7311191415	5.0	12.8	8.3	7.7	5.9	190.0												
SWFP5J	7311191415	8.0	13.0	8.3	7.7	5.8	190.0												
SWFP5J	7311191415	10.0	13.0	8.3	7.6	5.8	190.0												
LM102	7311191500	1.0	11.8	8.6	8.0	8.5	190.0	3.5	0.020	0.02	.	0.	7.5	147.0	4.20	0.80	2.1	70.0	10.0
LM102	7311191500	3.0	12.3	8.5	8.0	8.5	190.0												
LM102	7311191500	5.0	12.7	8.4	8.0	8.5	190.0												
LM102	7311191500	8.0	12.6	8.4	8.0	8.5	190.0												
LM102	7311191500	10.0	12.6	8.4	8.0	8.5	190.0												
LM080	7311191525	1.0	11.7	8.3	7.7	6.7	200.0	4.3	0.130	0.05	.	28.0	9.0	134.0	6.10	1.90	2.7	230.0	10.0
LM080	7311191525	3.0	12.4	8.4	7.7	6.3	200.0												
LM080	7311191525	5.0	12.8	8.4	7.7	6.4	200.0												
LM080	7311191525	8.0	13.3	8.3	7.7	6.3	200.0												
LM080	7311191525	10.0	13.3	8.3	7.7	6.3	200.0												
LM070	7311191220	1.0	11.4	8.7	8.3	7.8	200.0	4.5	0.140	0.08	.	57.0	7.0	145.0	5.70	1.10	3.2	130.0	10.0
LM070	7311191220	3.0	12.1	8.6	8.2	7.4	200.0												
LM070	7311191220	5.0	12.3	8.5	8.2	7.4	200.0												
LM070	7311191220	8.0	12.4	8.4	8.2	7.4	200.0												
LM070	7311191220	10.0	12.2	8.4	8.2	7.2	200.0												
CAL11	7311191050	1.0	11.2	8.3	9.3	9.0	220.0	5.2	0.160	0.09	.	50.0	7.0	143.0	7.30	0.80	2.9	300.0	10.0
CAL11	7311191050	3.0	11.8	8.3	8.8	7.5	220.0												
CAL11	7311191050	5.0	12.2	8.3	8.8	6.8	220.0												
CAL11	7311191050	8.0	12.5	8.3	8.6	6.0	215.0												
CAL13	7311191115	1.0	11.5	8.3	8.7	8.3	210.0	5.4	0.130	0.04	.	29.0	8.5	137.0	9.40	1.50	3.0	250.0	20.0
CAL13	7311191115	3.0	12.2	8.3	8.5	7.9	210.0												
CAL13	7311191115	5.0	12.4	8.3	8.4	7.6	210.0												
CAL13	7311191115	8.0	12.9	8.3	8.3	7.4	210.0												
CAL13	7311191115	10.0	12.7	8.3	8.2	7.6	210.0												

Table 11.3 Page 4

Station	Y MD HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
CAL16	7311191025	1.0	11.5	8.7	7.8	9.5	210.0	4.5	0.120	0.05	.	38.0	7.0	133.0	6.60	1.10	2.4	130.0	20.0
CAL16	7311191025	3.0	12.2	8.6	7.7	9.2	210.0												
CAL16	7311191025	5.0	12.4	8.6	7.6	9.2	210.0												
CAL16	7311191025	7.0	12.6	8.5	7.7	8.9	210.0												
*CAL16	7311191200	5.0		8.2	9.0	9.3	220.0	5.5	0.130	0.07	.	.	6.5	178.0	7.40	1.90	3.1	140.0	10.0
LM047A	7311191155	1.0	11.5	8.4	6.7	7.2	220.0	5.0	0.130	0.04	.	.	7.5	124.0	8.00	0.70	1.9	60.0	20.0
LM047A	7311191155	3.0	12.1	8.4	6.7	7.2	220.0												
LM047A	7311191155	5.0	12.3	8.4	8.7	6.8	220.0												
LM047A	7311191155	7.0	12.3	8.3	8.8	6.8	220.0												
*LM047A	7311191130	5.0		8.1	7.8	10.0	220.0	6.8	0.130	0.11	.	120.0	7.0	144.0	11.30	1.70	2.7	260.0	10.0
1HC35	7311191100	1.0		7.6	18.3	72.0	430.0	8.8	0.930	5.70	0.160	220000.0	14.5	283.0	9.40	0.40	4.6	580.0	30.0
CAL06	7311191300	1.0	8.0	7.7	14.0	40.0	310.0	7.9	0.610	2.80	0.060	30000.0	11.5	216.0	8.10	0.30	3.5	480.0	20.0
CAL06	7311191300	3.0	8.4	7.7	13.9	40.0	305.0												
CAL06	7311191300	5.0	9.1	7.7	12.0	35.3	290.0												
CAL06	7311191300	8.0	10.7	9.0	10.5	26.6	255.0												
LM068	7311191345	1.0	10.7	8.0	9.2	7.9	200.0	4.5	0.190	0.36	.	3600.0	8.0	164.0	5.30	2.00	2.8	210.[illegible]	[illegible]
LM068	7311191345	3.0	11.4	8.1	9.0	8.9	200.0												
LM068	7311191345	5.0	12.2	8.2	8.3	8.5	188.0												
LM068	7311191345	8.0	12.5	8.2	8.1	7.9	188.0												
SWFP6J	7311191545	1.0	10.7	8.2	6.8	7.6	205.0	4.2	0.180	0.21	.	1000.0	6.5	109.0	4.10	1.10	1.7	90.0	10.0
SWFP6J	7311191545	3.0	11.6	8.2	8.8	7.5	210.0												
SWFP6J	7311191545	5.0	12.2	8.2	9.0	7.3	200.0												
SWFP6J	7311191545	8.0	12.5	8.2	9.0	7.3	200.0												
CAL15	7311191630	1.0	10.9	8.2	8.3	7.6	210.0	4.1	0.180	0.21	.	1700.0	7.5	146.0	4.60	2.70	2.1	130.0	20.0
CAL15	7311191630	3.0	11.5	8.2	8.5	6.8	212.0												
CAL15	7311191630	5.0	11.7	8.2	8.5	7.1	212.0												
CAL15	7311191630	8.0	12.5	8.2	8.3	8.3	210.0												
CAL15	7311191630	10.0	12.5	8.3	8.0	8.3	205.0												
*CAL15	7311191030	9.0		8.3	9.0	8.5	220.0	5.6	0.150	0.22	.	140.0	8.0	128.0	6.00	1.60	2.7	20.0	10.0
SWFP7J	7311191610	1.0	11.7	8.3	7.9	9.3	190.0	4.8	0.020	0.06	.	21.0	8.5	168.0	5.80	1.10	1.7	80.0	20.0
SWFP7J	7311191610	3.0	12.4	8.3	7.8	9.5	190.0												
SWFP7J	7311191610	5.0	12.7	8.3	7.8	9.5	190.0												
SWFP7J	7311191610	8.0	13.2	8.3	7.8	9.3	190.0												
SWFP7J	7311191610	10.0	13.3	8.3	7.8	9.5	190.0												
*CAL14	7311191000	9.0		8.3	9.0	8.1	215.0	5.1	0.110	0.02	.	5.0	8.0	158.0	5.70	1.50	2.9	740.0	20.0

Table 11.3 Page 5

Station	Y M D HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
CAL17	7312071420	1.0	12.0	.	6.0	10.0	180.0	6.4	0.050	0.13	.	17.0	9.0	160.0	7.30	3.90	2.4	60.0	10.0
CAL17	7312071420	8.0	14.6	.	6.0	9.5	180.0												
S CAL17	7312070900	6.0		8.2	5.0	9.5	200.0	21.5	.	0.06	0.100	20.0	6.5	173.0	31.80	5.80	6.7	670.0	10.0
SWFP4J	7312071545	1.0	11.5	.	6.0	10.0	170.0	6.3	0.030	0.90	.	7.0	7.5	143.0	8.10	3.10	3.5	130.0	60.0
SWFP4J	7312071545	8.0	14.5	.	6.5	9.4	170.0												
SWFP5J	7312071030	1.0	12.0	.	6.5	9.5	180.0	6.6	0.030	0.02	.	40.0	9.0	191.0	7.20	2.60	2.5	60.0	10.0
SWFP5J	7312071030	8.0	14.7	.	5.5	5.9	180.0												
LM102	7312071215	1.0	11.6	.	6.5	10.0	170.0	6.3	0.030	0.03	.	6.0	7.5	172.0	4.30	2.30	2.8	70.0	10.0
LM102	7312071215	8.0	13.7	.	6.2	9.0	170.0												
LM080	7312071125	1.0	12.1	.	6.5	10.0	195.0	6.2	0.020	0.02	.	15.0	8.0	179.0	5.70	2.20	2.5	60.0	10.0
LM080	7312071125	6.0	13.7	.	6.5	9.2	195.0												
LM070	7312071010	1.0	12.2	8.5	7.0	12.0	200.0	7.3	0.040	0.10	.	450.0	9.5	176.0	5.70	3.00	3.4	130.0	10.0
LM070	7312071010	8.0	15.0	8.3	6.5	13.3	190.0												
CAL11	7312071455	1.0	10.2	.	10.0	16.0	200.0	6.6	0.140	0.36	.	700.0	9.0	130.0	6.10	3.20	3.2	120.0	10.0
CAL11	7312071455	8.0	13.9	.	7.5	11.7	185.0												
CAL13	7312071505	1.0	11.8	.	8.0	13.0	190.0	7.1	0.120	0.31	.	720.0	8.5	136.0	7.50	7.40	3.2	170.0	10.0
CAL13	7312071505	8.0	14.0	.	7.0	16.0	180.0												
CAL16	7312071620	1.0	11.9	.	6.5	12.0	180.0	6.7	0.040	0.14	.	720.0	9.0	137.0	8.90	5.20	3.1	110.0	10.0
CAL16	7312071620	8.0	14.0	.	6.5	10.8	180.0												
*CAL16	7312071200	5.0		8.1	10.0	11.0	205.0	8.5	0.040	0.07	.	500.0	6.5	123.0	14.40	4.00	5.2	200.0	10.0
LM047A	7312071605	1.0	11.6	.	6.5	12.0	180.0	9.9	0.080	0.16	.	2000.0	11.0	118.0	12.10	4.60	3.6	200.0	10.0
LM047A	7312071605	8.0	14.1	.	6.5	9.0	180.0												
*LM047A	7312071130	5.0		8.0	7.0	12.0	190.0	13.5	0.040	0.09	.	10.0	9.0	144.0	21.00	2.20	5.8	300.0	10.0

Table 11.3 Page 6

Station	Y MD HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
1HC3S	7312071100	1.0		7.4	13.0	71.0	450.0	12.0	1.340	6.30	0.180	190000.0	18.5	374.0	15.60	1.00	7.6	7400.0	80.0
CAL06	7312070940	1.0	9.3	7.6	12.5	28.0	270.0	11.0	0.300	1.50	0.070	4800.0	9.5	226.0	9.60	2.70	5.3	980.0	10.0
CAL06	7312070940	2.0	9.2	7.6	13.5	31.0	275.0												
CAL06	7312070940	3.0	9.2	7.6	13.0	32.0	275.0												
CAL06	7312070940	4.0	9.0	7.6	12.5	32.0	270.0												
CAL06	7312070940	5.0	9.2	7.6	12.0	30.0	265.0												
CAL06	7312070940	6.0	9.2	7.6	11.0	28.0	255.0												
CAL06	7312070940	7.0	9.6	7.6	10.5	24.0	250.0												
CAL06	7312070940	8.0	9.9	7.9	9.5	22.0	230.0												
LM068	7312071045	1.0	10.5	7.5	7.5	15.0	220.0	7.5	0.170	0.47	.	3200.0	9.5	223.0	8.20	2.70	3.5	250.0	10.0
LM068	7312071045	8.0	14.3	8.0	6.5	11.1	200.0												
SWFP6J	7312071105	1.0	10.2	.	6.5	12.0	205.0	8.4	0.040	0.22	.	500.0	11.0	170.0	10.30	3.50	4.5	90.0	10.0
SWFP6J	7312071105	8.0	13.7	.	6.5	13.8	205.0												
SWFP7J	7312071250	1.0	11.5	.	6.5	11.0	195.0	7.0	0.040	0.13	.	500.0	6.0	181.0	5.60	2.80	1.8	120.0	10.0
SWFP7J	7312071250	8.0	14.0	.	6.5	7.9	185.0												
CAL15	7312071405	1.0	11.3	.	6.5	12.0	195.0	6.7	0.100	0.17	.	400.0	9.5	178.0	7.50	3.20	5.0	140.0	10.0
CAL15	7312071405	8.0	13.8	.	7.0	9.7	200.0												
CAL14	7312071330	1.0	11.5	.	6.5	12.0	200.0	6.8	0.050	0.11	.	16.0	7.0	182.0	6.10	2.90	2.8	60.0	10.0
CAL14	7312071330	8.0	14.1	.	6.5	10.6	200.0												
*CAL14	7312071000	9.0		8.2	6.0	11.0	200.0	9.8	0.040	0.05	.	0.	9.0	170.0	13.40	4.00	5.0	200.0	10.0

Table 11.3 Page 7

Station	Y MD HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
* CAL17	7311050900	6.0		.	.	6.0	.	7.9	0.040	0.07	.	.	.	.	11.30	8.70	2.9	170.0	10.0
* CAL16	7311051200	5.0		.	.	6.5	.	5.8	0.050	0.05	.	.	.	.	13.20	7.30	4.6	120.0	20.0
* CAL15	7311051030	9.0		.	.	8.5	.	5.7	0.080	0.11	.	.	.	.	8.20	7.80	1.9	180.0	20.0
* LM047A	7311051130	5.0		.	.	7.5	.	5.9	0.050	0.06	.	.	.	.	6.40	8.80	2.1	140.0	40.0
* CAL14	7311051000	9.0		.	.	5.8	.	5.4	0.040	0.04	.	.	.	.	2.50	3.60	1.3	80.0	10.0
*CAL17	7311120900	6.0		8.0	6.2	8.2	.	3.6	0.130	0.03	.	.	7.0	.	3.00	1.80	1.3	50.0	10.0
*CAL16	7311121200	5.0		8.0	.	7.3	.	5.2	0.130	0.02	.	20.0	.	.	5.10	0.70	1.4	70.0	10.0
IHC3S	7311121100	1.0		7.7	18.3	55.0	.	14.0	0.870	5.30	.	20000.0	.	.	19.80	4.60	8.6	1300.0	10.0
* CAL15	7311121030	9.0		8.0	8.3	9.1	.	3.9	0.140	0.08	.	1.0	6.5	.	3.10	3.80	1.5	290.0	200.0
* CAL17	7311130900	6.0		8.1	9.5	7.5	228.0	2.9	0.130	0.02	.	8.0	8.0	.	4.10	7.10	1.7	70.0	10.0
* CAL16	7311131200	5.0		7.9	13.3	7.3	185.0	3.6	0.120	0.02	.	12.0	8.0	.	3.20	3.30	2.0	100.0	20.0
* LM047A	7311131130	5.0		7.9	10.0	8.9	205.0	4.8	0.140	0.09	.	.	9.5	.	3.50	4.10	2.2	80.0	20.0
IHC3S	7311131100	1.0		7.5	13.0	65.0	425.0	15.0	0.760	4.60	.	44000.0	15.0	.	20.70	2.80	10.8	1300.0	20.0
* CAL15	7311131030	9.0		8.0	.	7.1	210.0	3.7	0.140	0.04	.	2.0	6.5	.	1.80	2.70	1.9	80.0	20.0
* CAL14	7311131000	9.0		8.0	9.5	7.9	218.0	2.7	0.120	0.04	.	.	9.0	.	1.80	3.70	2.0	480.0	420.0
* CAL17	7311150900	6.0		8.2	.	7.0	210.0	5.2	0.120	0.03	.	140.0	11.0	167.0	9.30	3.80	0.8	120.0	10.0
* CAL16	7311151200	5.0		8.1	.	7.1	210.0	5.4	0.110	0.04	.	50.0	8.0	145.0	9.50	11.10	1.0	170.0	10.0
* LM047A	7311151130	5.0		8.2	.	7.4	200.0	9.0	0.120	0.02	.	700.0	9.0	169.0	12.60	5.40	0.6	220.0	10.0
IHC3S	7311151100	1.0		7.7	.	54.0	415.0	10.0	1.000	5.20	0.180	250000.0	12.0	297.0	14.30	4.00	3.2	860.0	50.0
* CAL15	7311151030	9.0		8.4	.	7.7	210.0	10.0	0.140	0.10	.	220.0	9.0	176.0	14.00	11.10	1.6	270.0	10.0
* CAL14	7311151000	9.0		8.1	.	5.0	210.0	3.7	0.120	0.09	.	100.0	8.0	176.0	6.80	11.80	0.2	70.0	10.0
S CAL17	7311160900	6.0		8.2	.	6.8	210.0	18.0	0.130	0.02	.	420.0	9.0	168.0	29.00	7.60	1.6	360.0	10.0
* CAL16	7311161200	5.0		8.1	.	7.8	210.0	8.0	0.130	0.07	.	15.0	9.5	179.0	13.20	5.40	1.5	220.0	10.0
* LM047A	7311161130	5.0		8.1	.	8.2	210.0	12.0	0.120	0.05	.	80.0	9.5	196.0	17.10	1.80	3.5	300.0	10.0
IHC3S	7311161100	1.0		7.6	.	65.0	450.0	9.0	0.130	5.40	0.250	250000.0	15.5	312.0	12.90	0.60	6.8	780.0	60.0
* CAL15	7311161030	9.0		8.2	.	7.9	220.0	15.0	0.170	0.25	.	690.0	7.0	186.0	25.10	5.60	3.8	480.0	10.0
* CAL14	7311161000	9.0		8.3	.	7.0	200.0	14.0	0.120	0.04	.	22.0	9.0	198.0	28.20	7.00	1.6	430.0	10.0
* CAL17	7311170900	6.0		8.4	9.0	6.1	210.0	7.5	0.110	0.02	.	910.0	9.0	156.0	11.50	1.20	2.6	230.0	10.0
* CAL16	7311171200	5.0		8.3	8.3	6.2	220.0	6.3	0.120	0.02	.	133.0	8.0	164.0	9.40	0.90	3.2	270.0	10.0
* LM047A	7311171130	5.0		8.3	6.0	10.0	230.0	9.0	0.130	0.04	.	200.0	12.0	163.0	12.60	2.20	4.6	190.0	20.0
IHC3S	7311171100	1.0		7.5	.	84.0	480.0	10.0	1.070	6.80	0.240	360000.0	17.0	376.0	13.50	0.60	7.0	980.0	20.0
* CAL15	7311171030	9.0		8.3	9.0	8.2	220.0	5.5	0.140	0.04	.	140.0	10.0	158.0	7.40	2.20	3.8	220.0	20.0

Table 11.3 Page 8

Station	Y M D HR	D-M	DO	PH	T	CL	COND	TURB	F	NH3-N	P	COLI	TOC	T-SOL	SSOL	CHLPH	V-SOL	T-FE	D-FE
* CAL17	7311180900	6.0		8.2	9.0	6.0	225.0	4.5	0.120	0.02	.	5.0	9.0	184.0	4.50	0.70	1.8	80.0	20.0
* CAL16	7311181200	5.0		8.1	9.0	9.0	220.0	4.8	0.110	0.04	.	80.0	7.0	172.0	5.20	0.70	2.8	90.0	10.0
* LM047A	7311181130	5.0		8.2	9.1	11.0	230.0	5.7	0.150	0.23	.	530.0	7.5	174.0	6.50	2.20	4.2	130.0	20.0
IHC3S	7311181100	1.0		7.5	19.5	46.0	380.0	10.0	1.000	3.70	0.180	50000.0	10.0	261.0	10.60	1.00	0.	0.	150.0
* CAL15	7311181030	9.0		8.2	9.0	6.4	220.0	4.9	0.140	0.04	.	22.0	7.5	128.0	6.20	1.30	2.1	60.0	20.0
* CAL14	7311181000	9.0		8.2	11.1	5.6	220.0	4.6	0.110	0.02	.	5.0	8.0	170.0	5.20	1.30	1.9	80.0	10.0
S CAL17	7311200900	6.0		8.1	7.0	9.6	210.0	7.8	0.030	0.02	.	18.0	9.5	163.0	14.70	5.20	0.9	230.0	10.0
* CAL16	7311201200	5.0		8.1	8.6	8.5	210.0	4.6	0.030	0.05	.	4.0	9.5	174.0	8.10	3.80	1.3	150.0	10.0
* LM047A	7311201130	5.0		8.0	.	7.9	210.0	6.3	0.140	0.03	.	0.	7.0	192.0	8.50	1.70	1.1	180.0	20.0
IHC3S	7311201100	1.0		7.4	.	45.0	370.0	15.0	0.780	3.40	0.140	25000.0	11.0	215.0	18.50	5.60	6.4	1470.0	50.0
* CAL15	7311201030	9.0		8.2	9.0	7.8	210.0	4.0	0.150	0.10	.	.	9.0	167.0	4.40	3.50	0.4	120.0	20.0
* CAL14	7311201000	9.0		8.2	9.0	10.0	210.0	5.2	0.030	0.06	.	50.0	6.5	177.0	5.00	3.50	0.4	110.0	10.0
S CAL17	7311290900	6.0		8.1	6.0	10.0	220.0	16.0	0.080	0.04	.	70.0	9.0	204.0	31.40	4.20	6.0	450.0	20.0
* CAL16	7311291200	5.0		8.1	8.4	10.0	230.0	18.0	0.110	0.06	.	20.0	8.0	163.0	13.00	3.30	2.5	220.0	20.0
* LM047A	7311291130	5.0		8.0	.	11.0	220.0	0.	0.100	0.13	.	100.0	7.0	160.0	21.70	3.20	7.6	400.0	20.0
IHC3S	7311291100	1.0		7.5	16.0	70.0	430.0	0.	1.070	4.80	0.230	11000.0	18.0	246.0	19.80	1.60	9.4	880.0	20.0
* CAL15	7311291030	9.0		8.0	9.4	12.0	230.0	26.0	0.140	0.12	.	80.0	8.0	180.0	21.20	26.20	4.1	440.0	20.0
* CAL14	7311291000	9.0		8.1	9.0	12.0	220.0	18.0	0.110	0.06	.	900.0	6.5	192.0	21.80	1.80	3.1	330.0	20.0
S CAL17	7311300900	6.0		7.8	5.8	11.0	220.0	18.0	0.120	0.04	.	6.0	6.5	178.0	12.40	20.00	4.3	340.0	20.0
* CAL16	7311301200	5.0		7.6	7.6	11.0	220.0	6.2	0.080	0.04	.	0.	7.5	122.0	8.60	2.20	4.2	210.0	20.0
* LM047A	7311301130	5.0		7.6	.	11.0	230.0	7.2	0.030	0.02	.	0.	7.0	167.0	10.00	0.70	3.3	540.0	20.0
* CAL15	7311301030	9.0		7.1	9.0	10.0	230.0	7.9	0.040	0.17	.	100.0	8.0	162.0	11.70	4.80	4.0	170.0	20.0
* CAL14	7311301000	9.0		7.8	9.0	11.0	220.0	7.9	0.110	0.04	.	6.0	6.0	157.0	9.20	1.80	4.0	140.0	20.0
IHC3S	7311301100	1.0		7.0	18.3	60.0	410.0	12.0	1.020	4.30	0.250	160000.0	13.0	344.0	11.70	2.50	4.7	770.0	50.0
* CAL17	7312080900	6.0		8.2	.	11.0	195.0	5.0	0.030	0.06	.	3.0	9.5	147.0	4.90	2.80	2.7	100.0	30.0
* CAL16	7312081200	5.0		7.6	10.0	11.0	205.0	5.3	0.030	0.08	.	870.0	9.5	145.0	4.70	2.30	2.2	70.0	10.0
IHC3S	7312081100	1.0		7.2	13.0	76.0	435.0	12.0	0.680	6.70	0.150	46000.0	15.0	287.0	14.60	1.80	6.0	660.0	80.0

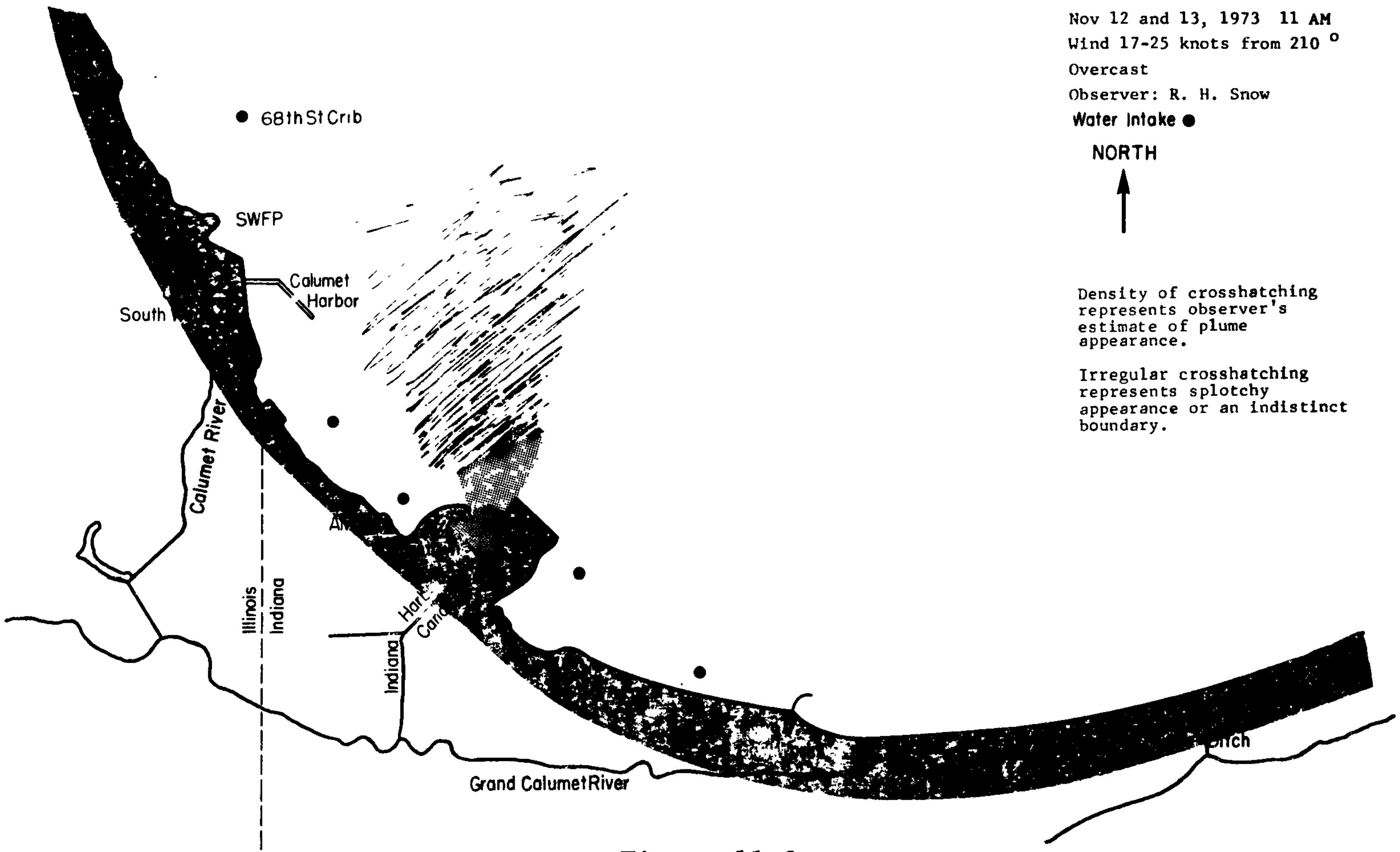

Figure 11.3

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 12 and 13, 1973

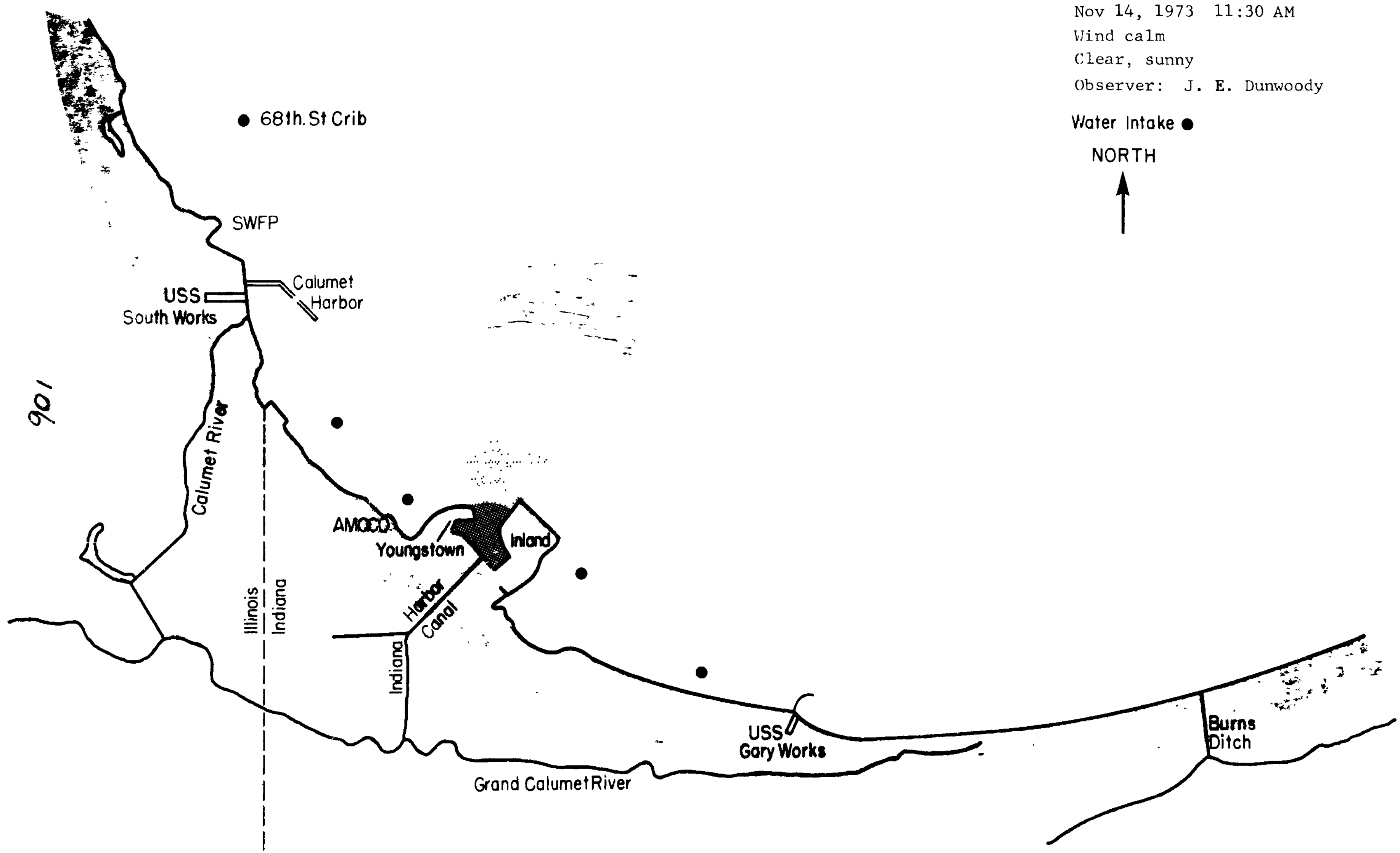

Figure 11.4

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 14, 1973

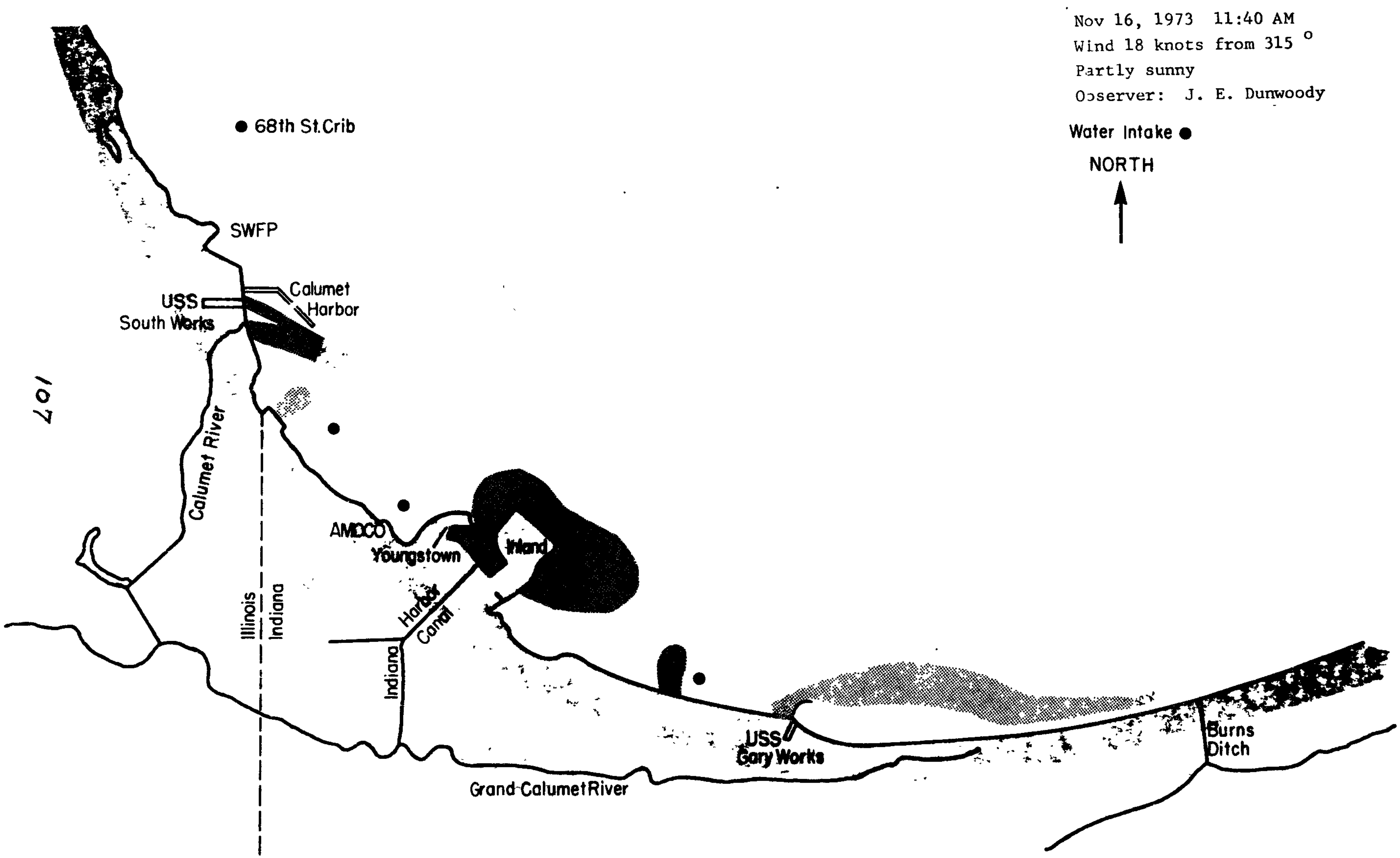

Figure 11.5

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 16, 1973

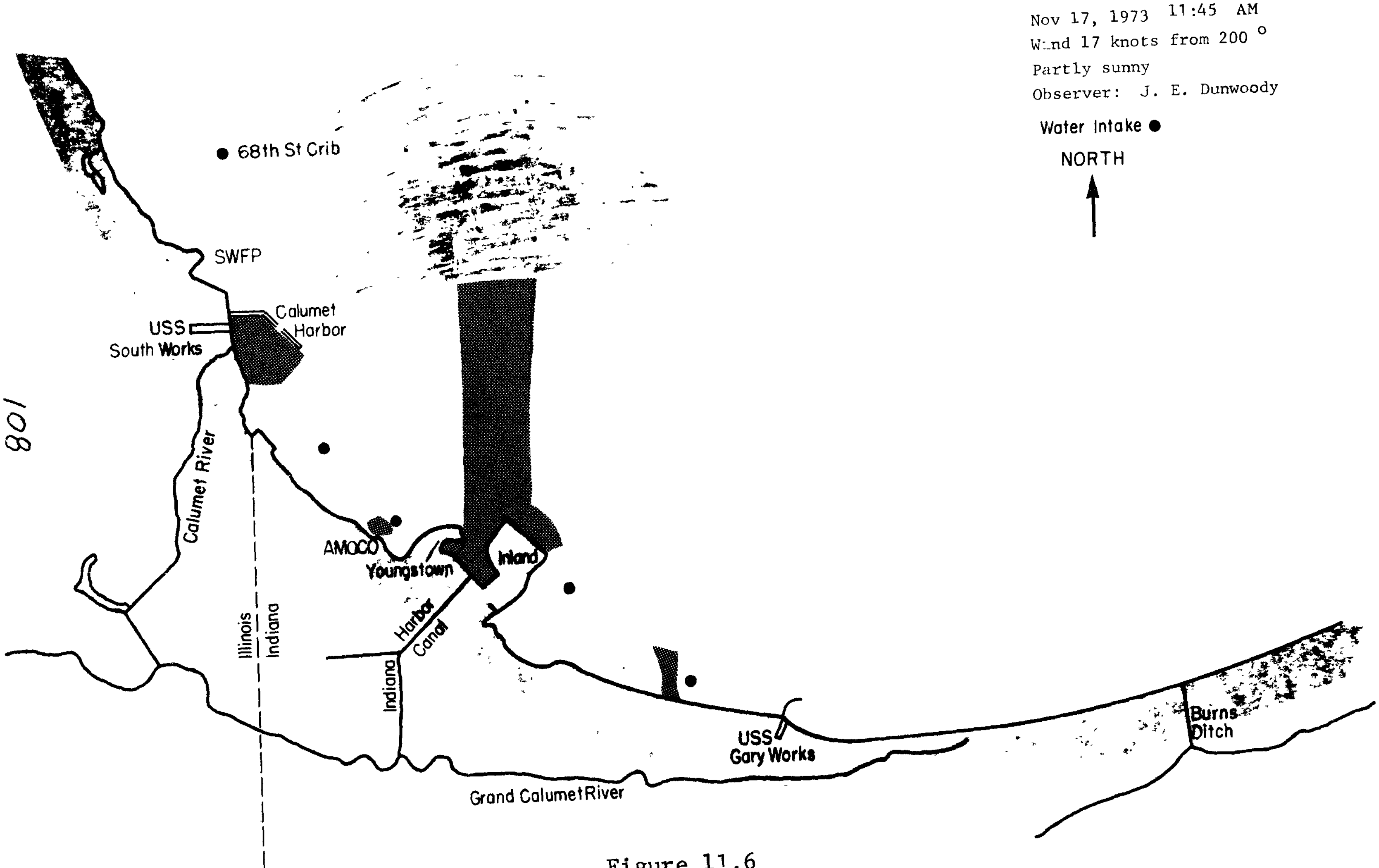

Figure 11.6

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 17, 1973

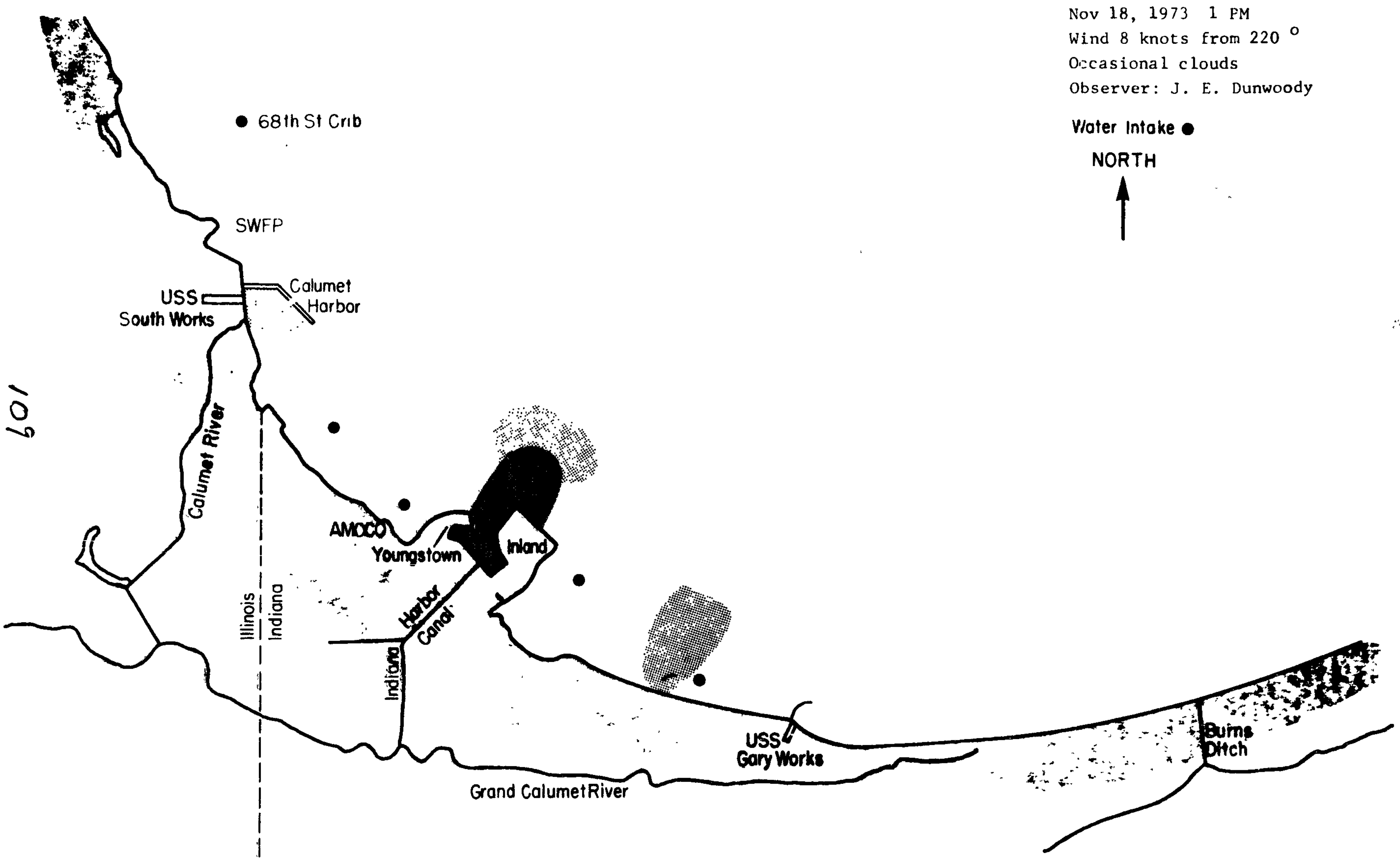

Figure 11.7

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 18, 1973

Nov 19, 1973 11:00 AM
Wind 4 knots from 20 °
Overcast sky
Observer: R. H. Snow

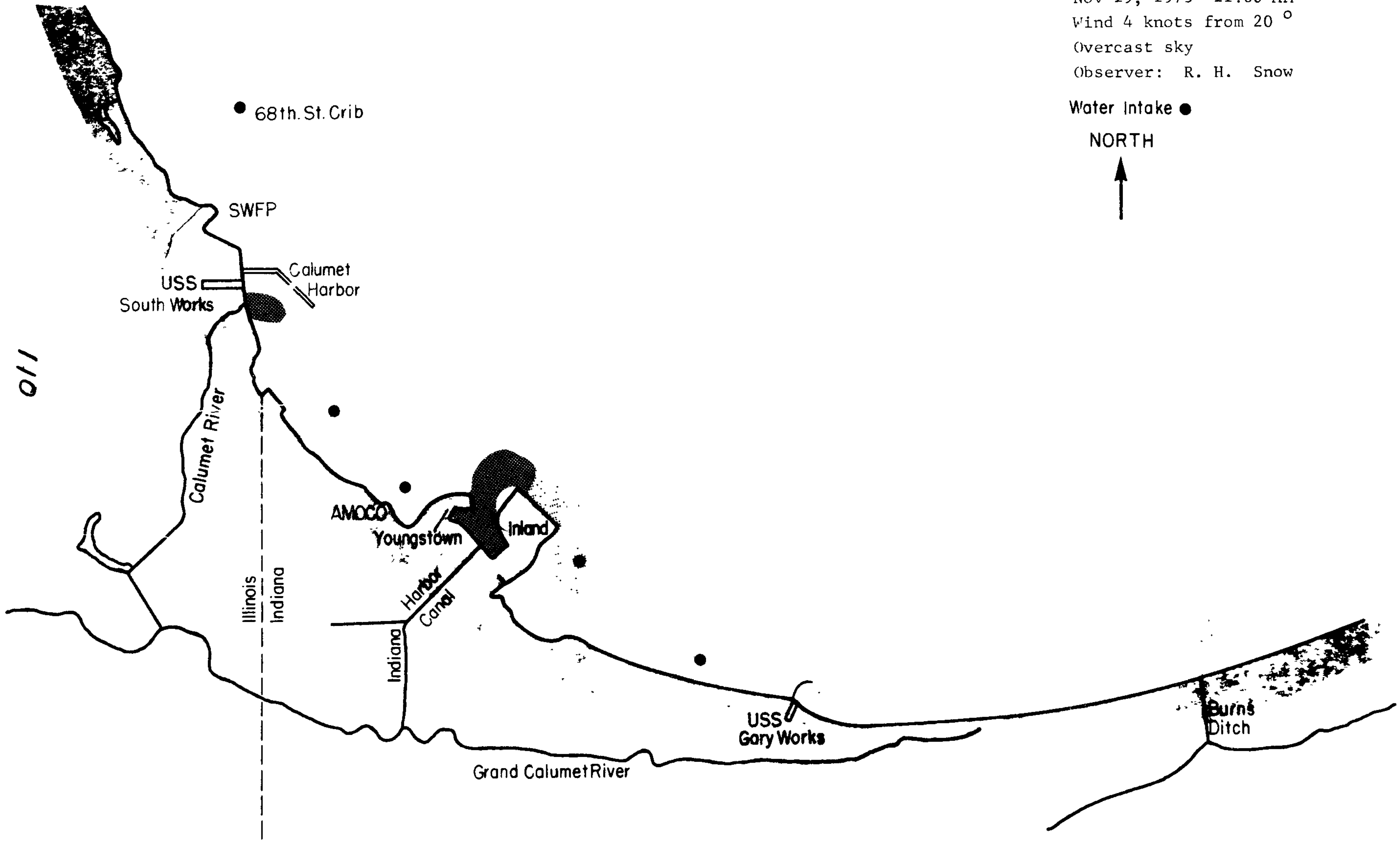

Figure 11.8

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 19, 1973

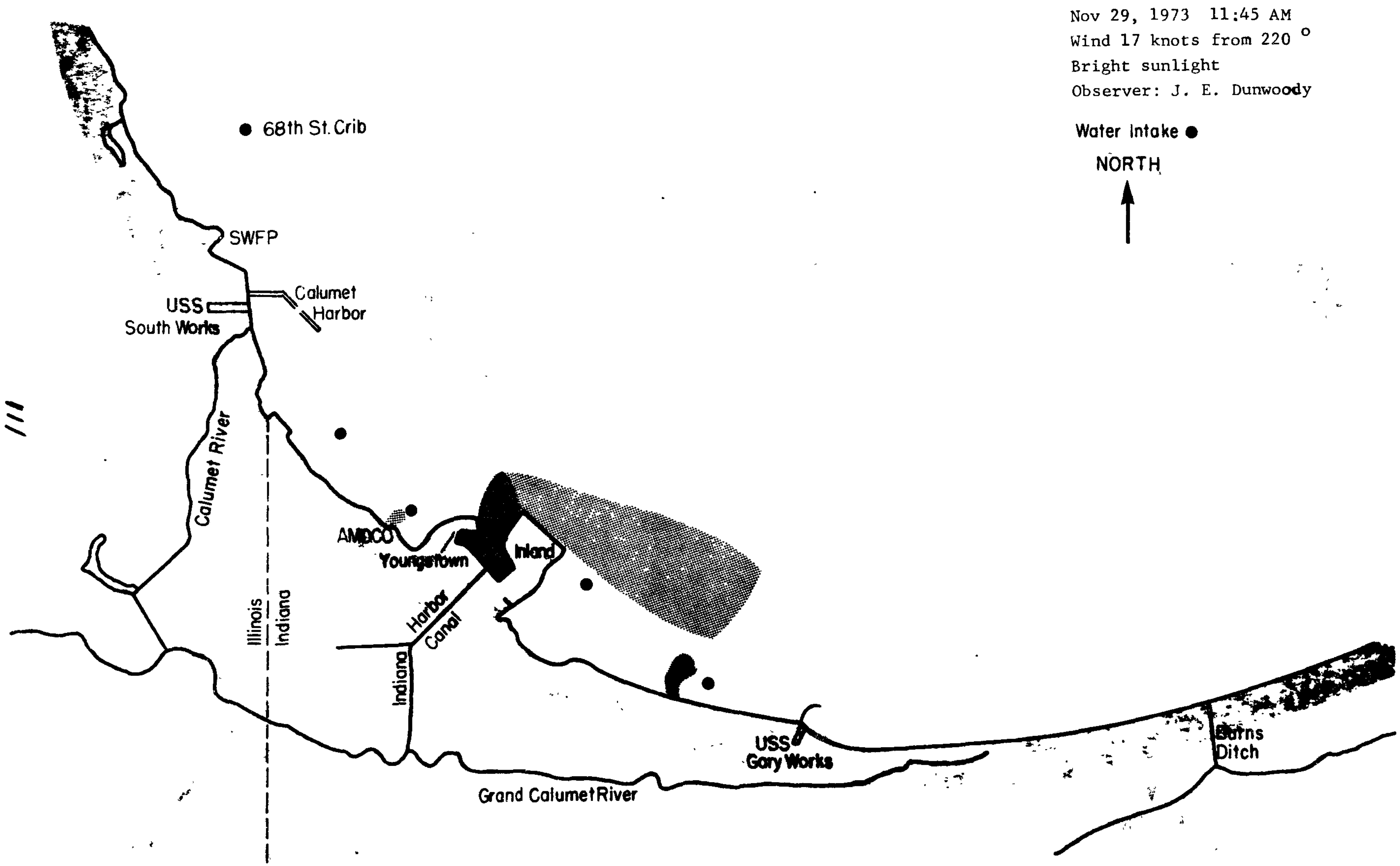

Figure 11.9

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 29, 1973

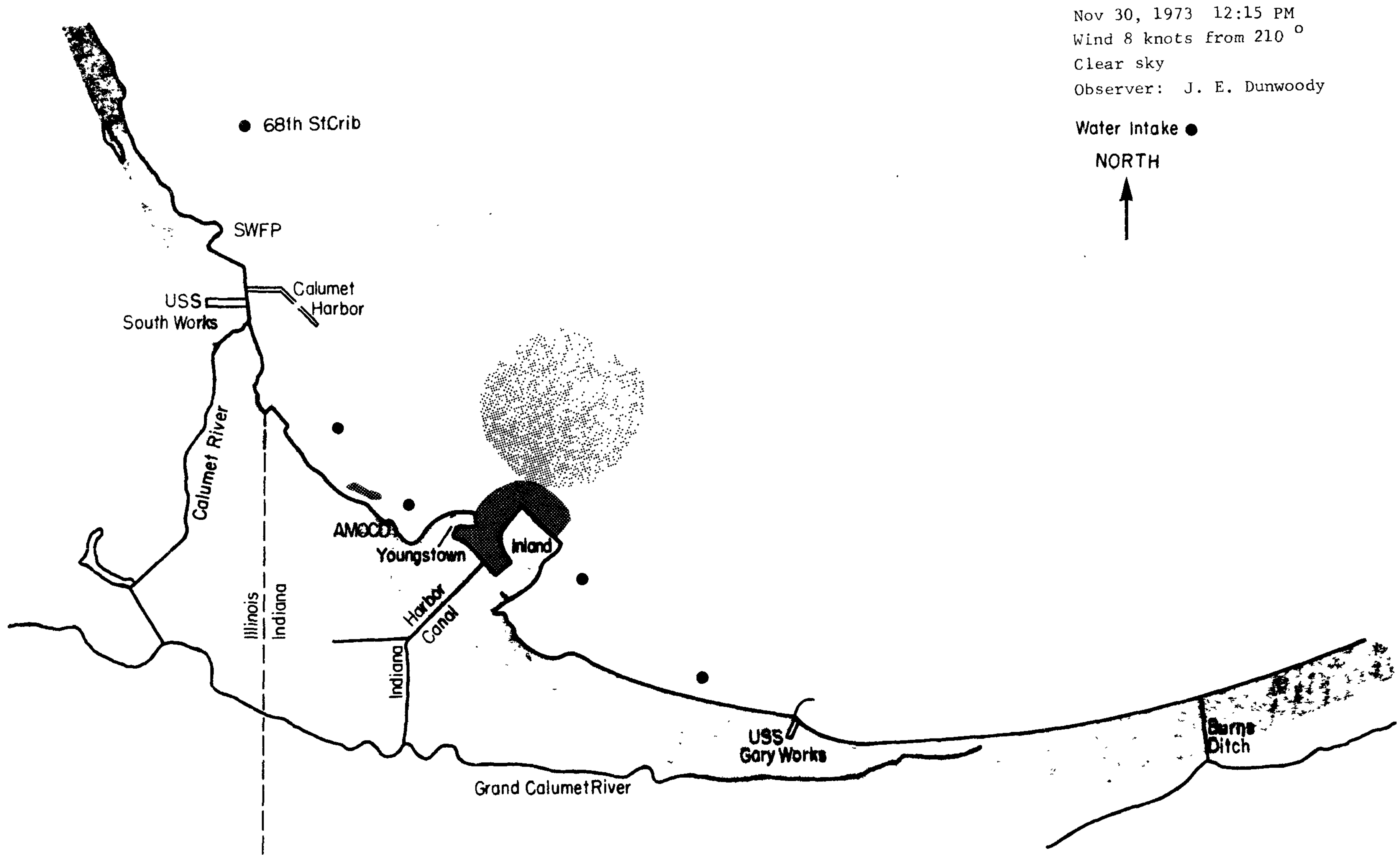

Figure 11.10

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
November 30, 1973

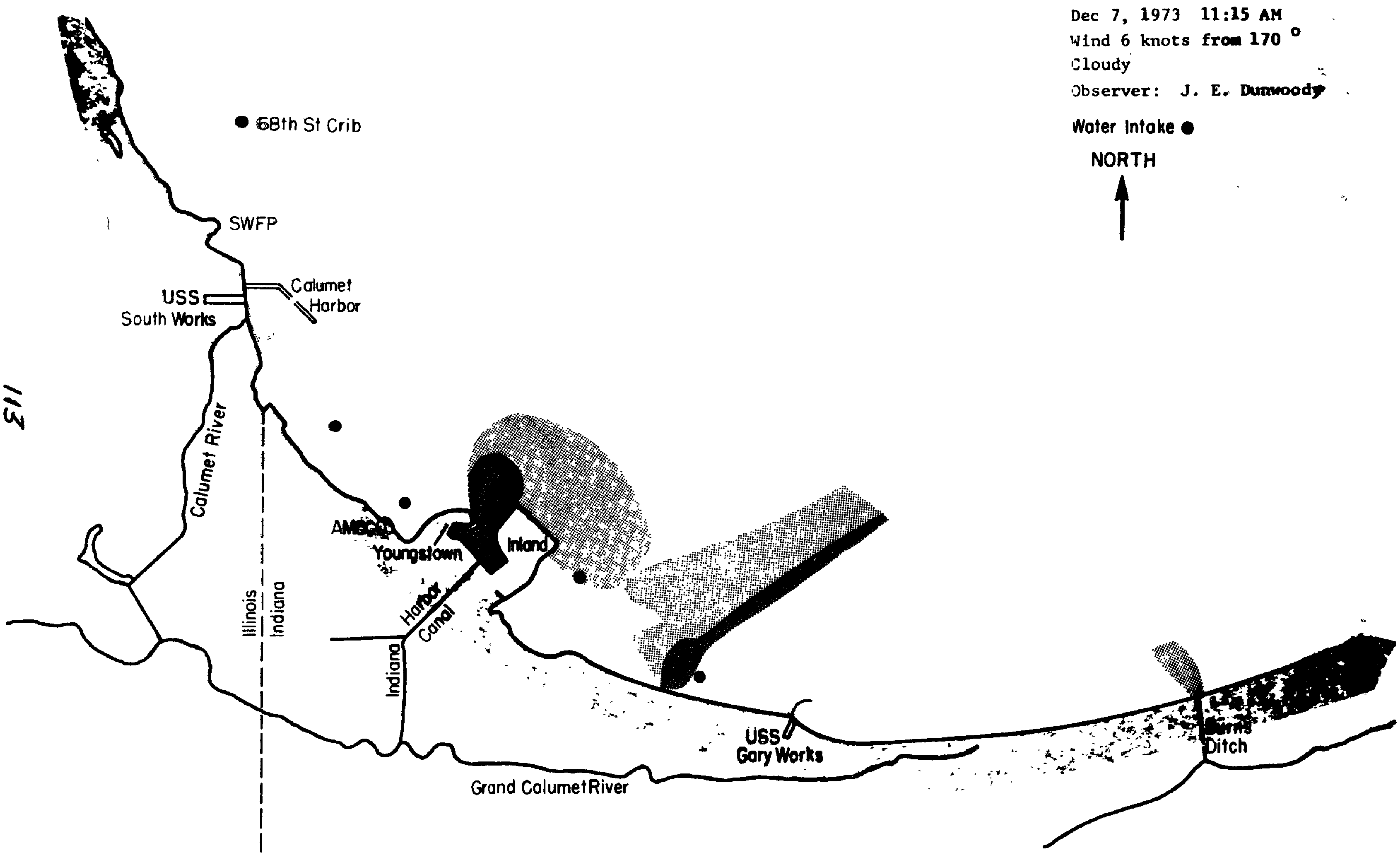

Figure 11.11

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
December 7, 1973

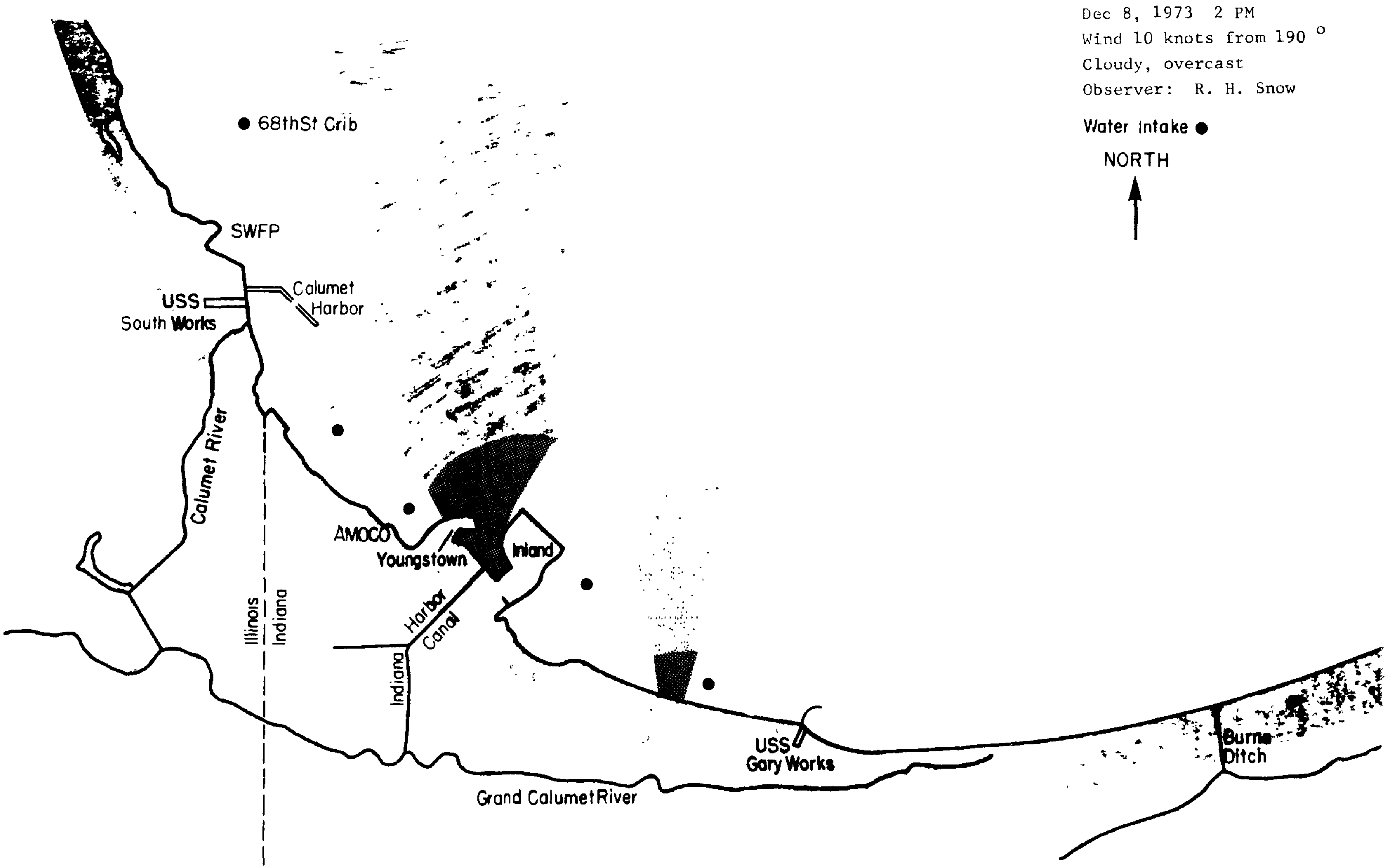

Figure 11.12

SKETCH SHOWING VISUAL APPEARANCE
OF EFFLUENTS BY AERIAL OBSERVATIONS
December 8, 1973

Flying north along the Calumet shore, outfalls of American Oil Co. were observed, as well as any visible pollution along the beaches. In the Calumet harbor, the colored plume from the Calumet River and the U.S. Steel South Works was noted. There was always a visible plume from this source, although its extent varied, and it was usually smaller and less dense in color than the plume from the IHC. The gap in the breakwater was checked for evidence of flow, as a clue to the direction of Lake currents. The northern limit of the flight path was the Calumet breakwater. At our flight altitude of 2500 ft, we would have entered the landing pattern for Meigs Field, Chicago, if we had gone further.

We then flew out over the Lake and headed in the direction of the IHC mouth, adjusting our course to best see the plume from the IHC. We then usually circled the Inland Steel landfill, to locate the IHC plume. We then continued south toward Gary, and noted the location of a large plume from the U.S. Steel Gary Works, that issues from an outfall near the American Bridge Works. We sometimes flew along the shore as far east as Burns Ditch, before returning to the airfield.

In general, we found that the IHC plume, which was a brownish or reddish purple color, could best be seen with the sun behind the observer. Oil slicks on the Lake could best be seen when looking toward the sun. The Lake itself varied in shades from blue to greyish green, depending on the amount of turbidity, and the illumination. It tends to appear more grey on overcast days. The prevailing illumination is indicated on the figures.

We found that the aerial observation provided an excellent way of locating the plume from the IHC as well as other plumes. In sketching the plume on the map, we related the dimensions of the plume and its position to prominent landmarks, such as the Inland Steel landfill revetment, and the Calumet Harbor breakwater. Subsequent comparison of the plume observations with the current meter records showed that in every case the plume was going in the direction of the Lake current.

Several patterns of plume behavior were observed. On November 12 and 13, November 17 and December 8, the Lake current was upshore, while the wind was to the northeast. The plume moved out into the Lake, met the upshore current, and was carried northward as it mixed with Lake water. On November 16 and 19 the wind was to the south; also on November 29 and December 7 the wind had just changed from this direction. On these four days the current was to the southeast, and the plume flowed downshore around the Inland landfill, in a similar manner to that shown in the Skylab photo, Figure 13.2. On November 14, 18 and 30 the current was just changing direction. On November 14, this situation resulted in flow of the plume directly out into the Lake; on the other two days these conditions produced puddles of colored water directly out in the Lake. The mechanisms of movement and dispersion of the plume are discussed in Chapter 12.

11.5 Flow Measurements

Flow measurements were made in the IHC at two stations. These measurements were made at Columbus Drive bridge on all sampling days except November 5 and 12. They were made at the mouth of IHC (CAL06) on boat sampling days, November 14 and 19, and December 7, 1973.

At Columbus Drive, we gauged the IHC by measuring the depth at each fencepost along the downstream side of the bridge. We then computed the cross-sectional area to be 1160 sq ft. The width of the bridge was 63 ft. To measure the flow we timed the passage of a piece of debris under the bridge. We selected debris that was just below the surface, rather than a floating object, because wind influenced the motion of a floating object. Since the depth was only about 10 ft, and the flow is turbulent, we felt that the velocity near the surface was representative of the total. Two measurements were made on each day. The results are given in Table 4.4 in Chapter 4.

At the mouth of the IHC, the flow pattern is more complex, because Lake water intrudes under the IHC water. For this measurement, Argonne personnel lowered a Bendix Q15 current meter over the side of the boat and measured the speed and direction of the current at each meter of depth, and repeated the measurements as the meter was pulled up. We then calculated the total outflow by numerically integrating over the depth where the flow was outward, multiplying by the cosine of the angle of the current vector with the channel axis. We followed the same procedure to calculate the Lake water inflow in the bottom portion of the channel. The results of these flow measurements are given in Chapter 12, Tables 12.1 and 12.2.

11.6 Lake Current Measurements

Currents were measured continuously at two stations in Lake Michigan during the period from November 8 to December 8, 1973. The measurements were made for us by Argonne National Laboratory using three current meters. These meters were modified by Argonne. The original meters, Braincon Model 381, were designed for deep-water moorings. They had a rotor that is omni-directional and would not respond to rapid reversals due to wave action. To make these meters suitable for use near the surface, where wave action must be averaged out, the rotor assembly was replaced with a wave-oriented, ducted impeller assembly. This impeller operates equally well in both directions and therefore is able to null out the oscillatory wave produced motions that are superimposed on the steady Lake currents.

The meters were calibrated in a tow tank facility at Northwestern University. Steady-steady motion was used to obtain the calibration curve shown in Figure 11.13 and to establish the threshold of the impeller (∿2 cm/sec). At speeds above 15 cm/sec, oscillatory motions produced by a wave generated produced no noticeable deviations from the steady-state calibration curve, but at speeds below this value, small but significant deviations

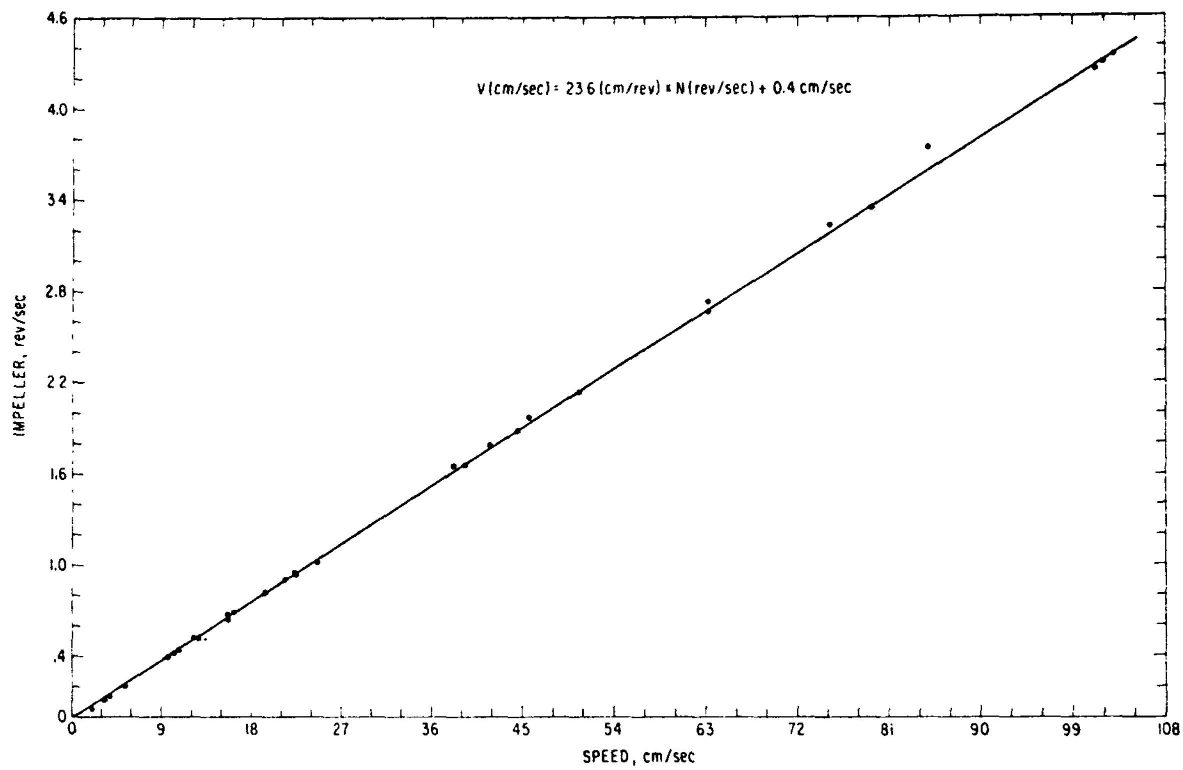

Figure 11.13

STEADY-STATE CALIBRATION CURVE FOR MODIFIED METER did occur due to the dead band associated with the threshold of the impeller. In addition to the speed calibration, the directional response of the meter to flows approaching from some angle other than parallel to the duct was observed and found to approximate a cosine-law response. The sensitivity of the vane to low-speed flow and the vane's distance constant were also observed. The vane responded to speeds as low as 3 cm/sec, and the vane's distance constant was 2.25 m. The accuracy should be about ±2 cm/sec. The directional accuracy should be ±10 or 20°. The spread in direction is an indication of the variability of direction during each 20-min interval of recording.

The current meter records agreed well with measurements made with the Q15 meter from the boat at 68th St. crib on November 14 and November 19, 1973, given in Table 10.1.

One current meter was installed adjacent to the 68th St. crib, at a depth of 17 ft. The other two meters were installed in the Lake off the Inland Steel landfill, at a position indicated on Figure 11.2. The coordinates of the meter locations are given in Table 11.1. The meters off Inland were at depths of 9 ft and 19 ft. The meter at 9 ft failed to record speed, but it did record direction. The direction was almost the same as that indicated by the meter at 19 ft.

The photographic records obtained from the meters were retrieved and processed by computer at Argonne. The results are presented in Figures 11.14 and 11.15. They present a continuous record of the Lake currents in these locations. Generally, the direction of flow is similar at the two locations. The flow generally follows the shore. The flow is related to the wind, but it is not directly related. In general, a wind to any direction near the north results in a current toward the north along the shore, but there may be a delay in change of current when the wind changes direction. The flow was north along the shore about half of the time. The flow was out toward the center of the Lake only for brief periods, that were associated with current

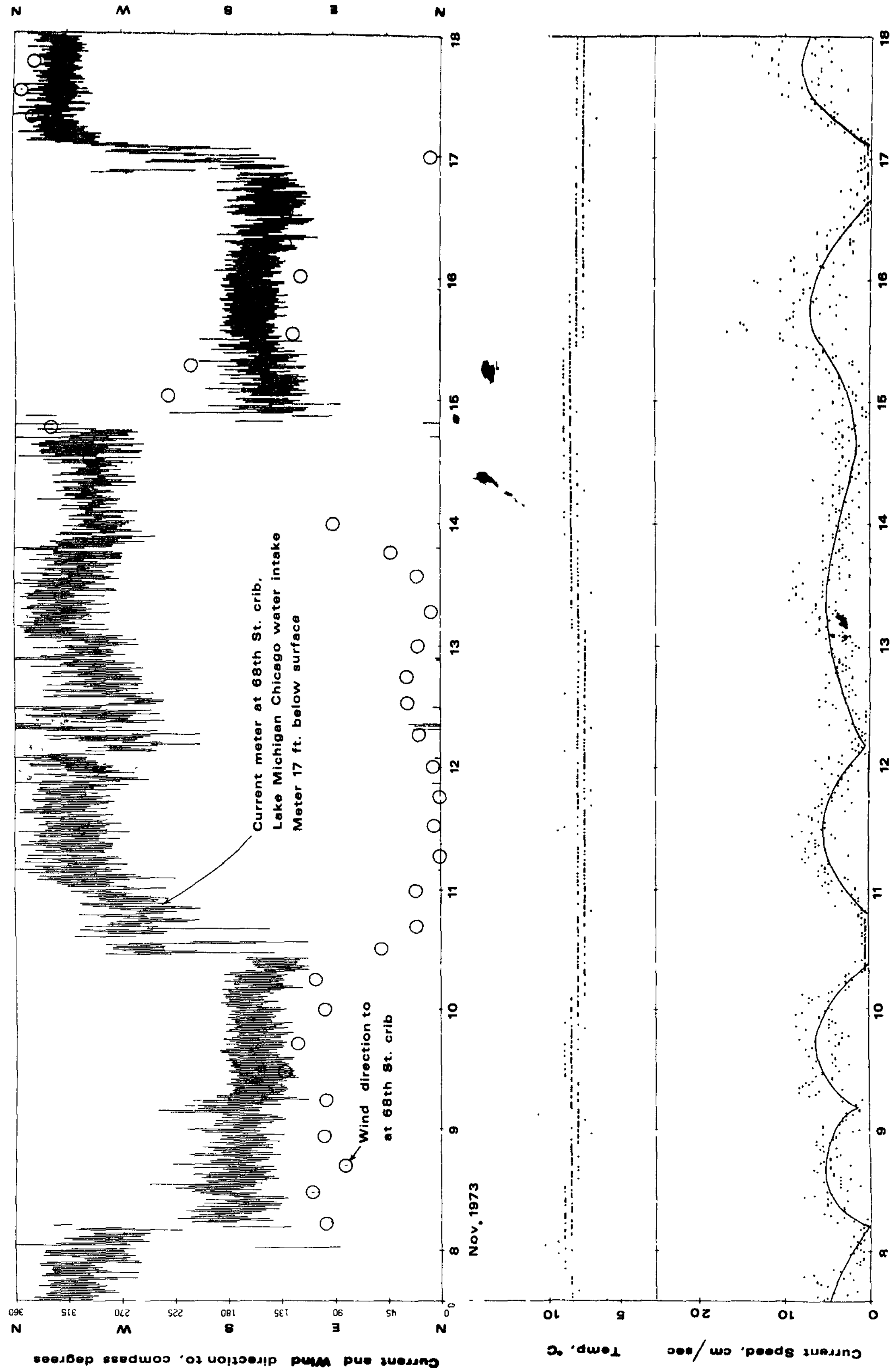

Figure 11.14

CURRENT METER RECORDS AT 68TH ST. CRIB
SHOWING CURRENT DIRECTION, WIND DIRECTION
FROM NATIONAL WEATHER SERVICE,
TEMPERATURE OF WATER. AND CURRENT SPEED

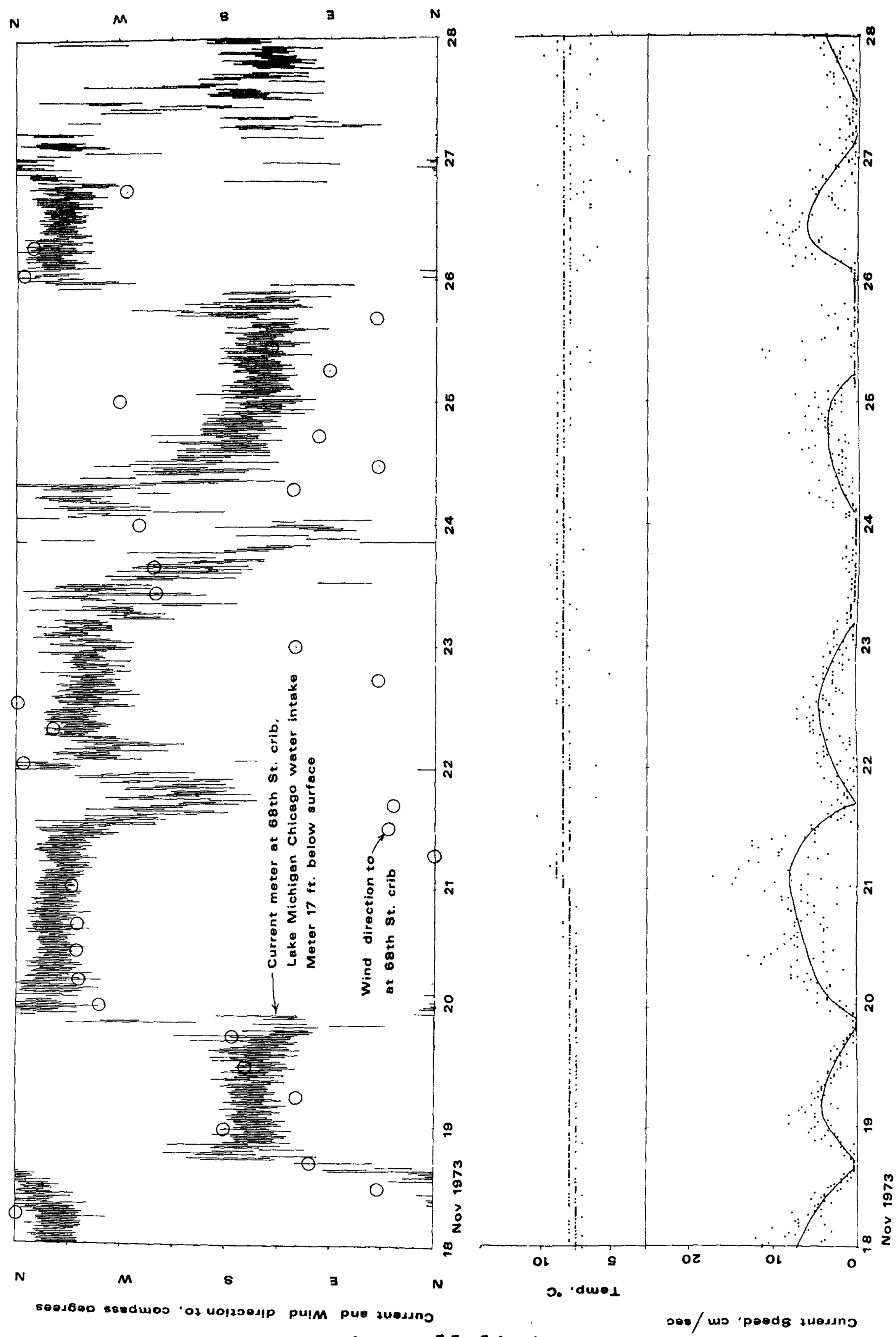

Figure 11.14 (cont.)

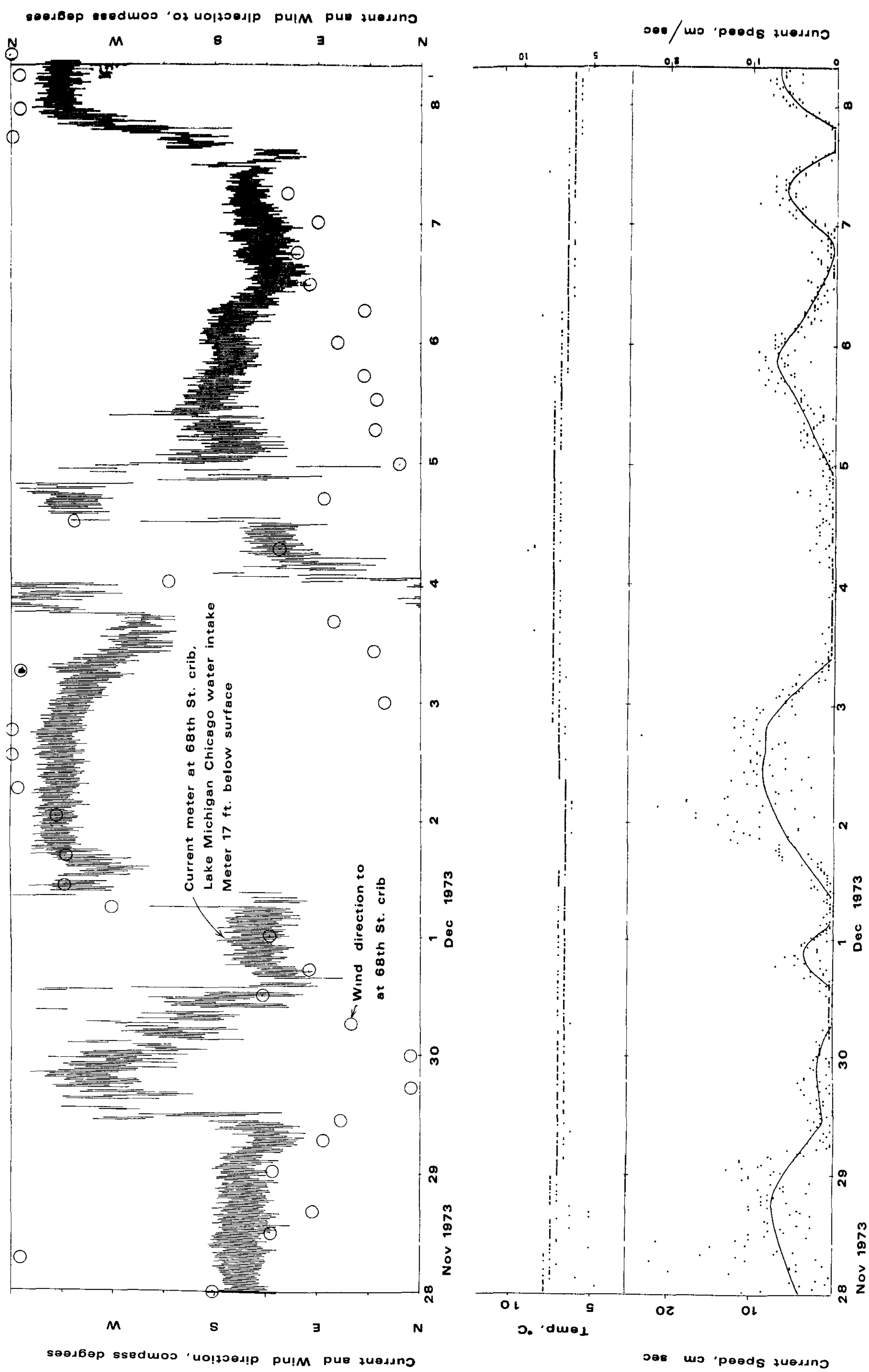

Figure 11.14 (cont.)

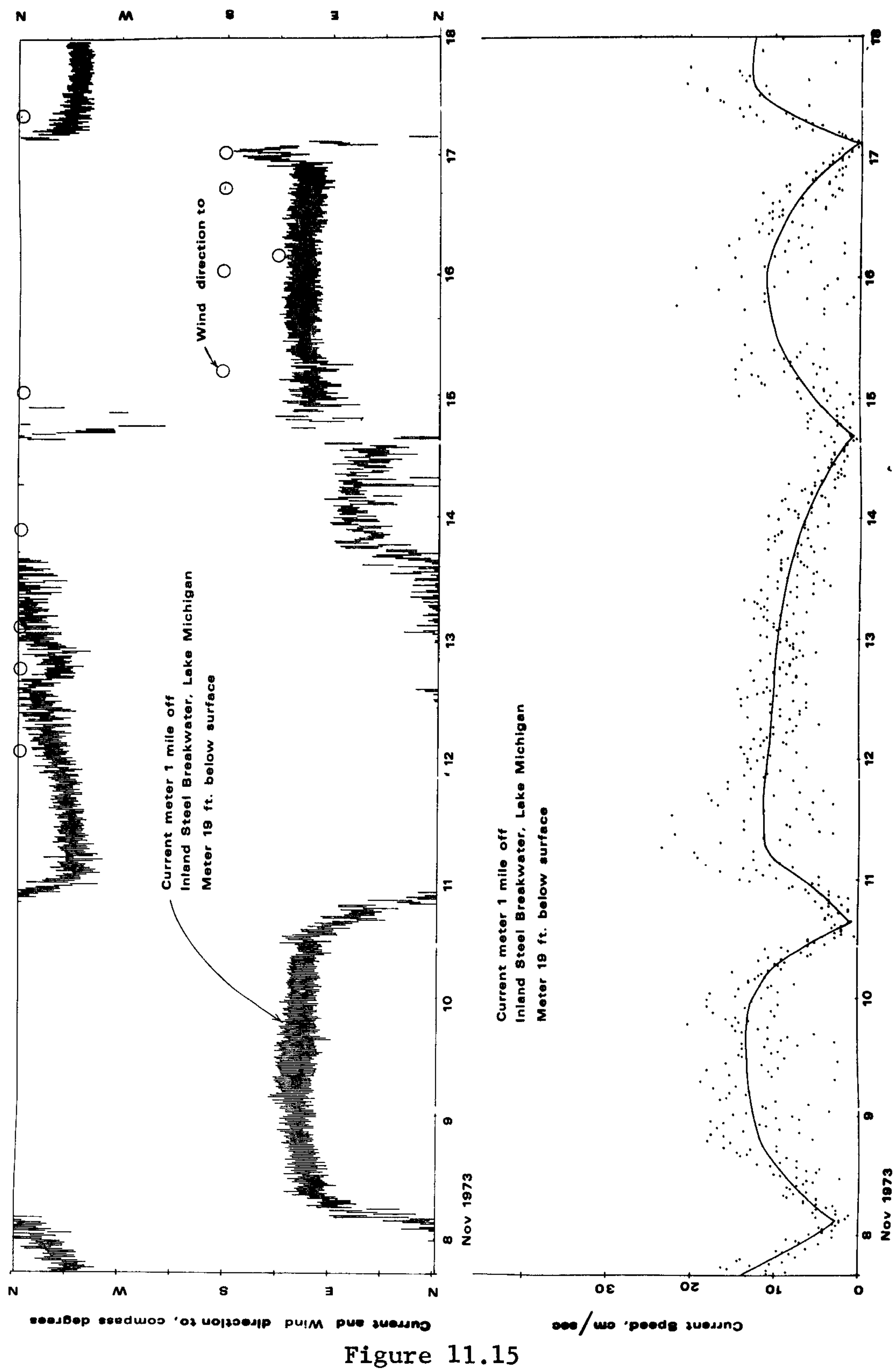

Figure 11.15

CURRENT METER RECORDS OFF INLAND STEEL LANDFILL,
SHOWING CURRENT DIRECTION,
WIND DIRECTION AT HAMMOND WATER LABORATORY,
AND CURRENT SPEED

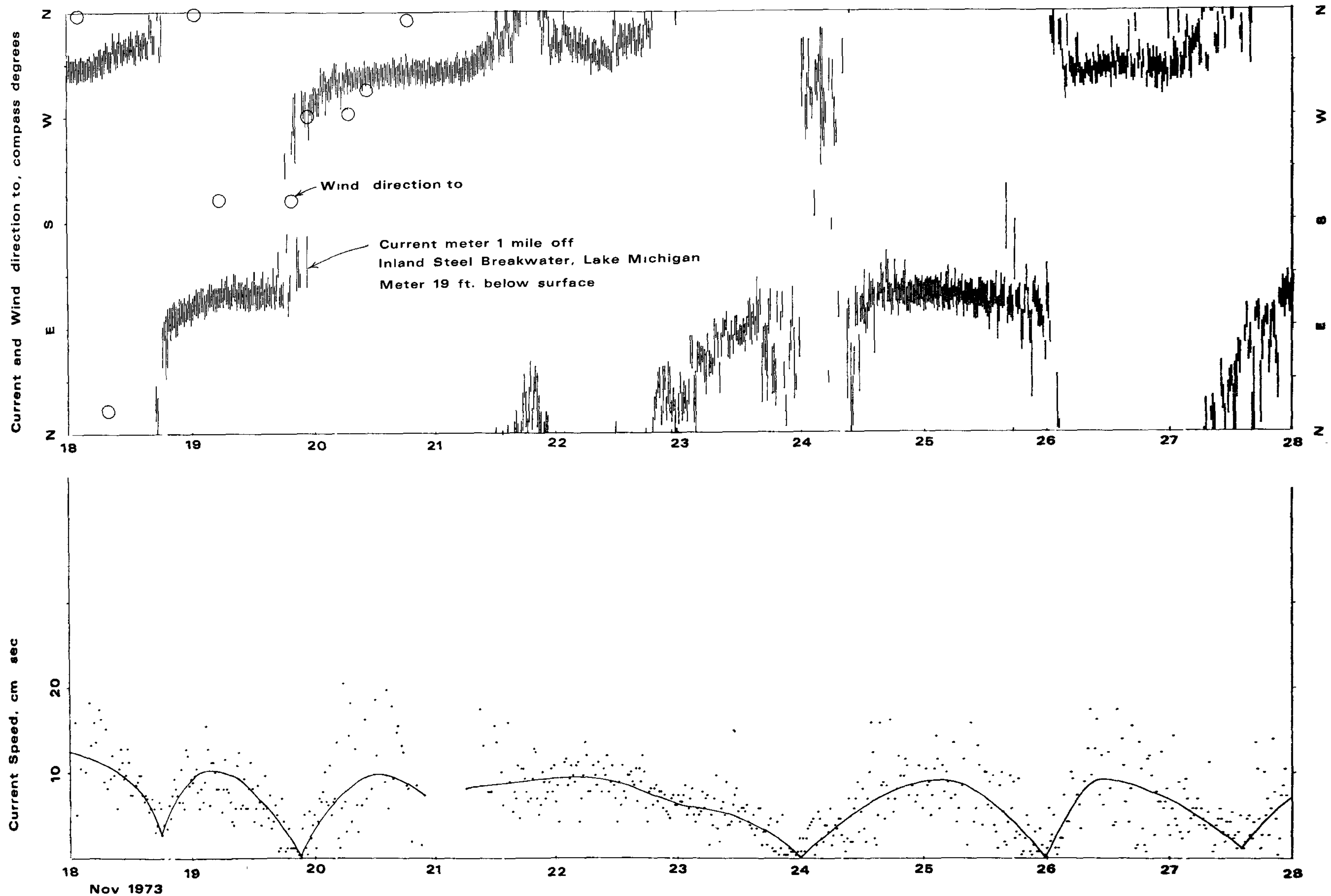

Figure 11.15 (cont.)

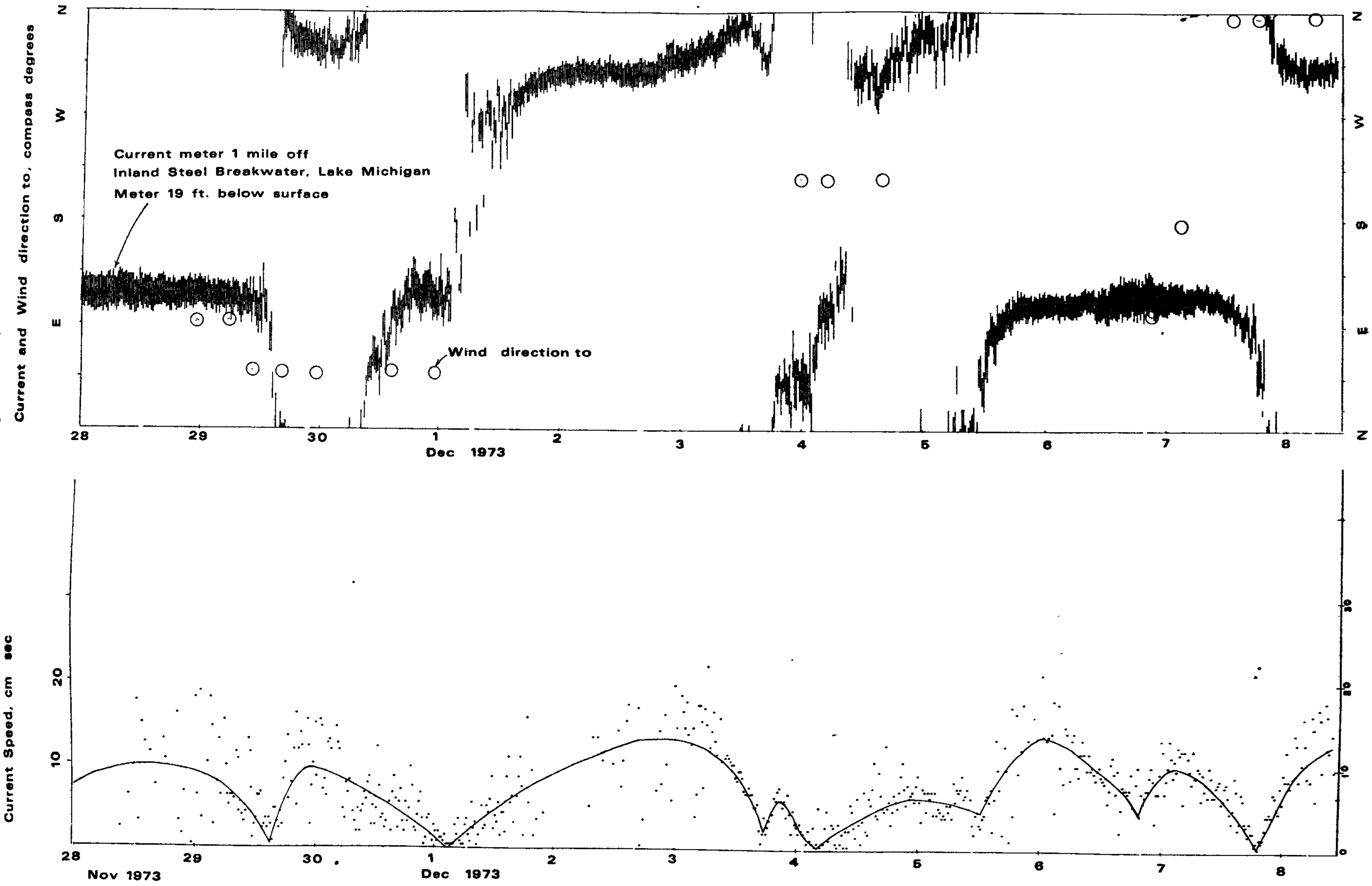

Figure 11.15 (cont.)

reversals. One of these periods occurred November 14, during a boat sampling time.

The current speed shows a cyclical variation with time, and dropped to zero or near zero between each cycle. These times of zero current correspond to the times at which current changes direction. This appears to be a shore effect. Further out in the Lake the current can swing to any direction (FWPCA, Lake Currents 1967) but the shore boundary limits the velocity component normal to the shore. Long periods of zero current correspond to calm weather periods. A small off-shore component is apparently possible, as is indicated by the plume observations shown in Figures 11.3 to 11.12. Although the two meters at 9 and 19 ft indicated practically no difference, the current closer to the surface than 9 ft could differ somewhat. Nevertheless, the observed plume directions agree well with the current meter records.

These results are discussed further in Chapter 12.

12. DISPERSION OF EFFLUENTS FROM INDIANA HARBOR CANAL (IHC)

The objective of this part of our study was to determine what mechanisms govern the behavior of effluents from the IHC and other sources, to determine the extent of dispersion on the days of our measurements, to estimate the fraction of time during which the observed dispersion is typical, and also to estimate cases that are likely to lead to extremes of effluent concentrations. Such estimates are based on observations, measurements, and mathematical models. A complete mathematical model of the transport and mixing of the effluents in the coastal waters is beyond present capabilities, unless a much larger study were undertaken with more extensive measurements of currents and mixing of tracers. Nevertheless, some conclusions can be drawn from the results and estimates given here.

Eventually, pollutants introduced into the Lake may be dispersed, deposited in sediments, released to the atmosphere, or flushed out the Straits of Mackinac. Whatever their eventual fate, the highest concentrations and most severe problems occur before the pollutants are dispersed. The extent of local pollution near sources such as the IHC depends on the rate of mixing or dispersion. It is the objective of this chapter to investigate this rate, and to determine dilution ratios of pollutants, at various distances from the source. It appears that several mechanisms govern the rate of dispersion, and these are discussed and analyzed. We also attempt to estimate the worst conditions that can result, if the dispersion mechanisms fail to act for a period of time. These conditions can lead to the most harmful effects.

For example, Chapter 13 presents measurements from the IITRI field sampling program of NH_3-N concentrations in the Lake. Some of the concentrations in the IHC plume exceed water quality standards for the Lake by at least ten-fold. Chapter 13 also presents data from the Radial and South Shore Surveys (Chicago Water Dept.

1967 to 1973) that show peaks of NH_3-N at stations 4J, 5J and 6J, and these peaks lie in the path of the IHC plume. Examples for other pollutants are given in Chapters 14 to 18.

The present study of the spread of pollutants in the Calumet area is mainly concerned with the effluents from the IHC, since this canal is the major source of effluents in the area; however, data were also obtained on other sources that flow directly into the Lake, particularly the municipal sewer outflows, the U.S. Steel South Works effluents at Calumet Harbor, the outfalls of American Maize and American Oil Co., the Burns Ditch effluents, and the Lake Michigan outfalls of U.S. Steel Gary Works. Data on these sources are given in Chapters 4 and 5.

12.1 Behavior of IHC Plume

We found evidence that several mechanisms can act to disperse the effluents from IHC, depending on conditions at the mouth of the canal and in the Lake. These mechanisms will be described and their impact on water quality assessed. The observations and measurements which lead us to describe these mechanisms will then be given. Then mathematical models will be given which allow us to calculate the concentration and extent of polluted zones for certain special cases.

Measurements to calibrate dispersion models are very important, because the models are partly empirical, even if they are based on an understanding of the actual mechanisms occurring. For this purpose, it is fortunate that a number of the pollutants in the IHC effluent are effective tracers. We make use of measured parameters at various Lake stations to determine the movement and dilution of the canal effluent, and to distinguish it from other sources of polluted water.

Several mechanisms operate to dilute the effluents from the IHC and to influence the spread of the plume and the location of the polluted area. These mechanisms begin with shear and eddy mixing within the canal; they include mechanisms of flow and spread of the canal plume; and they extend to mechanisms that mix the effluents with waters of a wider coastal zone; and eventually disperse them into the main part of the Lake. Although the pollutants are eventually dispersed, what is needed is an estimate of the concentrations that will exist while dispersion is taking place.

The following are some of the mechanisms and an estimate of their relative importance. The list is in order of when they occur, beginning with those that act at the mouth of the IHC, and extending to those that can act over a wider area.

1. Turbulent vertical mixing within the canal with intruding colder Lake water (important)

2. Inertial jet flow near canal mouth (not important)

3. Gravity spreading (important)

4. Vertical mixing of plume due to turbulent eddies in Lake (important)

5. Floating plume being carried along by natural Lake currents (important)

6. Mixing at edges of plume due to turbulent eddies in Lake (important only over a distance of two miles or more)

7. Shearing and dispersion of plume by Lake currents varying direction with depth (not important on the days of our measurements)

8. Gradual build-up of pollutants in near-shore area, with occasional return of polluted water along the coast due to current reversals, and periodic flushing with clean Lake water due to upwelling or downwelling (probably important).

There is evidence from aerial and satellite observations, and from current and dilution measurements in the Lake, to indicate that some of these mechanisms are operating on particular days. Calculations can be made to estimate the magnitude of these mechanisms; they are discussed in the following sections.

12.2 Estuary Mixing at Canal Mouth

The water of the IHC is almost always warmer and less dense than the Lake water, and this gives rise to a typical estuary effect at the mouth of the Canal. The IHC is dredged to a depth of about 10 m; the warmer canal water flows out in the top 3-5 m of this depth, and colder Lake water intrudes in the bottom portion. This behavior is similar to that observed in a salt-water estuary, and described by Ippen (1966) in Figure 12.1. The density differences are much more pronounced in the salt water estuary than in the IHC thermal estuary.

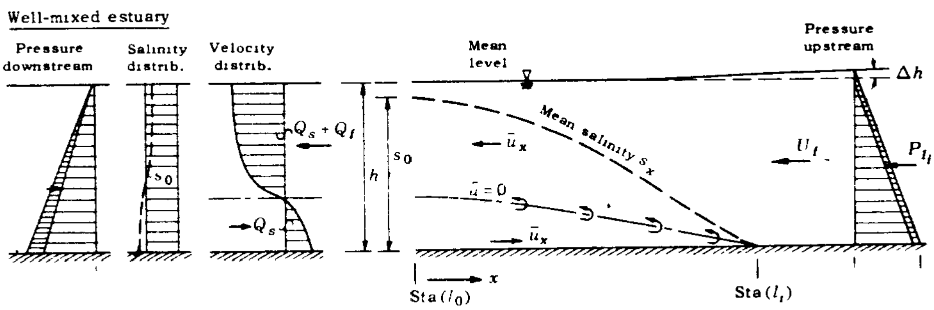

Figure 12.1

SCHEMATIC REPRESENTATION OF SALINITY INTRUSIONS IN ESTUARIES

Station ℓ_0 in the figure corresponds to station CAL06 at the mouth of the IHC.

The colder Lake water which intrudes under the canal water mixes with the IHC water in the lower part of the canal. Mixing is probably due to eddies caused by shear between the counter-flowing layers, and eddies due to change of flow direction in the Inland turning basin. As a result of this inflow and mixing, the IHC water is already diluted 20 to 50% at the mouth of the canal (Station CAL06). Flows measured with a current meter on three boat sampling days are listed in Table 12.1, and detailed measurements are given in Table 12.2.

Table 12.1

MEASURED FLOWS AT MOUTH OF IHC - IITRI DATA

	Total outflow		Lake inflow*	
Date	m^3/sec	cfs	m^3/sec	cfs
November 14, 1973	89	3150	44	1546
November 19, 1973	102	3590	(14)	(495)
December 7, 1973	120	4226	(22)	(778)

*Values in parentheses are uncertain, either because of the passage of a large eddy causing the flow to change direction during the measurement, or because the measurement was not made at the center of the channel. Nevertheless, there is no doubt that inflow was present on all three days, because the water was colder and less polluted near the bottom.

Inflow is produced because the warmer canal water flows out of the harbor faster than it is supplied from upstream. The Lake water is drawn in to make up the deficit, and to conserve mass. This behavior is also described by Harleman and Stolzenbach (1973, p. 21). The mechanism that governs the outflow appears to be the gravity spreading mechanism discussed in the next section.

12.3 Gravity Spreading Mechanism

The heated canal water tends to spread on the colder Lake water, just as oil spreads on water, because of the gravity difference. It seeks to flow out and become thinner, decreasing its gravitational potential. Such a wavefront is vertical and sharply defined (Cederwall, 1970). This is not an oscillatory wave like the usual waves that are seen on the water surface, but a solitary wave. Although the wave front is moving with respect to the bulk of the water, it may appear stationary if the water has the same velocity in the opposite direction. Such a wave occurring in an enclosed channel is a well-known effect, and is called a control section (Csanady, personal communication, 1974), or a wedge (Parker and Krenkel 1969). Parker and Krenkel (1969) describe the phenomenon in some detail and review mathematical descriptions of it. Cederwall (1970) applied the mechanism to estuaries.

The differential equations describing the movement of the wave front were given by Abbot (1961), and Cederwall (1970) and Parker and Krenkel (1969) give some useful relations. The wave velocity is given by

$$U_{\Delta} = \sqrt{\frac{\Delta\rho}{\rho} gH} \qquad (12.1)$$

where

ρ is density of water, consistent units

g is acceleration of gravity, 9.80 m/sec^2

H is depth of heated water, m

Measurements of temperature and depth of heated water were taken at the mouth of IHC, Station CAL06, on three boat-sampling days, and are given in Tables 12.2 and 12.3. From these data and Equation 12.1 we can calculate the outflow velocity based on the spreading mechanism. It is compared with the measured outflow velocity in the last two columns of the table. The agreement is so good that this confirms the mechanism of outflow.

Table 12.2

CURRENT METER MEASUREMENTS AT MOUTH OF IHC (CAL06)

Depth, m	Speed, knots	Speed, ft/sec	Direction, degrees	Temperature °C	Flow increment, cfs Direct	Flow increment, cfs x cos θ	Flow integral cfs	Flow integral m^3/sec
				November 14, 1973	2 P.M.			
1	0.3	0.51	330	14.9	1121	1082		
2	0.29	0.49	330		1077	1042	out	
3	0.28	0.47	310	15.0	1033	1029	3153	89
4	0.12	0.20	270		440	-		
5	0.12	0.20	150	12.5	440	424		
6	0.07	0.12	135		264	264		
7	0.10	0.17	130		374	372	in	
8	0.16	0.27	100	9.0	594	486	1546	44
Downstream is 350°. Upstream is 170°. Width of channel is 670 ft.								
				November 19, 1973	1 P.M.			
1	0.3	0.51	330	14.0	1681	1623		
2	0.25	0.42	340		933	846		
3	0.25	0.42	345	13.9	933	808		
4	0.1	0.17	355	12.0 (5 m)	374	286	out	
6	0.01	0.02	355		37	28	3591	102
8	0		45	10.5	-	-	nil in	-
				December 7, 1973	9:40 A.M.			
1	0.25	0.42	340	12.5	1400	1315		
2	0.25	0.42	330	13.5	933	901		
3	0.25	0.41	330	13.0	901	870		
4	0.20	0.34	350	12.5	747	612	out	
5	0.20	0.34	360	12.0	747	528	4226	120
6	0.20	0.34	50	11.0	uncertain			
7	0.45	0.70	80	10.5	-			
8	0.40	0.68	90	9.5	-			
9	0.20	0.34	130		-	in		
10	0.50	0.84	250					
1	0.25	0.41	350					
2	0.30	0.51	330					
3	0.25	0.41	360					
4	0.15	0.26	340					
5	0.10	0.17	340					
6	0.20	0.34	240					
7	0.40	0.68	250					
8	0.40	0.69	110					

Table 12.3

GRAVITY FLOW AT IHC MOUTH (CAL06)

Date, 1973	Depth of outflowing layer, m	Temperature, °C		Density deficit, g/mℓ	Outflow velocity, m/sec	
		Top	Bottom		Calculated	Measured
November 14	3.5	15.9	10.0	0.00076	0.15	0.15
November 19	3.5	15.0	11.5	0.00045	0.12	0.13
December 7	3.5 5*	13.5	10.5	0.00034	0.10 0.12	0.13

*Depth of outflow was uncertain because a large eddy passed during one of two measurements.

We may ask what would happen if the temperature difference were greater or less than on the days of our measurements. The temperature differences we measured in November 1973 varied from 3 to 5.0°C. Examination of Storet data indicates that the IHC is usually 5°C warmer than the Lake, and this is due to the fact that IHC water consists of Lake water that has been pumped through industrial processes and used for cooling; however, there are occasions in November when it is the same temperature as Lake water, or occasionally even colder. Presumably this depends on the weather conditions.

Equation 12.1 indicates that the flow velocity will be varied by a factor of $\sqrt{\Delta T}$. This assumes that density is proportional to temperature, which is true for temperatures above 10°C. Thus an increase in temperature difference will increase flow, and a decrease in temperature difference will decrease flow for a given H. At lower temperatures approaching the temperature of maximum density, the density varies only slightly with temperature, and the temperature effect will be less. There is another mechanism that decreases the effect: an increase in outflow will cause a greater intrusion of Lake water into the IHC, and as this Lake water mixes with the water in the IHC it decreases the temperature difference. Thus the net effect of a temperature difference on flow will vary by a power less than 0.5.

A more important effect can occur if the Lake temperature is close to 0°C. In this case the IHC water may be near 4°C, the temperature of maximum density, and the plume will tend to sink. Such a sinking plume was measured at the Point Beach power plant on the Wisconsin shore of Lake Michigan by Hoglund and Spigarelli (1972). A report by Industrial Biotest (1974) shows inverted temperatures near the mouth of the IHC on January 28, 1974, indicating a sinking plume. Pritchard (1972) discussed the effect that sinking may have on the dispersion of a thermal plume. He suggests that the plume may not actually sink if it mixes sufficiently by the inertial jet mechanism, but the IHC plume has low inertia and apparently did sink on January 28, 1974. The mixing coefficient generally decreases with depth, so mixing may be less when the plume sinks. Furthermore the water intakes of municipal water plants are located at some depth, and may receive higher concentrations of pollutants under these conditions. Reed and Pawlowski (1974) report more frequent taste and odor problems at the Chicago south water crib in winter of 1973-74.

Sinking of toxic water only once a year could control the absence or presence of those benthic organisms having a one-year life cycle (Beeton 1974).

12.4 Behavior of Plume in Lake Just Outside IHC Mouth

The behavior of the plume just outside the IHC mouth appears to depend on the interaction of gravity spreading with Lake currents that usually run parallel to the shore, as will be described. Since this region is heavily polluted, it is important to be able to predict concentrations there under various conditions.

A calculation shows that gravity spreading (sometimes called buoyant spreading) is more important than inertial jet flow of effluents out of the IHC mouth. The ratio of these two effects is measured by the Froude number, F.

$$F = \frac{U_0}{\sqrt{\frac{\Delta\rho}{\rho} g H}} \qquad (12.2)$$

where

U_0 is centerline velocity of jet, m/sec

ρ is density of water, consistent units

g is 9.8 m/sec^2

H is depth of plume, m.

At the mouth of IHC (CAL06) we measured $U_0 = 0.13$ m/sec, $\Delta\rho/\rho = 0.00045$, H = 3m, and from these we calculate F = 1.1. A value of F < 2 means that the gravity effect is more important than the inertia of the jet (Cederwall 1970). (Some authors define F as the reciprocal of Equation 12.2).

There is visual evidence that gravity spreading interacts with Lake currents to determine plume behavior outside the mouth of the IHC. As shown in Figure 12.2, the spreading plume usually encounters a Lake current flowing parallel to the shore. In Figure 12.2 the Lake current is to the southeast, around the Inland landfill, across the direction of spreading of the plume. This pattern is clearly shown by the Skylab photo, Figure 13.2. This photo suggests that there was a fairly strong general current in the main Lake water flowing from north to south, dragging the plume around the landfill into a whorl centered on the East Chicago water intake crib located just south of the landfill. We observed this type of behavior on several days, including November 16, 19, 29 and December 7, 1973.

Even when the plume is flowing around the landfill, it gives the appearance of gravity-spreading behavior on the north boundary. Typically it fills the region as far north as a line running eastward from the Youngstown landfill breakwater, and the demarcation between clear Lake water and the plume is sharp. A gravity plume is said to have a sharp, vertical wavefront (Cederwall 1970). This would be the case if the rate of gravity spreading was about equalled by the rate at which the Lake current pushes the water southward around the Inland landfill. The Lake current flows under the plume, and the plume width is determined by a balance between the spreading velocity and the Lake current. The effect was described above (Section 12.4). The effect has been recognized, but it is usually neglected in comparison with the jet inertia effect. Power plant plumes usually have a higher velocity, and the inertial effect exceeds the gravity spreading mechanism; whereas the opposite is true in the case of the IHC. The width of the plume as it passes around the Inland Steel landfill (Figure 13.2) varies according to our observations from 100 m to several km, presumably depending on the magnitude of the Lake

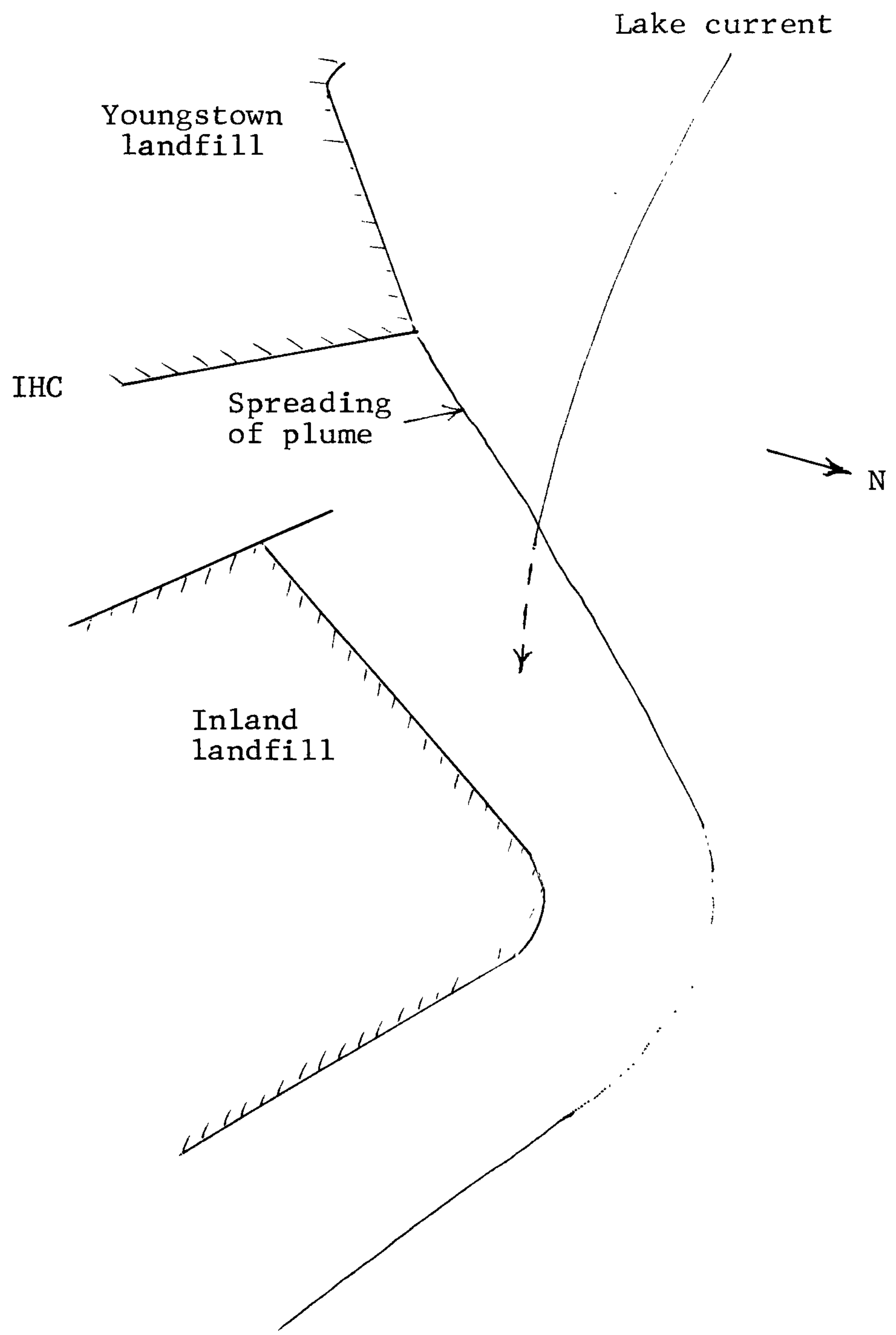

Figure 12.2

CROSS-FLOW OF LAKE CURRENT AND GRAVITY SPREADING OF PLUME than the inertia of the jet (Cederwall 1970). (Some authors define F as the reciprocal of Equation 12.2).

There is visual evidence that gravity spreading interacts with Lake currents to determine plume behavior outside the mouth of the IHC. As shown in Figure 12.2, the spreading plume usually encounters a Lake current flowing parallel to the shore. In Figure 12.2 the Lake current is to the southeast, around the Inland landfill, across the direction of spreading of the plume. This pattern is clearly shown by the Skylab photo, Figure 13.2. This photo suggests that there was a fairly strong general current in the main Lake water flowing from north to south, dragging the plume around the landfill into a whorl centered on the East Chicago water intake crib located just south of the landfill. We observed this type of behavior on several days, including November 16, 19, 29 and December 7, 1973.

Even when the plume is flowing around the landfill, it gives the appearance of gravity-spreading behavior on the north boundary. Typically it fills the region as far north as a line running eastward from the Youngstown landfill breakwater, and the demarcation between clear Lake water and the plume is sharp. A gravity plume is said to have a sharp, vertical wavefront (Cederwall 1970). This would be the case if the rate of gravity spreading was about equalled by the rate at which the Lake current pushes the water southward around the Inland landfill. The Lake current flows under the plume, and the plume width is determined by a balance between the spreading velocity and the Lake current. The effect was described above (Section 12.4). The effect has been recognized, but it is usually neglected in comparison with the jet inertia effect. Power plant plumes usually have a higher velocity, and the inertial effect exceeds the gravity spreading mechanism; whereas the opposite is true in the case of the IHC. The width of the plume as it passes around the Inland Steel landfill (Figure 13.2) varies according to our observations from 100 m to several km, presumably depending on the magnitude of the Lake

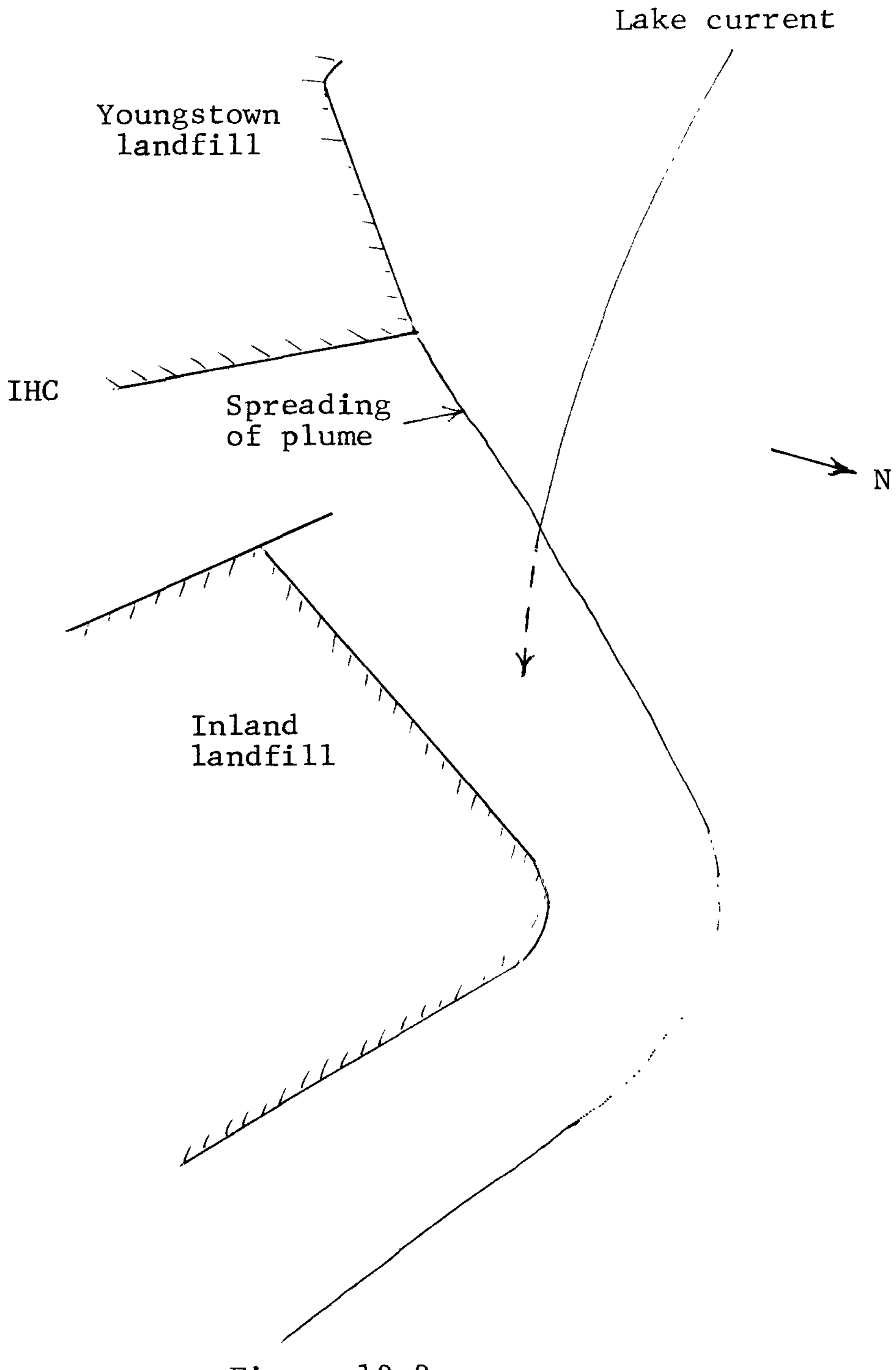

Figure 12.2

CROSS-FLOW OF LAKE CURRENT AND GRAVITY SPREADING OF PLUME current and the density difference. In one infrared color photo taken by IITRI on November 29, 1973, there can be seen four superimposed boundaries of the plume curving around the landfill, as if four successive advances of gravity waves were being carried around, each having penetrated to a different depth and perhaps a different dilution.

When the Lake current is upshore to the northwest, the plume motion is different. From airplane observations in Chapter 11, such as Figures 11.3, 11.6 and 11.12, it appears that the plume drifts out into the Lake until it reaches the end of the Inland landfill, and then it meets the cross-flowing Lake current. A splotchy-looking plume results, that spreads out into the Lake several km and is visible for 15 km (10 miles) or more to the north.

On November 18, 1973, (Figure 11.7) the effluent did not look like a normal plume, but looked like a round puddle centered on the north corner of the Inland landfill. The puddle was about 3 km (2 mi) in diameter, and a second puddle of similar size lay further out in the Lake. The current meter record showed that the Lake current was zero at this time, due to the fact that it was just changing direction. Again on November 30, 1973 (Figure 11.10) a larger puddle was seen in the Lake off the north corner of the landfill, in addition to the curving plume; again the current was just changing direction and was stagnant. Such puddles could be caused by gravity spreading. Estimates of the rate of gravity spreading given in Section 12.6 below indicate that ten hours are required to form a puddle of 2300 m (1.4 miles) in diameter. When an upshore durrent again sets in, it could carry such a puddle along and cause stronger than usual pollution at water intakes along the shore.

12.5 Rate of Gravity Spreading in Lake

The rate of spreading of a buoyant plume was determined in model experiments by Sharp (1969). In these experiments, water was floated on dilute brine. The water was supplied at the center of the tank surface, and the spreading of the circular puddle of water on the brine was measured as a function of time after the start of flow. The data are plotted in Figures 12.3 and 12.4.

Sharp expressed the results in terms of three dimensionless groups. They are

$$\frac{t\,g'^{3/5}}{Q^{1/5}}, \quad \frac{R\,g'^{1/5}}{Q^{2/5}} \quad \text{and} \quad \frac{Q\,g'^{1/3}}{\nu^{5/3}}$$

where

t is time, sec

g' is $g\ \Delta\rho/\rho = 9.8\ \Delta\rho/\rho\ \text{m/sec}^2$

Q is flow from source, m^3/sec

R is radius of puddle

ν is kinematic viscosity of water, $1.3\text{x}10^{-6}\ m^2$/sec at 5°C.

Sharp's (1969) data are presented in Figure 12.3. For a given flow Q and constant conditions, the abscissa value is a constant at various times. The figure can be used to calculate the spread of warmer water over time by reading up from the abscissa, and relating values of spread distance R to time t. Note the curved portions of the graph to the left side. This curvature arises because of the influence of viscous drag between the spreading liquid and the substrate at long times or large spread distances, especially for smaller flows. Larger flows correspond to points to the right, on the horizontal portion of the curves. It is safe to extrapolate to larger flows, since viscous forces can then be neglected. In fact the horizontal portions of the curves can be expressed in a single graph, Figure 12.4. This graph is valid if ratio of

$$\frac{Q\,g'^{1/3}}{\nu^{5/3}} \text{ to } \frac{R\,g'^{1/5}}{Q^{2/5}}$$

is at least $(2\text{x}10^3)/3$. For values of the abscissa greater than 20, Figure 12.4 can be represented by the following straight line:

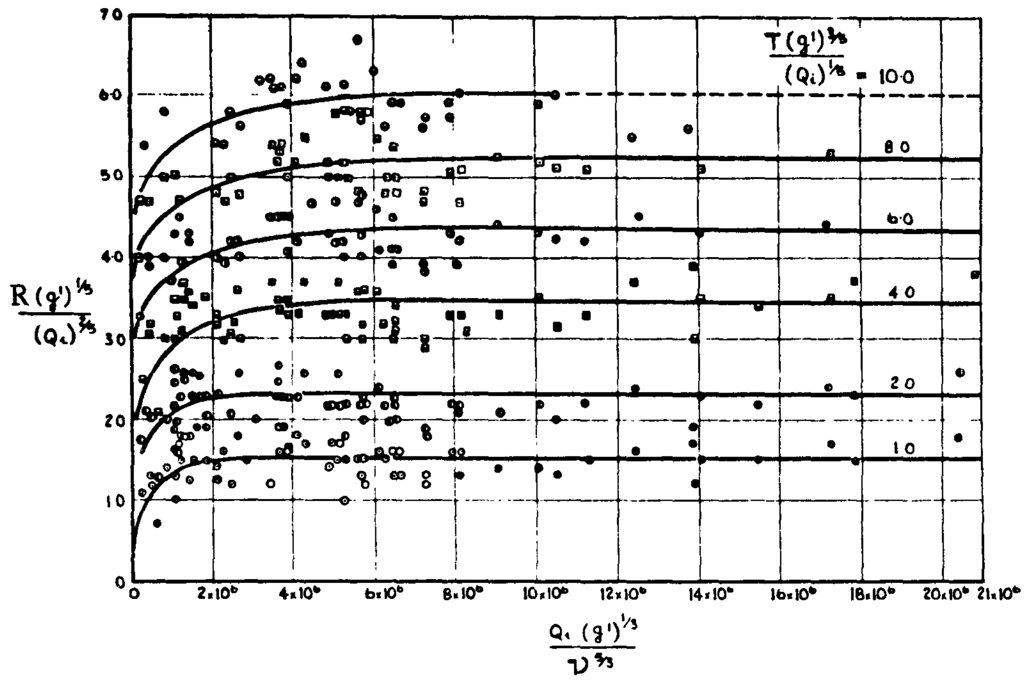

Figure 12.3

SPREAD DIAGRAM
from Sharp (1969)

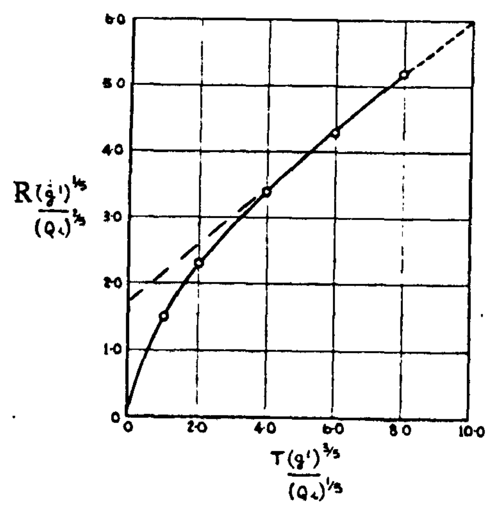

Figure 12.4

NONVISCOUS SPREAD DIAGRAM
from Sharp (1969)

$$\frac{R\, g'^{1/5}}{Q^{2/5}} = 1.6 + 0.44\, \frac{t\, g'^{3/5}}{Q^{1/5}} \qquad (12.3)$$

Calculations were done for two cases.

November 19 at CAL06 (mouth of IHC)

$\Delta\rho/\rho$ = 0.00045 (Table 12.2) Q = 102 m^3/sec (Table 12.1)

t	R, m
1 min	37
10 min	106
1 hr	487
4 hr	1860

This means that it would take about 1 hr for IHC effluents to reach the north edge of the Youngstown landfill breakwater. These values are within the range where viscous forces can be neglected.

November 14 or December 7 at LM68

$\Delta\rho/\rho$ = 0.00008 Q = 89 m^3/sec

t	R, m
10 min	78
1 hr	266
2 hr	490
10 hr	2300 (1.4 miles)

The normal width of the plume when it flows around the Inland landfill is about 500 m, which means that 2 hr was required to reach this width.

12.6 Measured Dilutions

The dilution of the IHC plume was determined experimentally on three boat sampling days. The experimental procedure was described in Chapter 11. The results are plotted in Figures 12.5 to 12.7.

We define the dilution factor as the ratio of concentration of a substance measured at the mouth of the IHC, to that measured at a point in the Lake, less the background concentration. The background for each pollutant was chosen to be the lowest value measured on that day at stations that appeared to be well outside any plume. Generally these backgrounds were consistent with Lake backgrounds discussed in Chapters 13 to 18.

Although there is some spread in the dilution curves for the various parameters, the trends are similar. Coliform bacteria is an exception, but its behavior is not unexpected. Howmiller (Appendix A) reviews available data on the rate of decay of fecal organisms. With few exceptions there is a substantial mortality of such bacteria within 24 hr. This was attributed to an unknown "toxic factor" in Lake water, since the mortality in well water was slight. The apparently greater dilution for coliform given in the Figures actually represents dilution plus decay. The presence of coliform is still an indicator that the samples contain IHC effluents, although the coliform data cannot be used to measure dilution.

The curves for chlorophyll show an apparent decrease in dilution. This is because the IHC effluents have a nutritive effect causing growth of algae. This subject is discussed in Chapter 17.

Some scatter in the data for the remaining parameters occurs. The reason for this is not known, although it might be due to fluctuations in the composition of IHC effluents with time.

12.7 Interpretation of Dilutions in Terms of Dispersion Mechanisms

Two different situations are represented by Figure 12.5 (November 14) and by Figures 12.6 and 12.7 (November 19 and December 7). On the first date the plume was flowing out into

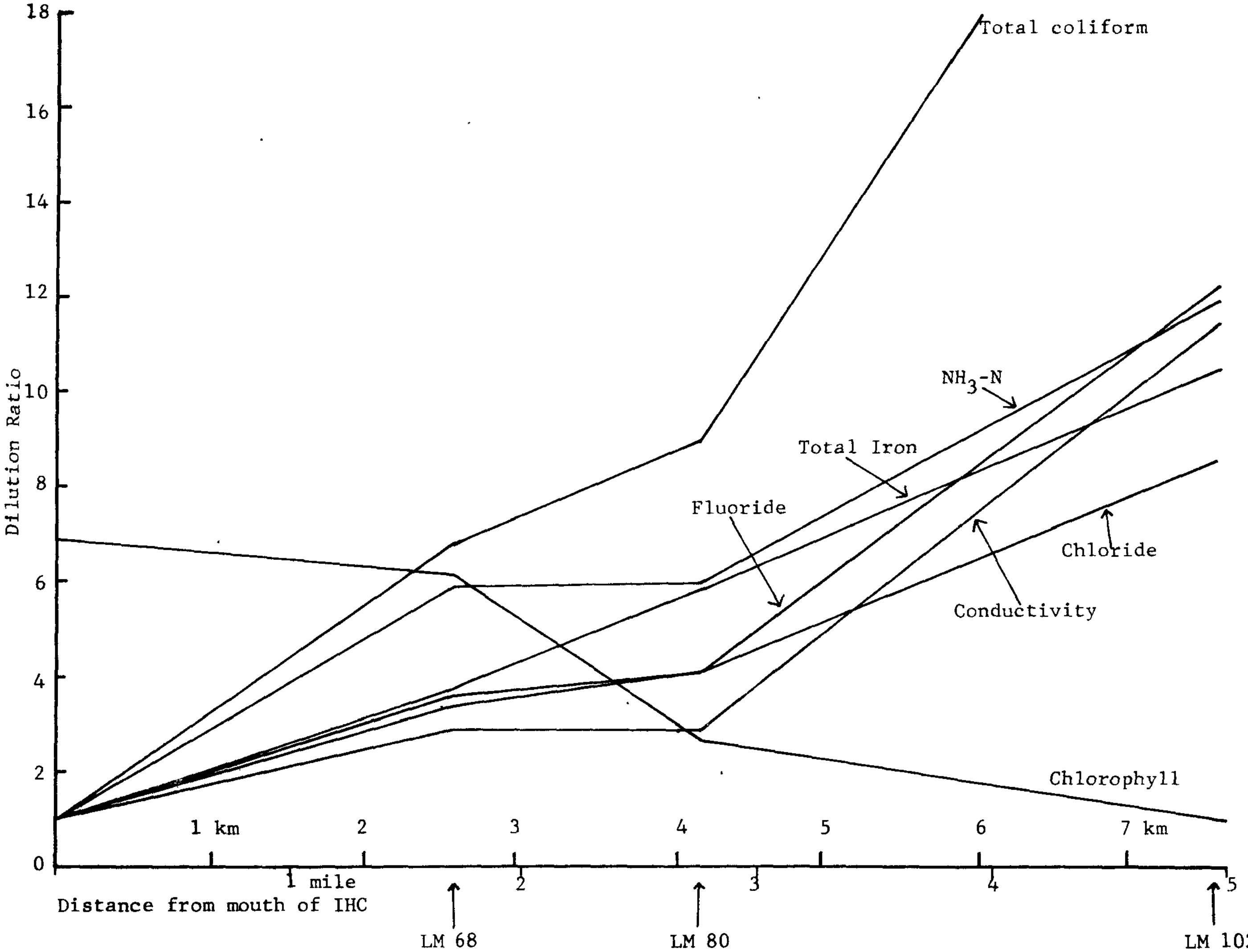

Figure 12.5

DILUTION OF IHC EFFLUENT AT LAKE MICHIGAN STATIONS
BASED ON WATER QUALITY MEASUREMENTS BY IITRI
November 14, 1973

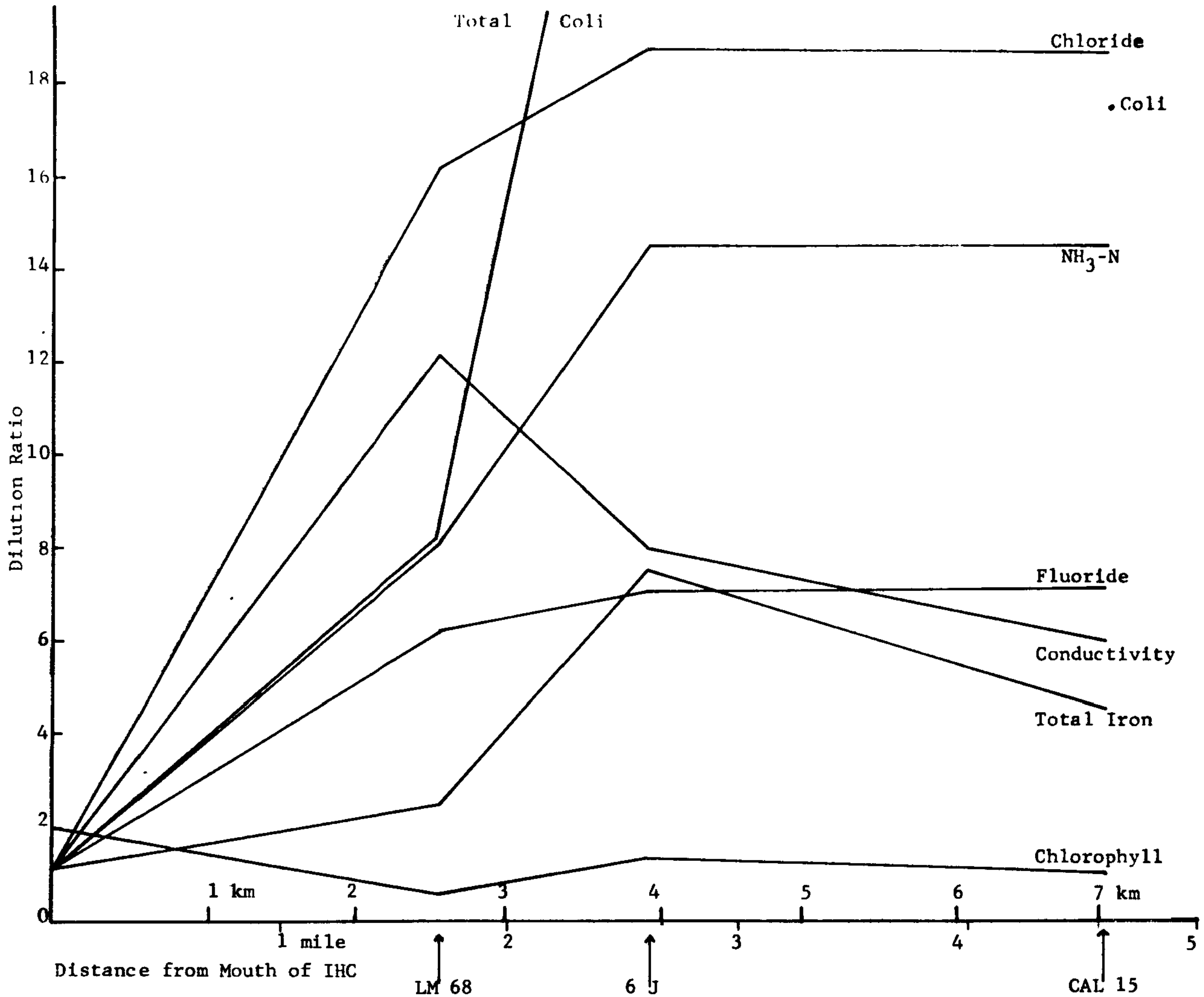

Figure 12.6

DILUTION OF IHC EFFLUENT AT LAKE MICHIGAN STATIONS
BASED ON WATER QUALITY MEASUREMENTS BY IITRI
November 19, 1973

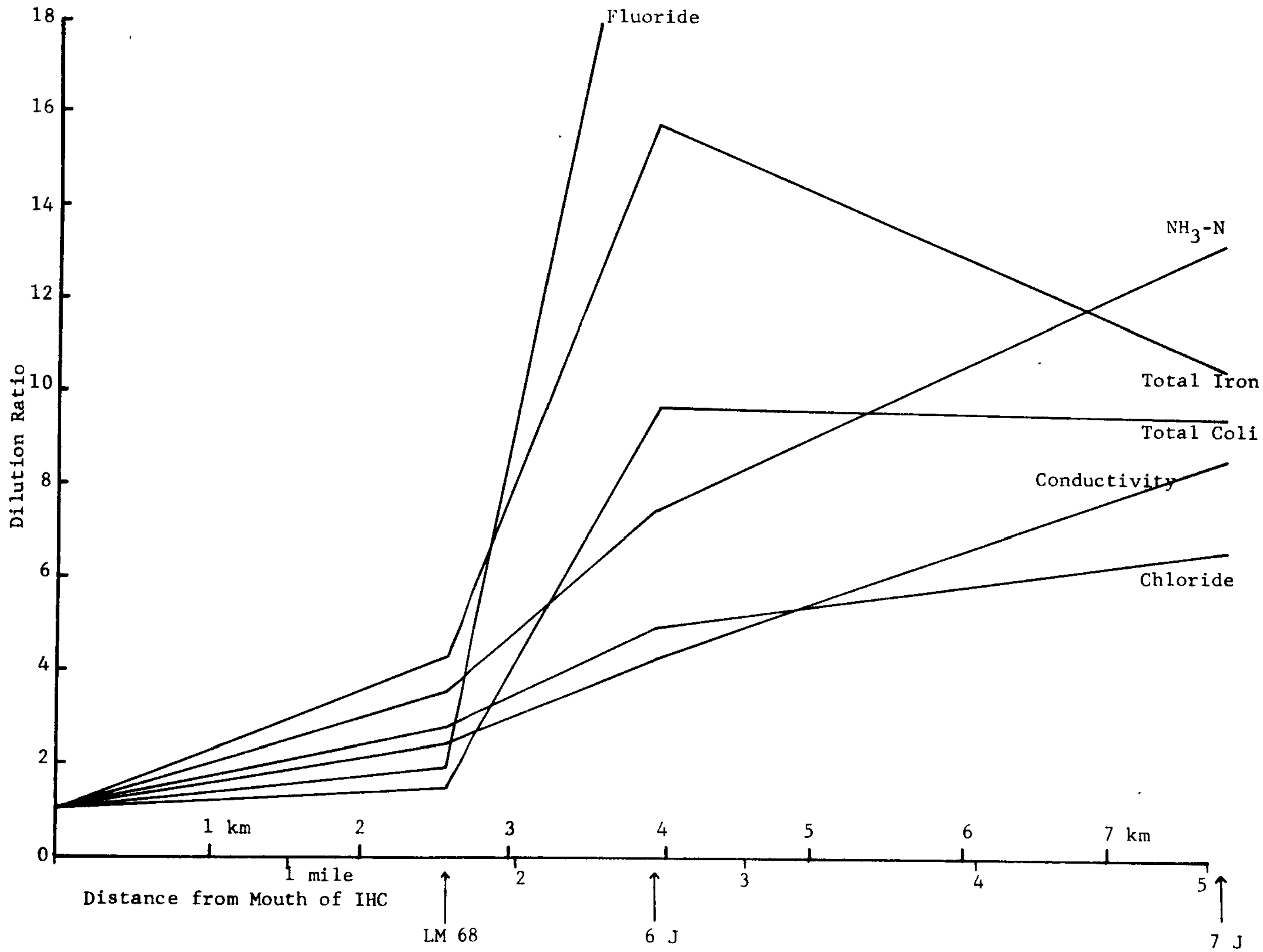

Figure 12.7

DILUTION OF IHC EFFLUENT AT LAKE MICHIGAN STATIONS
BASED ON WATER QUALITY MEASUREMENTS BY IITRI
December 7, 1973

the Lake. On the other dates it was flowing around the Inland Steel landfill. The dilutions appear to exhibit several of the mechanisms discussed in preceding sections. There is an initial spreading in width of the plume over colder Lake water. This is followed by turbulent mixing of the surface plume with the underlying water, resulting in an initial dilution between the mouth of the IHC and Station LM068, 2400 meters out along the Inland landfill. Hydrolab measurements (Table 11.2) taken at Station LM068 indicate substantial vertical mixing at this point, although gentle gradients with depth persist for several miles beyond this point. The dilution at LM068 was 2.5 on November 14 and December 7; and was 6 on November 19.

On November 19 there was little further dilution as the plume flowed around the Inland landfill to Stations 6J and 7J. This is probably due to the fact that as the plume hugs the landfill there can be no lateral mixing in the landfill side. Lateral eddy mixing is normally slow, and when this mixing is limited to the outside edge it should not affect the center of the plume for some distance. On December 7 a similar effect occurs between Stations 6J and 7J, but a sharp increase in mixing occurs betwen Stations LM068 and 6J. On this day, the Hydrolab measurements (Table 11.2) show that the plume was not vertically mixed at Station LM068, but vertical mixing continued until Station 6J.

The dilutions for November 14 (Figure 12.5) show some similarities and some differences. There is a relatively horizontal portion of the dilution curve between Stations LM068 and LM080; during part of this distance one side of the plume was partly protected from lateral mixing by contact with the Inland landfill. Except for this partial break in slope, the mixing continues almost linear with distance. Extrapolating to greater distances one would expect these dilutions curves to become flatter as the width of the plume increases, since this is the usual behavior of plumes.

In general, the behavior of the dilution curves fits the other observations and the mechanisms that are postulated to determine its behavior.

13. AMMONIA-NITROGEN

Our own studies, together with extensive data from other agencies, indicate that violations of ammonia-nitrogen (NH_3-N) standards occur regularly in Lake Michigan as a result of effluents from the IHC, and that reduction of NH_3-N levels in the IHC will be needed to correct this condition. In the following, we review the available data and recommend that NH_3-N loadings from the IHC be reduced by a factor of 7.7.

This will substantially improve water quality in the "inner harbor." Further study is needed to determine whether reductions of IHC loads or of other sources could allow water quality standards to be met outside of the inner harbor.

13.1 Water Quality Standards

The Indiana Standards (1973) for Lake Michigan are 0.02 mg/ℓ NH_3-N monthly average, and 0.05 single value. The Illinois Standard for Lake Michigan is 0.02 mg/ℓ. The Indiana Standard for the "inner harbor" including the water within a line from the Calumet Harbor breakwater to the Inland Steel Company breakwater is 0.05 monthly average and 0.12 for single value. The Indiana Standard for IHC is 1.5 mg/ℓ.

In the following we show that in order to meet Lake Michigan standards, the effluents must be reduced below the IHC standard.

Ammonia is harmful to Lake waters because of its toxicity to fish, its consumption of chlorine in water treatment plants, and its nutritive effects promoting eutrophication of the near-shore waters. The last two effects are described by Vaughn and Reed (1972) and by Thomas, Hartwell and Miller (1972). The National Academy of Sciences (1974) reviewed measurements showing toxic effects in various fish including trout and perch at un-ionized ammonia concentrations of 0.27 mg/ℓ, and at 0.006 mg/ℓ with Chinook salmon fingerlings. Because the pH of Lake Michigan water is relatively high, ranging from 8.0 to 8.7, the fraction of ammonia that is un-ionized is high, reaching as much as 25%.

Twenty-five percent of 0.025 is 0.006; therefore, an NH_3-N concentration of 0.025 can result in 0.006 mg/ℓ un-ionized ammonia. Thus, the toxicity data provide some support for the existing standards, although the problem of toxicity to fingerlings is avoided by growing salmon in hatcheries.

13.2 Background NH_3-N Concentrations

Even if the NH_3-N were completely eliminated from large sources such as the IHC, there would still be some NH_3-N in the nearby Lake, due to background levels in the Lake. In this section, we review available data on background levels.

We define background as a concentration that exists in the main body of the Lake, uninfluenced by fluctuations due to local effluents. Background levels can be reached in near-shore waters, on occasions when these waters are flushed by movements of water from the main body of the Lake. Therefore, background levels can be determined from measurements at places in the Lake far from polluted areas, or in near-shore areas on occasions when they appear to be flushed by water from the main body of the Lake.

Few values of NH_3-N have been reported at places in the Lake far from populated areas. Schelske and Roth (1973) reported 16 measurements in the summer of 1970 near Charlevoix in the north-east corner of the Lake. Readings were taken at six stations and four depths. The average was 0.018 ± 0.006 mg/ℓ. Variation with depth was slight. These values are similar to the lowest non-zero values reported by the Chicago Water Dept. at the 68th St. water intake. The lowest value measured by IITRI in Nov-Dec 1973, Table 11.2, was 0.02 mg/ℓ. These readings were found at stations that were in clear water, that apparently was not polluted by local sources, such as station LM102 on Nov. 19, 1973 (Table 11.2).

It is difficult to decide what is the true background concentration of NH_3-N because there is a large variation in reported measurements, both at near-shore locations and in deep water locations. Fluctuations in near-shore data (Illinois EPA 1972) may be due to currents carrying polluted waters from sources along the shore. If we assume that the lowest values reflect incursions of relatively pure open-Lake water, as our visual observations (Chapter 11) tend to suggest, then these low values should reflect the background. On this basis, the lowest measurements in the Calumet area would indicate a background of 0.02 mg/ℓ.

On the other hand, the deep-water measurements (FWPCA, Physical and Chemical Water Quality 1968) also show fluctuations. Values range from below the detection limit of 0.02 to 0.50, while the average of 429 samples was 0.06. Values of 0.50 seem too high to represent the background, and may be influenced by local sources of pollution, but this cannot be determined retrospectively. Therefore some doubt exists as to the true background, but the author favors a value of 0.02 mg/ℓ.

13.3 Water Quality Data

The most extensive data are those obtained by the Chicago Water Department. Not only has the Chicago Water Department measured the quality of water at its own intake cribs, but since about 1950 it has measured the water quality at Hammond and several other municipal intakes in Indiana, and they have also sent a boat to take Lake water samples for analysis. The samples were taken weekly and the Lake survey samples were taken about 6 to 8 times during each year.

Results of the South Shore Lake survey are plotted in Figure 13.1. Station 5S, located one mile off the mouth of IHC, shows high values of NH_3-N. In order to meet the open-Lake standards at 5S, a reduction of ten-fold in both average and individual values would be needed from 1971-72 levels, or five-fold from 1973 levels. Values at other stations that are not usually in the plume are also in violation and would require reductions of two- to three-fold.

The following additional data will show that IHC is the main source of NH_3-N, and that the situation is at least as bad as the above figures show. Table 13.1 presents results of a sampling program conducted by IITRI for the U.S. EPA in November and December 1973. Figure 11.2 (Chapter 11) is a map showing the location of sampling stations. They are all Lake Stations, except for IHC-3S (IHC at Columbus Drive) and CAL06 (mouth of IHC). Our observations of the plume of pollutants from IHC were described in Chapter 11. These observations clearly showed that

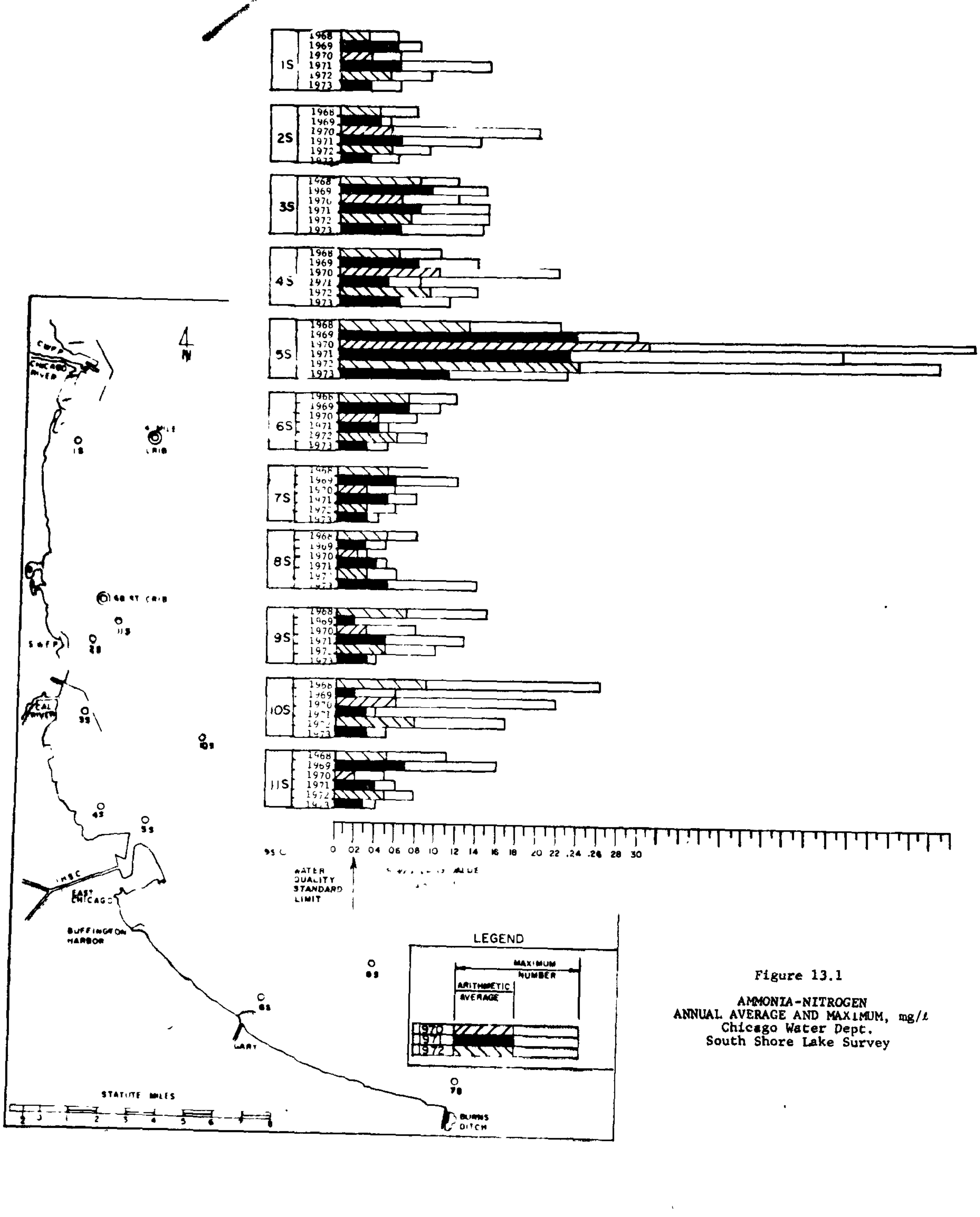

Figure 13.1

AMMONIA-NITROGEN
ANNUAL AVERAGE AND MAXIMUM, mg/ℓ
Chicago Water Dept.
South Shore Lake Survey

Table 13.1

AMMONIA-NITROGEN IN LAKE MICHIGAN
IITRI measurements
mg/ℓ

	CAL17		CAL16		CAL15		LM047		CAL14		IHC	CAL06	CAL11	CAL13	LM68	LM70	LM80	LM102	4J	5J	6J	7J
	Boat	Crib	Boat	Crib	B	C	B	C	B	C	3S	B	B	B	B	B	B	B	B	B	B	B
November 14, 1973	0.03	0.07	0.05	0.02	0.05	0.04	2.03	0.03	-	0.05	4.5	2.7	0.35	0.05	0.50	0.11	0.50	0.27	0.03	0.18	-	0.11
November 19, 1973	0.02	0.03	0.05	0.07	0.21	0.22	0.04	0.11		0.02	5.7	2.8	0.09	0.04	0.36	0.08	0.05	0.02	0.03	0.04	0.21	0.06
December 7, 1973	0.13	0.06	0.14	0.07	0.17		0.16	0.09	0.11	0.05	6.3	1.5	0.36	0.31	0.47	0.10	0.02	0.03	0.90	0.02	0.22	0.13

on November 14, an off-shore wind was moving the plume out from CAL06, past stations LM68, to LM70 and LM80, and finally to LM102 (four miles out in Lake Michigan). The concentration at LM80 was 0.50 and at LM102 it was 0.27. These values are ten and five times higher than the single value standards. Other parameters measured at these stations (coliform bacteria, total iron, chloride, conductivity, pH, fluoride, and temperature) gave a signature of tracers to definitely identify the plume as coming from IHC.

Measurements of NH_3-N in the same area of the Lake were conducted by Industrial Biotest Inc. (1973) on the same day as these IITRI measurements, November 14. The agreement of their data with IITRI data in Table 13.1 is excellent.

On the other two dates (November 19 and December 7) the plume was observed to flow around the Inland Steel Company landfill breakwater and to mix with the waters south of this landfill, in the region where the water intake for the city of East Chicago, Indiana, is located. The flow on these dates was similar to that shown in Figure 13.2, which is a photo taken by Skylab in September 1973. The Skylab photo clearly shows the iron-colored plume. In Table 13.1 the pollutants can be traced from station CAL06 (mouth of IHC) to LM68 to 6J to 7J and CAL15 (East Chicago intake) and even to CAL14 (Gary water intake). These values are five times greater than the standards for individual Lake values for NH_3-N.

The Chicago Water Department has also made measurements in the Lake at some of the stations used by IITRI. Figure 6.3 in Chapter 6 is a map of stations in their SWFP Radial Survey. Figures 13.3 to 13.5 show measurements at these stations during 1970 to 1972. High values are often observed at station 6J, as would be expected when the plume is flowing around the Inland landfill as in Figure 13.2. These 1970-1972 levels are ten times higher than single-value standards.

Figure 13.2

SKYLAB PHOTO SHOWING PLUMES FROM IHC AND CALUMET RIVER
September 13, 1973

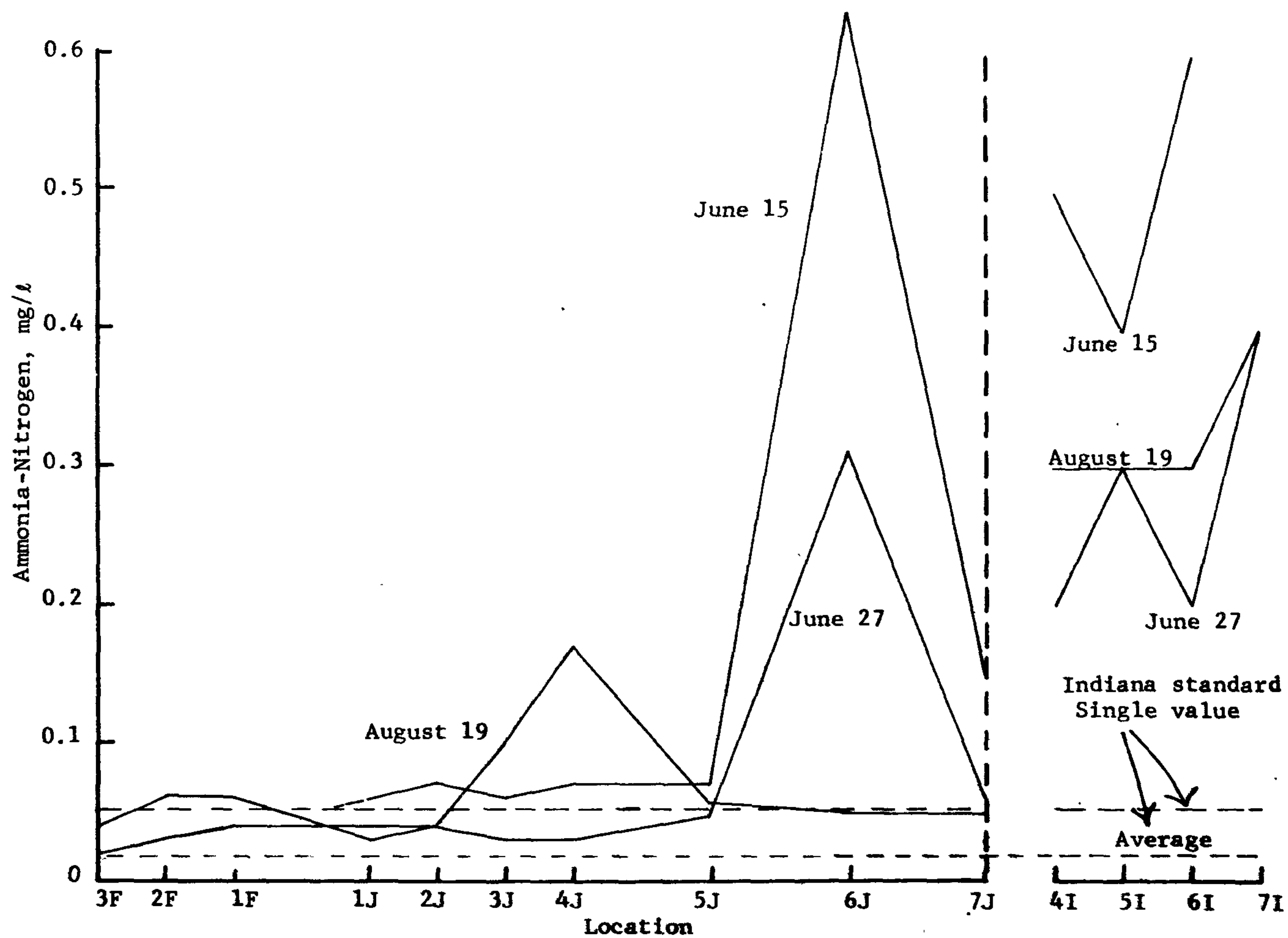

Figure 13.3

RADIAL SURVEY OF AMMONIA NITROGEN CONCENTRATION - 1971
Chicago South Water Filtration Plant

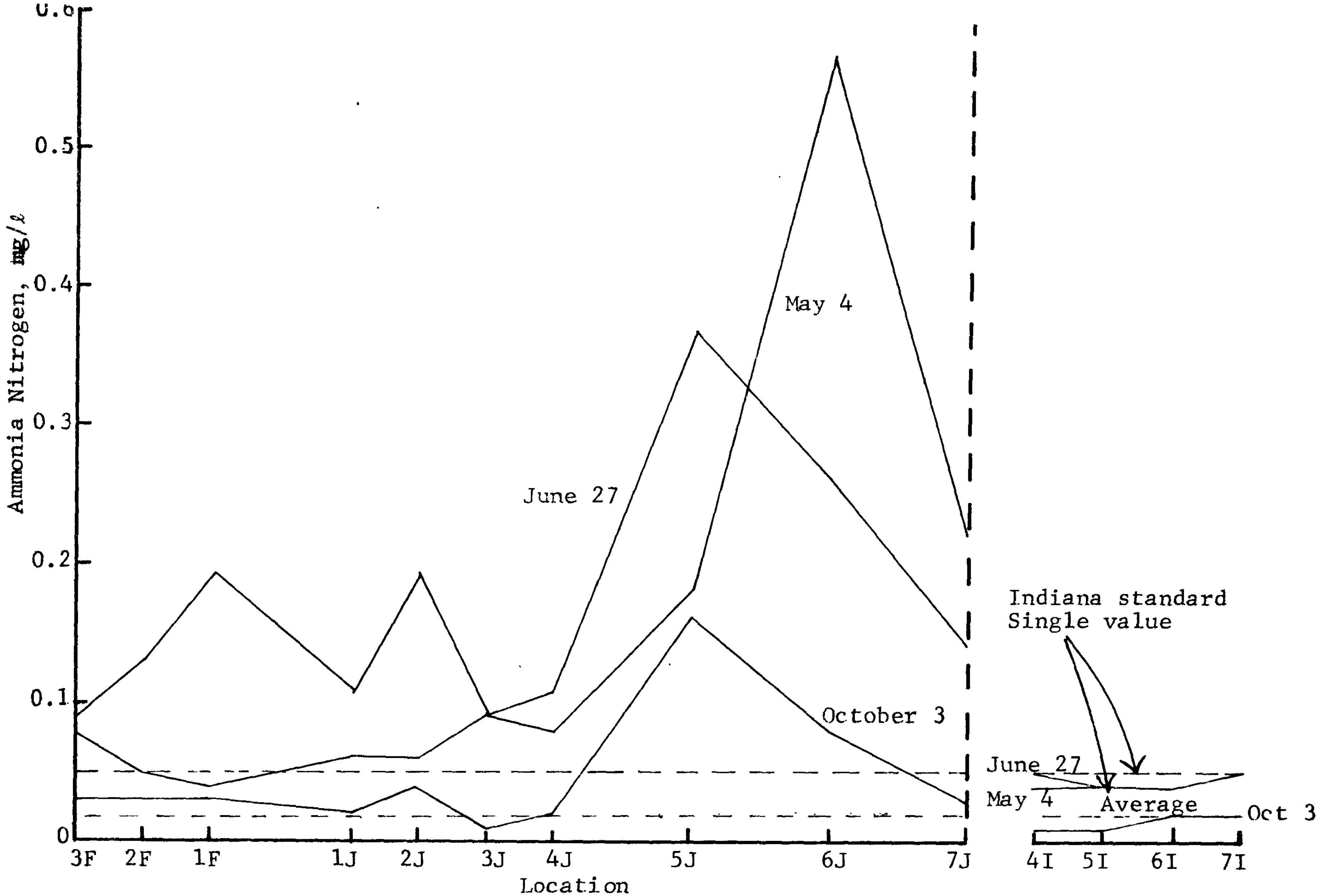

Figure 13.4

RADIAL SURVEY OF AMMONIA NITROGEN CONCENTRATION - 1972
Chicago South Water Filtration Plant

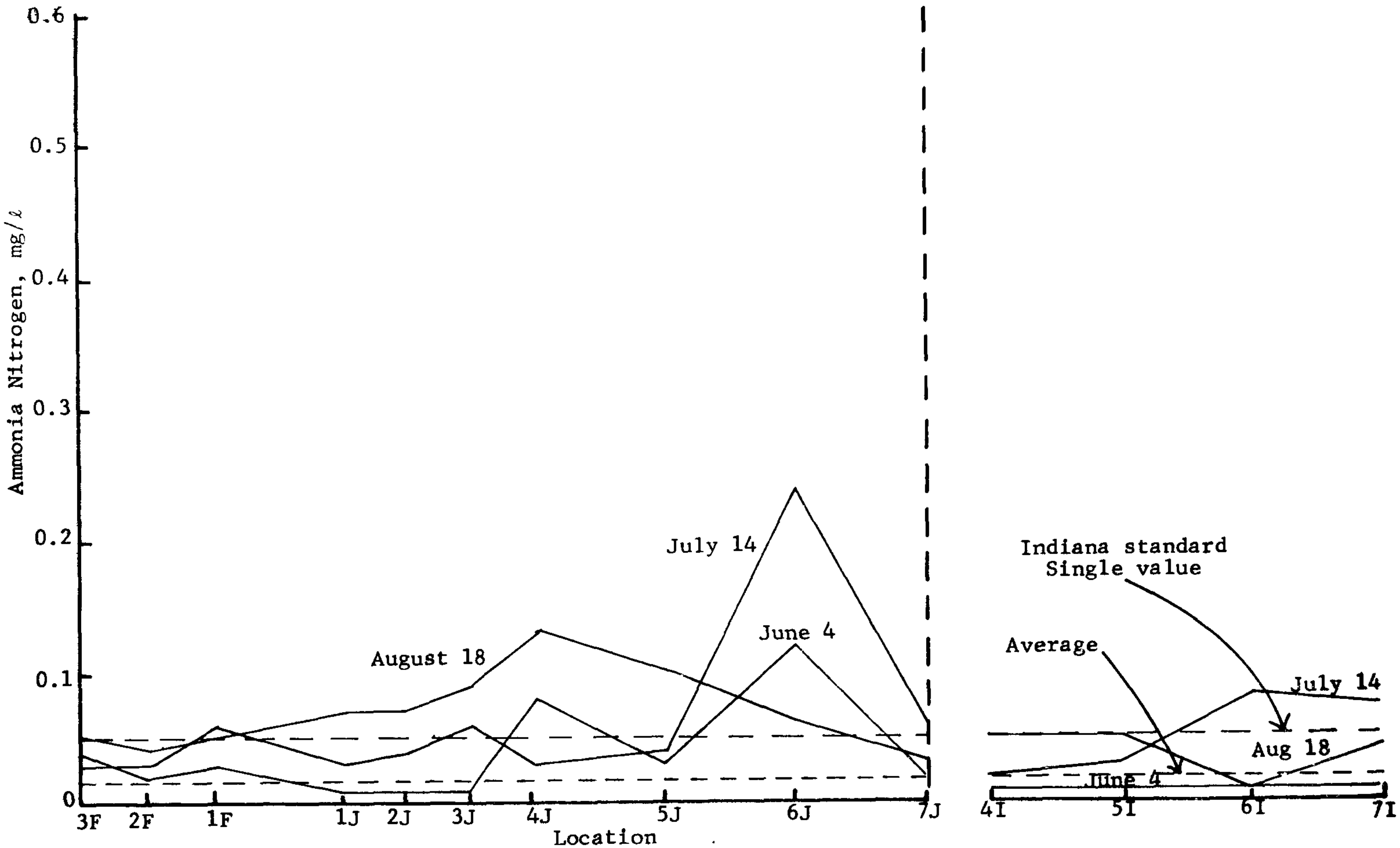

Figure 13.5

RADIAL SURVEY OF AMMONIA NITROGEN CONCENTRATION - 1970
Chicago South Water Filtration Plant

The Chicago Water Department has also recorded the highest value of NH_3-N at the 68th St. water intake each year since 1950. Peaks of 0.60 were observed in the late 1950's, but since 1970 the peaks have reached only 0.20. Earlier peaks may have been due in part to effluents from U.S. Steel South Works, which is close to the 68th St. intake. Improvements at the South Works have lowered NH_3-N effluents so that this is no longer a significant source in comparison with the IHC (see effluent loads, Tables 4.3 and 4.5).

13.4 Behavior of IHC Plume

The dilutions that we measured from the IHC mouth to stations 6J, 7J, and CAL15 appear to be typical ones, based on our current meter data. Current meters were installed for us by Argonne National Laboratory in the Lake one mile off Inland Steel landfill and also adjacent to the 68th St. Chicago water intake crib, at depths of 19 and 17 ft, respectively. On November 19, the current at Inland landfill averaged 9 cm/sec in the direction E/SE, and on December 7 it was 10 cm/sec in the same direction. A plot of measured currents (Figure 11.14) shows that this speed is about average for the whole period of measurement, November 8 to December 8. The current flowed in this same direction for 13 out of the 30 days measured. According to our understanding of the dispersion mechanism of the plume, the dispersion depends mainly on the magnitude of Lake currents in the area, and so these dilution results on these two days are expected to be typical of those to be found during the whole period. The only other factor of importance is the buoyancy of the plume from the IHC as a result of industrial heating of the IHC water. Storet records show that the IHC is normally about 5°C warmer than Lake water. On the days of our sampling, it varied from 3.5 to 5.9°C warmer, and we therefore expect that the behavior of the plume was normal with regard to its thermal buoyancy behavior. We can conclude that the measured open-Lake NH_3-N values quoted above are typical ones, and correspond to typical plume spreading behavior.

13.5 IHC As an Ammonia Source

We will now show that the IHC is actually the source of the NH_3-N peaks measured in the Lake studies quoted above. This can be seen by examining the loadings in the IHC, and checking these by means of measured concentrations and flows in the IHC.

IITRI measurements of flow and concentration of NH_3-N at CAL06 (mouth of IHC) indicated loadings totaling 45,900, 54,200, and 34,200 lb/day for the three sampling days (November 14, 19, and December 7). The agreement is reasonable with loadings determined from permit and effluent data (Combinatorics 1974) shown in Table 4.5. These quantities can certainly account for the quantities measured in the Lake near the mouth of the IHC.

A summary of data obtained by the State of Indiana in early November 1973, and summer 1973 are given in Table 13.2. Other measurements of NH_3-N in the IHC are those of the U.S. EPA, presented in the bottom three lines of Table 13.3. These values are in reasonable agreement.

The most extensive data, however, are from the Chicago Water Department at Dickey Rd, presented in Figure 13.6. This figure indicates a significant increase from 1969 to the present. The values in Figure 13.6 are likely to be most representative, because they average one sample every week in the year, whereas the EPA and Indiana data were taken only for brief periods in recent years.

The dramatic increase in NH_3-N at Dickey Rd can be explained by diversion of Inland Steel and Youngstown Sheet and Tube effluents from the IHC to the East Chicago STP. Dickey Rd is upstream of Inland Steel and most of the Youngstown outfalls, but downstream of the STP. This diversion also explains the very high NH_3-N loading from East Chicago shown in Table 13.4, far in excess of the population equivalent of that city.

Table 13.5 gives a detailed list of the effluents of NH_3-N from each outfall on the IHC. The data are from permit applications

Table 13.2

IN-STREAM WATER QUALITY, 1973
Combinatorics (1974)

Description	NH_3		
Water quality standard	1.5 mg/ℓ		
Monitoring stations	72 Average	73 Average	72-73 Maximum
GCR 41 Grand Calumet River Gary (U.S. 12)	1.9	1.8	5.6
GCR 37 Grand Calumet River East Chicago (Kennedy Rd.)	2.3	2.35	5.70
GCR 36 Grand Calumet River East Chicago (Indy. Blvd.)	-	44.8	86
GCR 34 Grand Calumet River Hammond (U.S. 12)	-	15.0	36.0
IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.)	5.1	4.1	9.0
IHC 3S Indiana Harbor Canal East Chicago (Columbus Drive)	3.4	3.14	8.5
IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.)	4.7	3.3	8.5
IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel)	-	2.3	4.2

Table 13.3

AMMONIA-NITROGEN, mg/ℓ

Averages
Storet Data, U.S. EPA

Station		1971	1972	1973	1965-1971
		Year			
CAL17	Chicago SWFP	0.048			0.05
CAL16	Hammond WFP	0.115			0.12
CAL15	East Chicago WFP	0.122			0.12
CAL14	Gary WFP				0.06
CAL13	Calumet Harbor	0.192			0.19
CAL06	IHC Mouth	1.69	5.19	2.0	1.7
CAL02	IHC 151 St.	3.3	3.25	4.1	3.3
CAL03	IHC Dickey Rd.	4.7	2.9	4.7	3.6

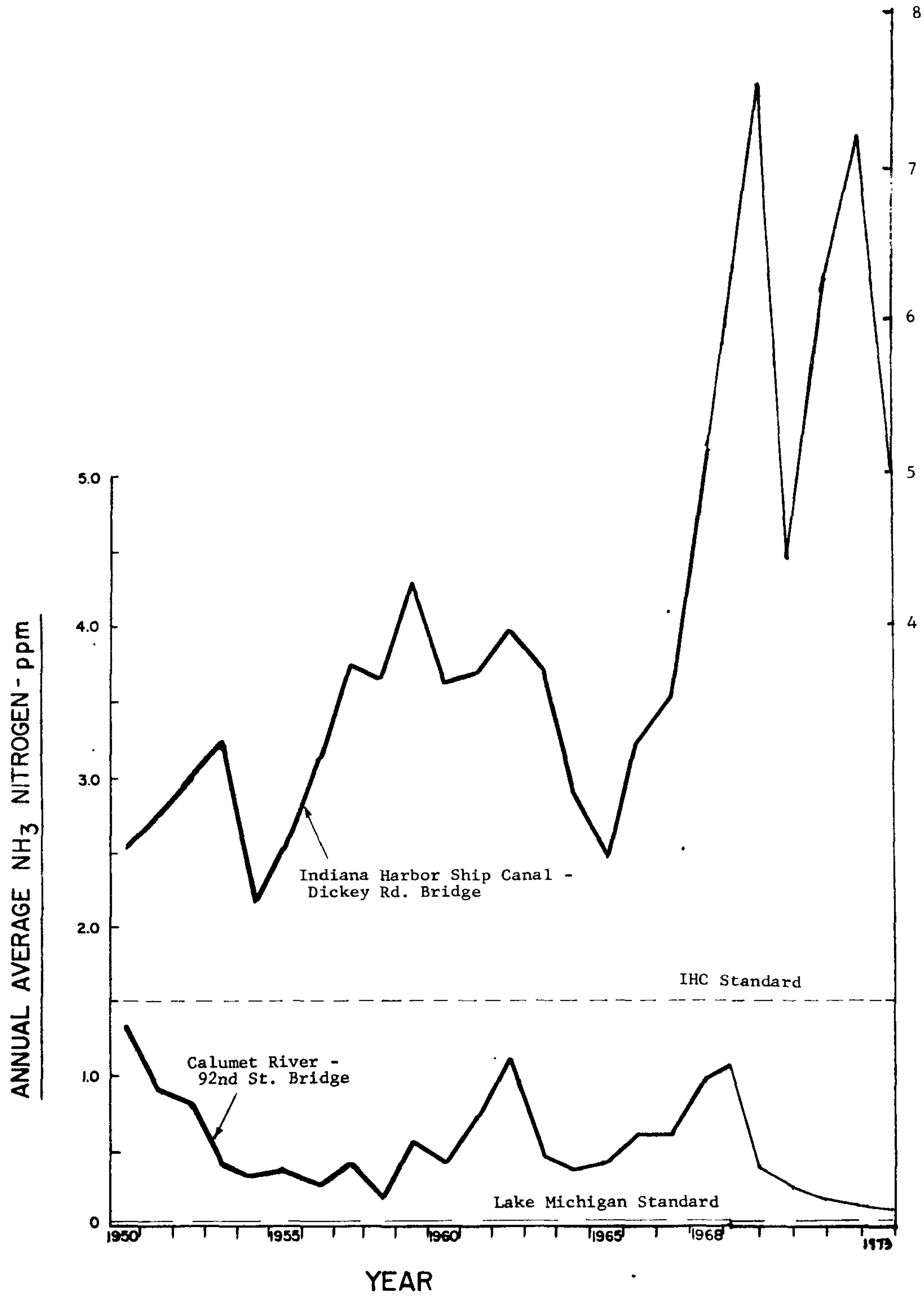

Figure 13.6

ANNUAL AVERAGE AMMONIA NITROGEN
WEEKLY SANITARY SURVEYS
Chicago Water Department

Table 13.4

SUMMARY OF EXISTING AMMONIA EFFLUENT LOADS TO IHC
Source: Combinatorics (1974)

Discharger		NH_3-N, lb/day Existing average
U.S. Steel Corp.		5,056.80
Gary		4,080.00
E. I. duPont de Nemours		1,243.87
U.S.S. Lead		0.30
East Chicago		10,700.00
Hammond		2,480.00
Union Carbide		41.00
ARCO		601.00
American Steel Foundry		0.08
Youngstown		4,535.40
Inland		4,573.51
	Total	33,309.00

Table 13.5

INVENTORY OF NH_3-N DISCHARGES TO IHC
Source: Combinatorics (1974)

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	NH_3 Avg. Load (lb/day)	Max. Load (lb/day)	Water Quality Standard 1.5 mg/l Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
U. S. Steel								
GW-1	19.9	28.9	40.7	482.0		2.0		
GW-2	10.9	16.4	23.0	274.0		2.0		
GW-2A	1.4	2.2	3.9	86.0		4.7		
GW-3	2.7	3.8	4.5	38.0		1.2		
GW-3A	0.4	1.7	3.7	68.0		4.8		
GW-4	0.5	0.7	0.9	0.5	1.5	0.1	0.2	
GW-5	82.4	87.7	95.3	3510.0		4.8		
GW-6	23.4	29.5	39.4	49.0	131.3	0.2	0.4	
GW-7	5.8	10.6	16.9	17.6	56.4	0.2	0.4	
GW-7A	93.3	120.1	146.0	201.0	486.0	0.2	0.4	
GW-9	24.7	34.7	39.7	57.6	132.1	0.2	0.4	
GW-10A	26.3	34.6	47.2	57.5	157.0	0.2	0.4	
GW-11A	81.3	94.7	115.6	158.0	385.0	0.2	0.4	
GW-13	1.8	2.9	4.8	4.8	16.0	0.2	0.4	
ST-14	0.8	1.8	3.3	3.0	11.0	0.2	0.4	
ST-17	20.1	30.0	39.3	49.8	131.0	0.2	0.4	
GSTP	44.0	52.7	62.0	4080.0		9.3		
E.I. duPont								
001	0.5	1.8	2.4	1240.0	1860.0	90.0	610.0	
002-004	7.24	10.31	11.66	-	-	-	-	
005	0.07	0.08	0.12	.13	.40	0.2	0.4	
006-010	0.89	2.24	2.98	3.74	9.96	0.2	0.4	
U.S.S. Lead		0.36		-	-	-	-	
HSTP	35.0	40.7	44.0	2480.0		7.3		
ECSTP	10.0	14.0	20.0	10,700	29,700	92.0	178.0	35% of the avg. load
Union Carbide	0.05	0.07	0.11	0.41	1.1	0.7	1.2	
ARCO		5.04	6.77	601.0	1,640	14.3	28.6	
Amer. St. Foundries	0.09	0.15	0.27	.08	.20	0.07	0.09	

Table 13.5 (cont.)

NH_3 Water Quality Standard 1.5 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
Youngstown								
001 YS-20	8.46	13.70	23.60	114.0	295.0	1.0	1.5	
002 YS-2	1.50	3.62	7.50	30.2	45.3	1.0	1.5	
003 YS-4	0.53	0.98	1.40	8.2	12.3	1.0	1.5	
004 YS-8	1.03	1.40	1.75	12.0	17.5	1.0	1.5	
005 YS-11	1.19	1.60	3.00	40.0	66.7	2.0	3.0	
006 YS-12	3.30	5.70	8.40	536.0	900.0	11.7	13.0	
007 YS-13	6.30	14.00	18.90	234.0	6,197.0	2.0	53.0	
008 YS-22	3.00	5.00	11.70	166.0	2,000.0	4.0	35.0	
009 YS-14	34.00	48.70	60.00	406.0	750.0	1.0	1.5	
010 YS-15	36.60	58.00	67.00	969.0	1,680.0	2.0	3.0	
011 YS-18A	107.80	121.60	138.70	2,020.0	3,460.0	2.0	3.0	
Inland								
001 IE-2		.14	.29	.23	.97	.2	.4	
002 4E-1		190.00	228.00	1,000.0	12,050.0	.63	6.44	
003 5E-1		7.20	8.60	12.0	28.6	.2	.4	
004 5E-2	8.60	0.86	1.04	1.4	3.5	.23	.4	
005 5E-3		8.60	10.40	108.0	172.0	1.5	2.0	
006 6E-1		0.65	1.30	1.1	4.3	.2	.4	
007 7E-1		21.60	25.90	35.9	86.4	.2	.4	
008 10E-1	Unknown & Highly Variable							
011 13G-1	126.96	158.70	190.44	238.0	333.44	.18	.21	
012 13H-1	67.68	50.80	70.00	1,450.0	8,000.0	3.42	13.70	
013 14H-TT	85.52	106.90	128.28	641.9	3,263.0	.72	3.05	
014 15H-TT	85.52	106.90	128.28	651.73	2,785.1	.73	2.59	
015 16H-1	17.28	21.60	25.92	23.42	43.23	.13	.20	
016 16H-2	7.20	9.00	10.80	18.26	27.02	.23	.30	
017 16H-3	115.28	144.10	172.92	204.30	288.43	.17	.20	
018 16F-1	119.76	149.70	179.64	187.27	599.22	.15	.40	

and industry monthly operating reports to Indiana, and were compiled by Combinatorics (1974).

13.6 Other Ammonia Sources

Table 4.2 in Chapter 4 lists the sources in the Calumet area other than those entering the Lake via the IHC. A significant source in the Calumet area is Amoco Chemicals, 1300 lb/day net. Amoco Chemicals is close enough to influence the Lake values quoted above, but it is small compared to the effluents from IHC. Also in the Whiting area are two combined sewer outfalls discussed in Chapters 5 and 16. These outfalls and the Amoco outfall could be responsible for some of the high NH_3-N values at the Whiting and Hammond water intakes, but their total loads are too small to compare with the impact of IHC effluents on the Calumet area. Prior to 1973 the U.S. Steel South Works was a significant local source, as may be seen from Figure 13.6 but at present the load from this source is not significant.

Although the IHC is responsible for the peaks of NH_3-N measured in the Calumet area of Lake Michigan, high NH_3-N concentrations are regularly measured in all of the near-shore waters of the southern basin. Winters (1974) points out that stations sampled by Indiana show high NH_3-N values that cannot be attributed to the IHC plume. For example, at Michigan City, Indiana, less than one-third of the samples have values less than 0.10 mg/ℓ. (See Figure 6.2 for Indiana sampling locations.) The maximum value at Michigan City is 0.5 and the average is 0.23. Winters (1974) also compares the concentrations and loads of the two tributaries near Michigan City with the IHC as follows:

Tributaries	NH_3-N concentration, mg/ℓ			Load, lb/day
	Minimum	Maximum	Average	
IHC Dickey Rd.	1.8	5.9	3.6	57,709
Burns Ditch Mouth	0.3	0.8	0.48	1,807
Trail Creek	0.2	3.4	1.4	861

In addition, the Illinois data (Illinois EPA 1970, 1971, 1972) also show appreciable NH_3-N concentrations all along the Illinois shore. In 1972, 12 Lake county stations averaged 0.26 mg/ℓ; 19 Cook county stations averaged 0.07 mg/ℓ, and 13 Chicago stations averaged 0.07 mg/ℓ. There are known to be sewage and steel mill effluents to Lake Michigan in Lake County, Illinois. In 1971, the average of all stations was 0.06. The average of 1751 samples of in-shore water measured in 1962-1963 was reported by FWPCA (Physical and Chemical Quality Conditions 1968) to be 0.13 mg/ℓ. We agree with Winters (1974) that the NH_3-N standards for open water are very seldom met, and also with a statement by Moore (1974) to Indiana SPCB that "there are other sources of ammonia-nitrogen from Burns Ditch, Trail Creek, Illinois, Michigan, rainfall, agricultural and urban sources, and algal decomposition. Because Lake Michigan is very cold, maximum of 77°F, nitrification is a very slow process and distant sources must be considered."

On the other hand, Palmer (1974) measured the residence time of pollutants in the waters near a city in Lake Superior to be 40 days. If the residence time of NH_3-N in the Calumet waters is of this magnitude, then the IHC effluents could account for both the total amount and the wide extent of NH_3-N measured in the Lake. Further study is needed to resolve this question. We agree with Moore (1974) that "Additional studies to identify sources of ammonia-nitrogen are necessary as well as the study of Lake currents, quantification of the nitrification rate in the Lake, and identification of ammonia concentrations with variable lake depths." This is similar to the conclusion we reached with regard to phosphorus in Chapter 17.

In conclusion, on the basis of the loads, and on the basis of tracing of the motion of the plume from IHC, we can conclude that IHC is the main local source of NH_3-N, but there are also other sources of unknown magnitude. Reduction of NH_3-N from the IHC is the most important step to be taken, but it may not eliminate NH_3-N standards violations in the open waters of the Calumet area. In the following section we recommend reductions in effluent loads from the IHC. These recommendations are based on standards for the inner harbor rather than the open water, because of the possible effect of other sources on the open water.

13.7 Required Reductions in NH_3-N from IHC

An average value of NH_3-N at the mouth of the IHC for 1973 is about 2.5 (from Section 13.5), and values of 4 are not uncommon. Our measurements in the IHC indicate that dilutions by a factor of 5 are usual by the time the effluent reaches LM068 and 6J; dilutions of 10 are usual at LM102 and CAL15. In accordance with the discussion in the previous section, we will calculate only the reduction in IHC loadings needed to reach water quality standards at the inner harbor locations.

The concentration of NH_3-N at a Lake station is the mean value determined by mixing one part of IHC effluent water with an amount of Lake water containing the background amount of NH_3-N. A mixing equation based on this concept is

$$C_1/R + (D - 1)C_b = D \cdot C_{std} \qquad (13.1)$$

where

C_1 is concentration at mouth of IHC

R is required reduction ratio of effluent loads

D is expected dilution ratio in Lake of IHC water, so that one volume of IHC water mixes with D-1 volumes of Lake water

C_b is background concentration of NH_3-N in Lake

C_{std} is water quality standard concentration in Lake.

We will consider station LM068 to represent IHC plume conditions in the inner harbor (although it is actually just outside the original boundary of the inner harbor). For station LM068 we showed in Chapter 12 that a typical dilution ratio is five-fold (D = 5.). In Section 13.2 we showed that the background C_b = 0.02. This assumes that other nearby sources are also reduced to achieve a Lake-wide background.

If C_1 is 4 mg/ℓ at the mouth of IHC, then Equation 13.1 can be solved for R

$$4/R + (5 - 1)0.02 = 5 \cdot 0.12$$
$$R = 7.7.$$

An even greater reduction is needed to reach the average standard of 0.05, but this does not appear possible since higher values than 0.05 are reported outside the IHC plume. We therefore recommend a reduction of 7.7 in the effluent loads from IHC.

In making this calculation we have been concerned only with the effects of the effluents that can be identified with the IHC plume. If it could be shown that the IHC effluents are responsible for the observed NH_3-N water quality violations over a wider area than we have done, then further reductions in NH_3-N loads could be required.

As indicated in Section 13.5, present NH_3-N loadings to Lake Michigan from the IHC range from 34,000 to 54,000 lb/day. In order to achieve water quality standards in the inner harbor, the recommended reduction of a factor of 7.7 would lower these to 4400 to 7000 lb/day.

13.8 Recommended Implementation of Reductions

The way in which the reductions are achieved is important. Ammonia removal is a difficult task for municipal sewage treatment plants, because the available processes are somewhat uncertain, especially when the wastes contain varying amounts of toxic industrial effluents. It is usually easier and more cost-effective to take out ammonia at the source, where concentrations are greater.

Evidence presented in a current court case (People of the State of Illinois vs. Inland Steel Co.) indicates that peak values of industrial effluents to the East Chicago STP are higher than was indicated in the Combinatorics report (1974); and that these peaks are disrupting the performance of the STP. As a result, NH_3-N effluents from the STP are showing higher peaks of NH_3-N of 130 mg/ℓ, rather than 92 as indicated by Combinatorics (1974).

A recent EPA report (EPA 1974) states that steam stripping is the best practicable method of removing NH_3 from steel wastes. Coke plant operating records (People of the State of Illinois vs. Inland Steel Co. 1974) show the effluent from an ammonia stripper to have low values of 14 mg/ℓ, but these are interspersed by effluents of 1300 mg/ℓ to the STP on single days about a week apart. Furthermore, the effluents are sometimes overloaded with lime. (Lime is used to raise the pH and convert the ammonia ion to NH_3 that can be stripped out.) The uncontrolled lime can upset the activated sludge sewage treatment process. These fluctuating industrial inputs not only provide more NH_3 than the East Chicago STP can handle; they also result in intermittent poor sewage treatment. Furthermore, the high ammonia concentrations in the East Chicago STP effluent prevent effective chlorination at a reasonable chlorine cost. This is the reason bacteria counts in the IHC are so high, representative of a stream with raw sewage.

The municipal sewage treatment plants in the area must be protected from upsets due to dumping of toxic wastes into them from industry. We recommend that the municipalities be required to limit the amount of NH_3, lime, toxic metal, oil and other unmanageable inputs from industry, and that the industries be required to install equipment that will provide back-up protection against upsetting peak emissions. Alternatively, the municipal treatment plants could be expanded to handle peak loads of all pollutants from industry, appropriately charging the industries for this service. A separate study of the economics of this approach would be needed to show that it is feasible and cost-effective. We further recommend that these steps be supplemented by lowered municipal loadings if necessary to achieve the recommended total loading reductions.

The ammonia reductions must be accomplished without releasing the ammonia to the atmosphere. Moore (1974) has expressed this as follows: "A part of the requirement for reduction of ammonia-nitrogen must be control of the contribution from the steel mill coke plant operations. Youngstown and Inland presently discharge to the East Chicago sewer system, and U.S. Steel Corporation discharges a portion to the Gary sewer system and the bulk to be quenched on coke. Only Inland practices any recovery of ammonia. Ammonia emitted to the atmosphere from quenching may eventually fall back to the watershed with rainfall; therefore, this practice is not recommended. All three companies should recover both free and fixed ammonia and discharge the residual to the municipal sewer system for removal in the biological nitrification systems to be installed."

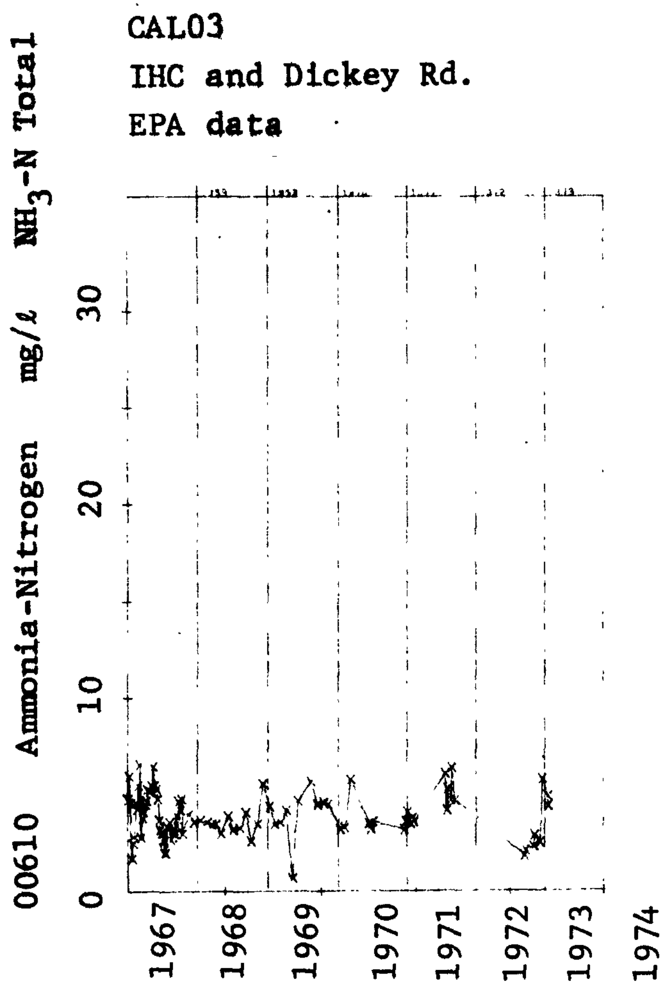

Figure 13.7

STORET WATER QUALITY PLOT

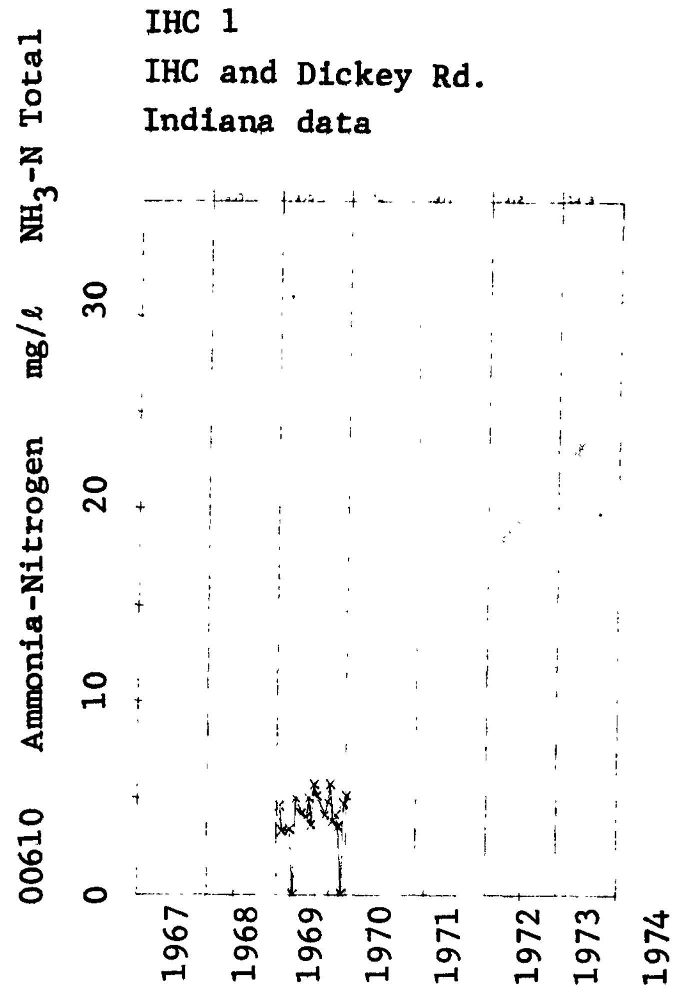

Figure 13.8

STORET WATER QUALITY PLOT

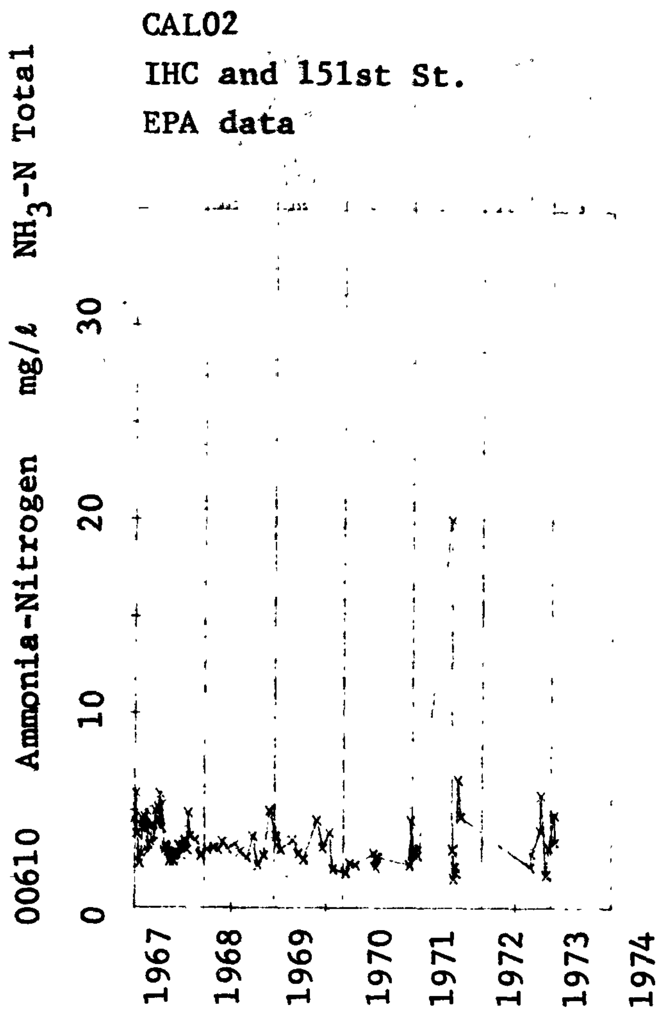

Figure 13.9

STORET WATER QUALITY PLOT

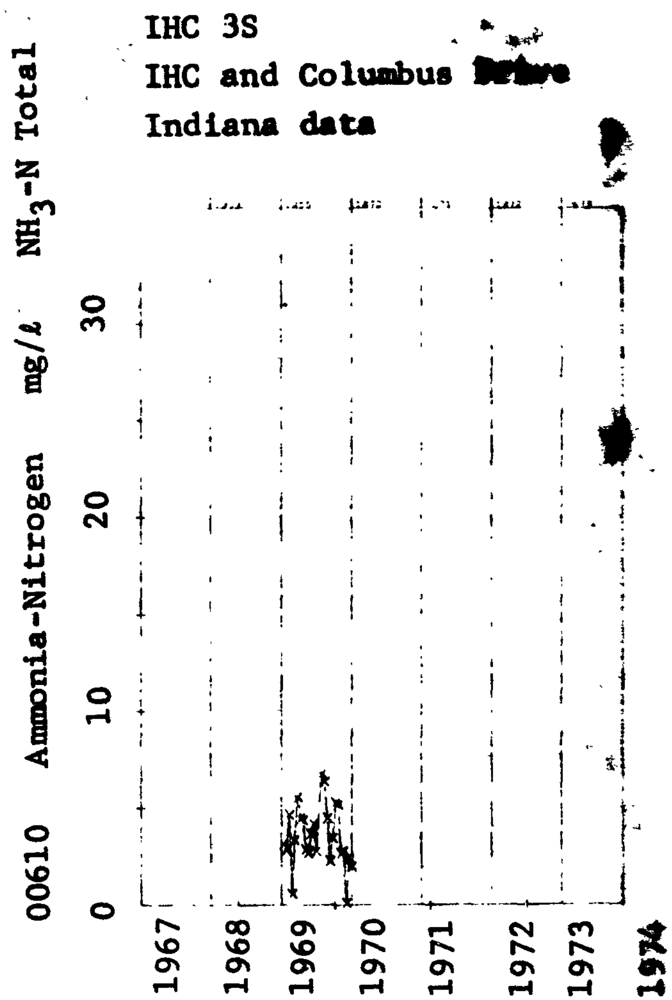

Figure 13.10

STORET WATER QUALITY PLOT

CAL17
Chicago SWFP Intake
EPA data

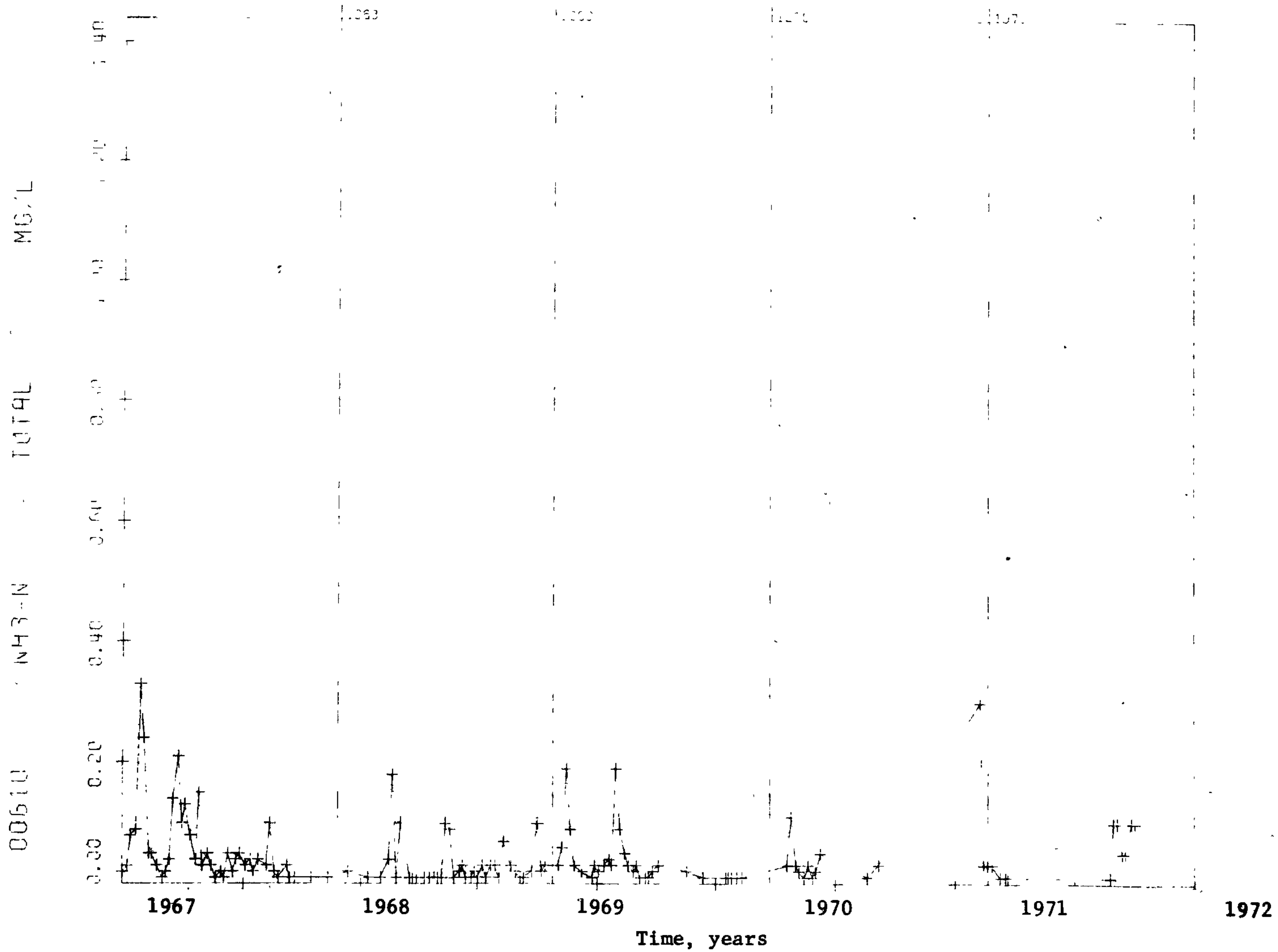

Figure 13.11

STORET WATER QUALITY PLOT

CAL13
Calumet Harbor
EPA data

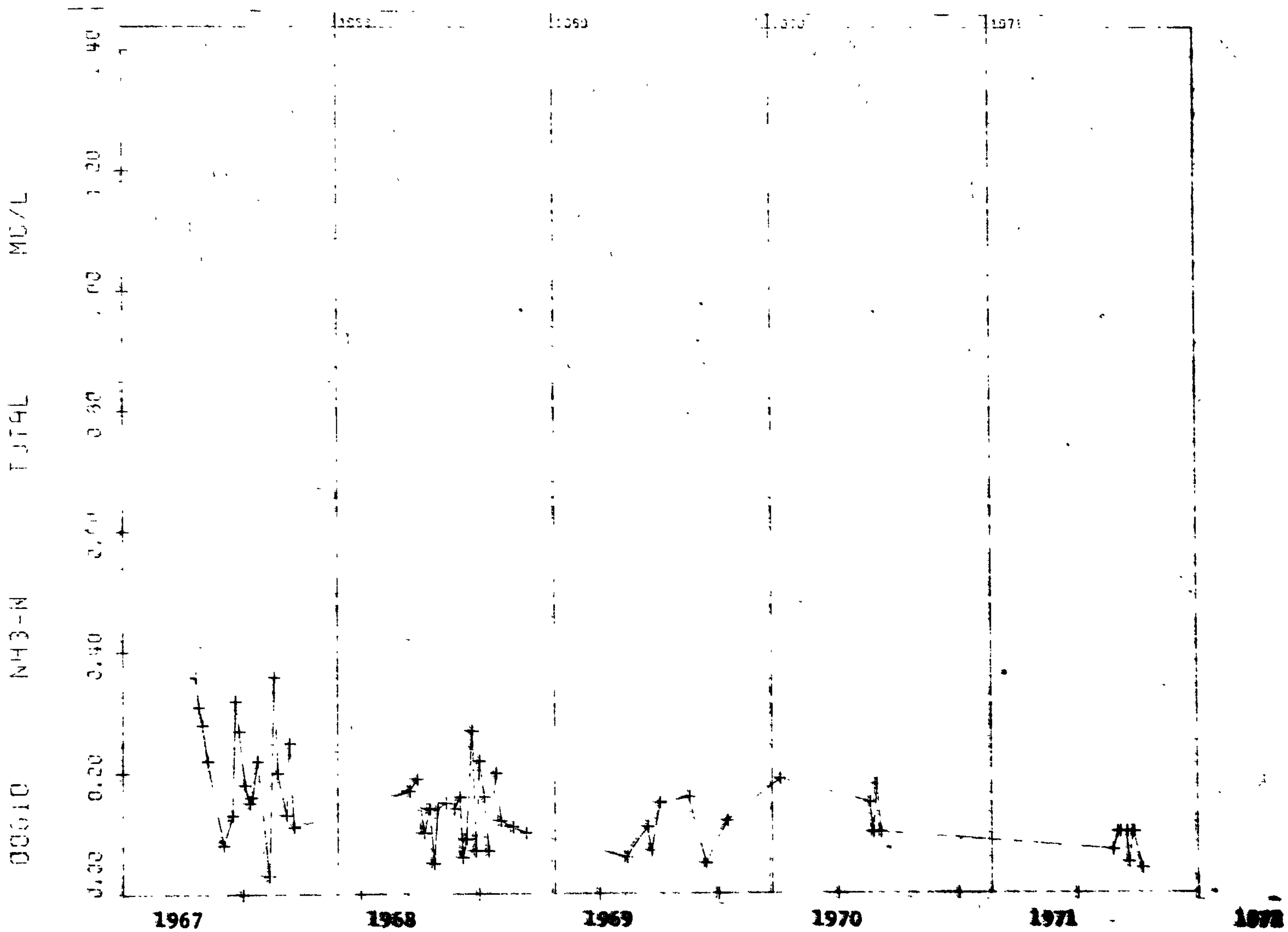

Figure 13.12

STORET WATER QUALITY PLOT

CAL16
Hammond Water Plant Intake
EPA data

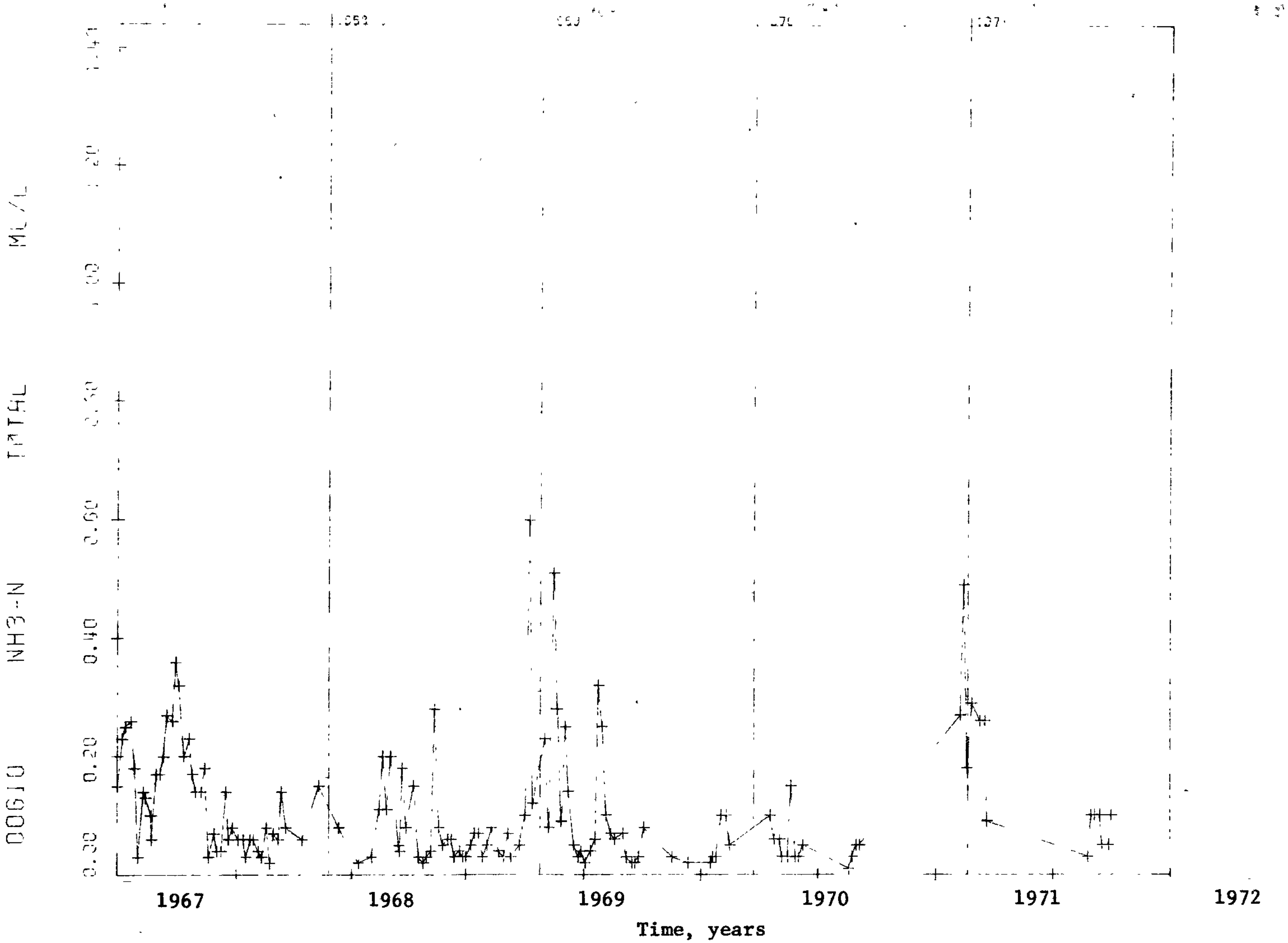

Figure 13.13

STORET WATER QUALITY PLOT

LM W
Whiting Water Plant Intake
Indiana data

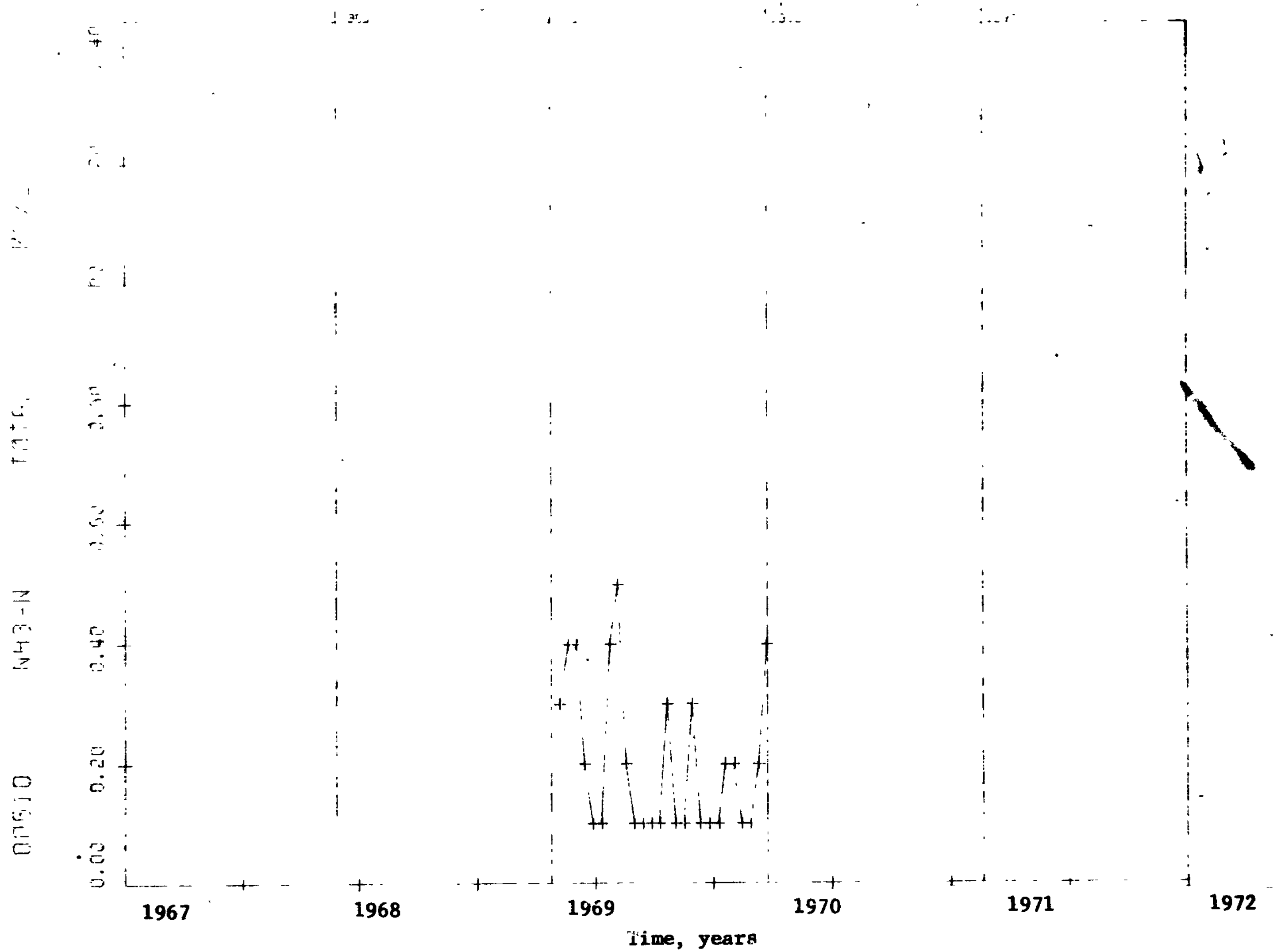

Figure 13.14

STORET WATER QUALITY PLOT

CAL15
East Chicago Water Plant Intake
EPA data

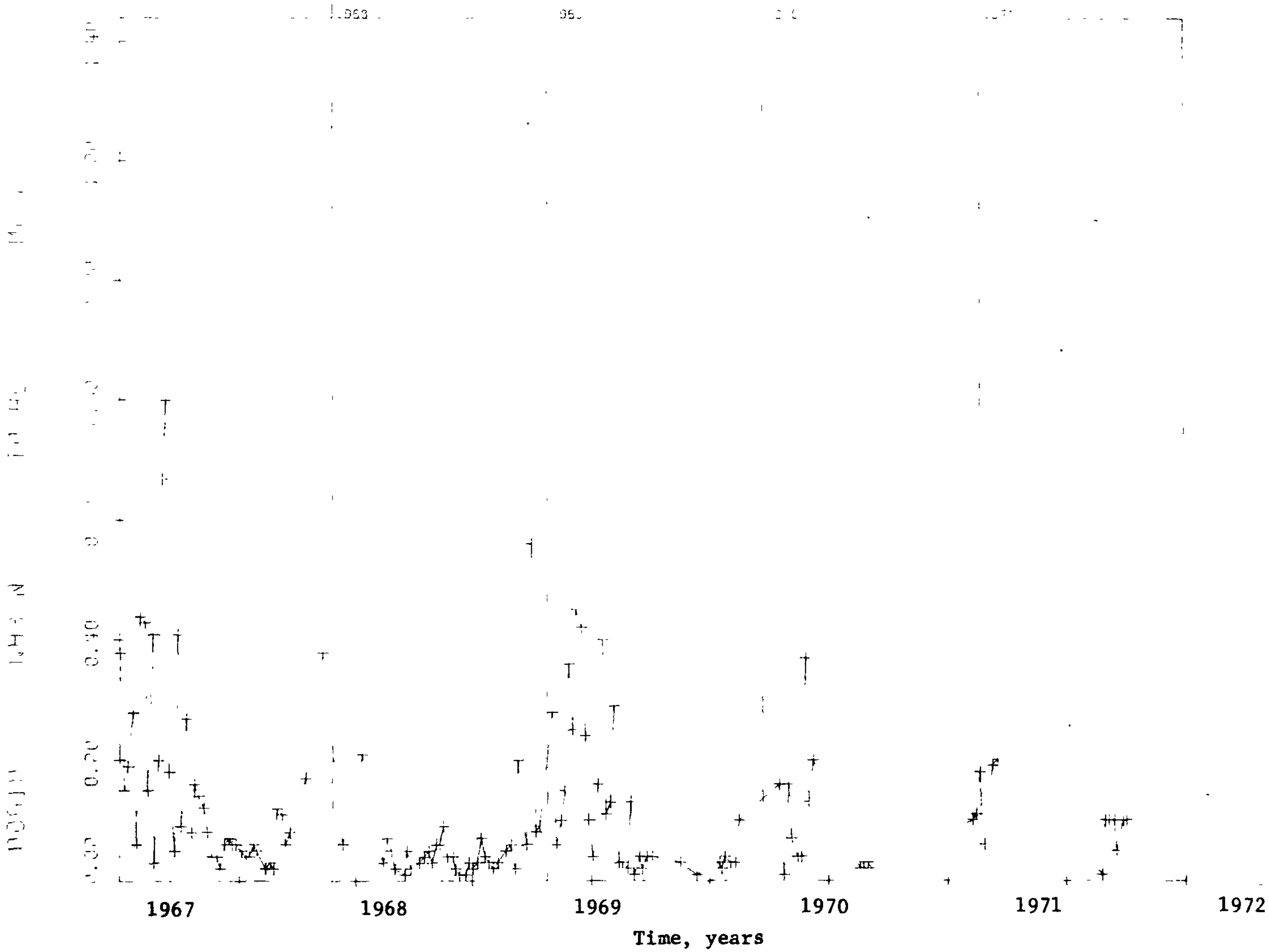

Figure 13.15

STORET WATER QUALITY PLOT

CAL14
Gary Water Plant Intake
EPA data

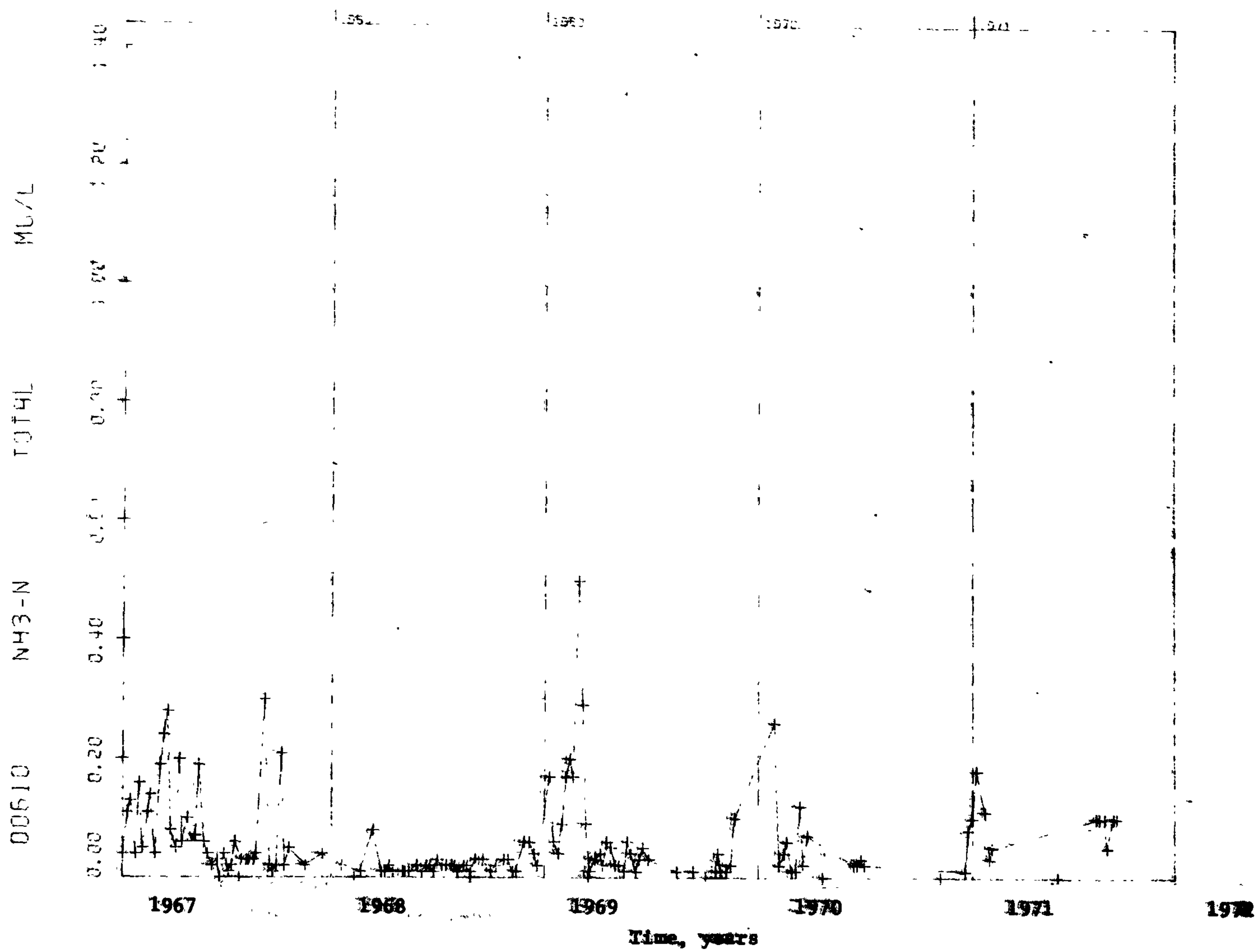

Figure 13.16

STORET WATER QUALITY PLOT

LM G
Gary West Water Plant Intake
Indiana data

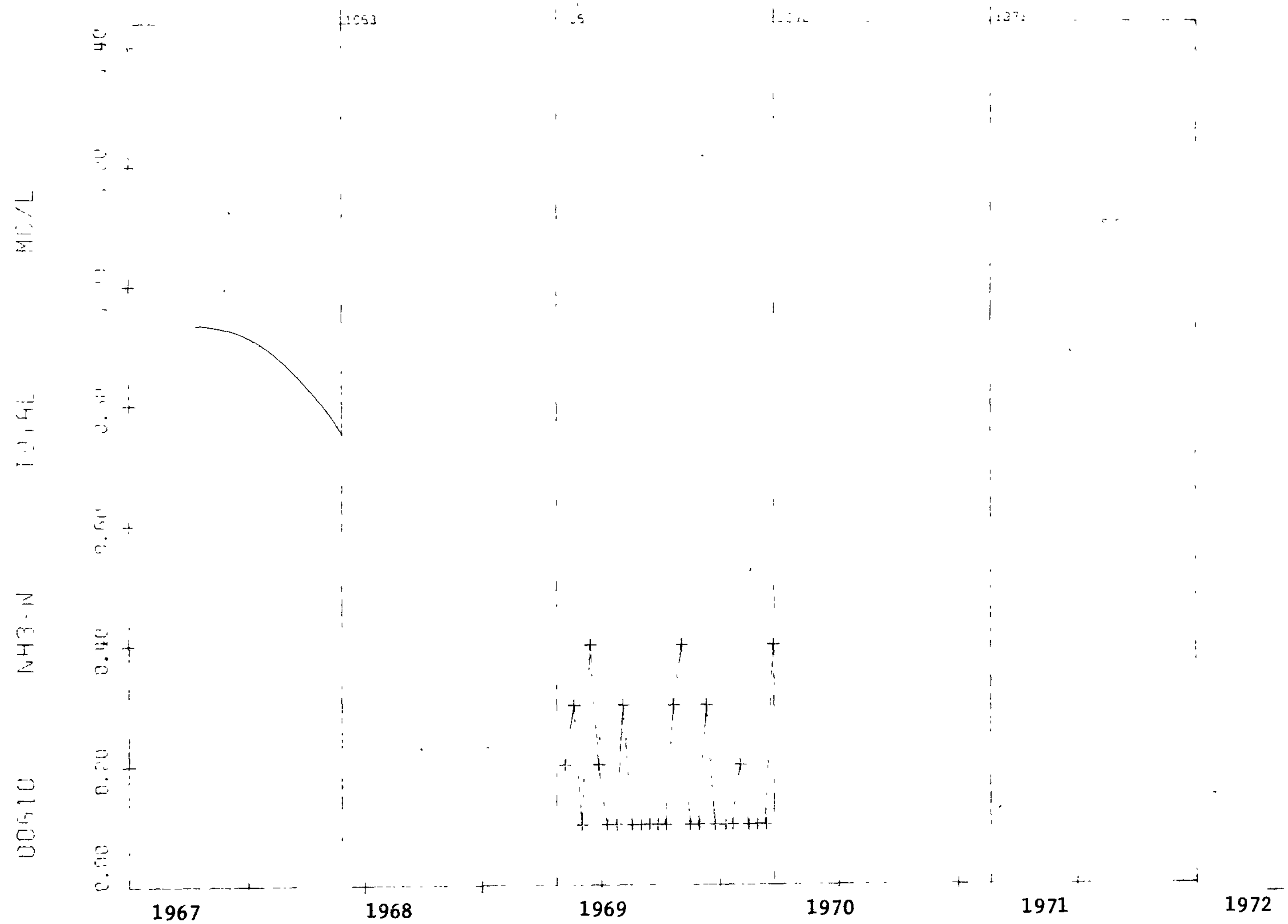

Figure 13.17

STORET WATER QUALITY PLOT

14. PHENOLS

Measurements of phenols at Dickey Rd on the IHC show steady decreases in the last few years, reaching a level which falls within the Indiana standard for the IHC; however, additional phenols are discharged into the IHC below Dickey Rd. by Inland and Youngstown Steel Companies. In 1973, the average values in the Lake just met water quality standards; previous years showed water quality violations. On the other hand, the Chicago Water Dept. experienced a series of taste and odor periods in December 1973 which, because they were combined with high NH_3-N values, were attributed to the IHC effluents. Periods of high emissions of phenols are still possible, but the average values are improved sufficiently so that average water quality standards are not exceeded. The load allocations should be reduced to reflect the present observed performance, to prevent degradation of phenol levels back to earlier conditions.

14.1 Water Quality Standards

The Indiana (1973) water quality standards for phenol-like substances are 1 $\mu g/\ell$ monthly average for Lake Michigan, and 3 $\mu g/\ell$ single value. For the "inner harbor" they are 2 and 5, respectively. For the IHC the standard is 10 $\mu g/\ell$. The Illinois standard for water intakes is 1 $\mu g/\ell$.

Very low limits of phenols are permissible in drinking water primarily because of their offensive tastes. Chlorine reacts with phenols to produce even worse-tasting compounds; because of the high phenol levels in the Lake near Whiting, the Whiting water treatment plant uses ozone instead of chlorine for disinfecting its water supply.

14.2 Phenol Sources

There has been a marked improvement in the amounts of phenols emitted from the IHC in the last ten years. Figure 14.1 shows

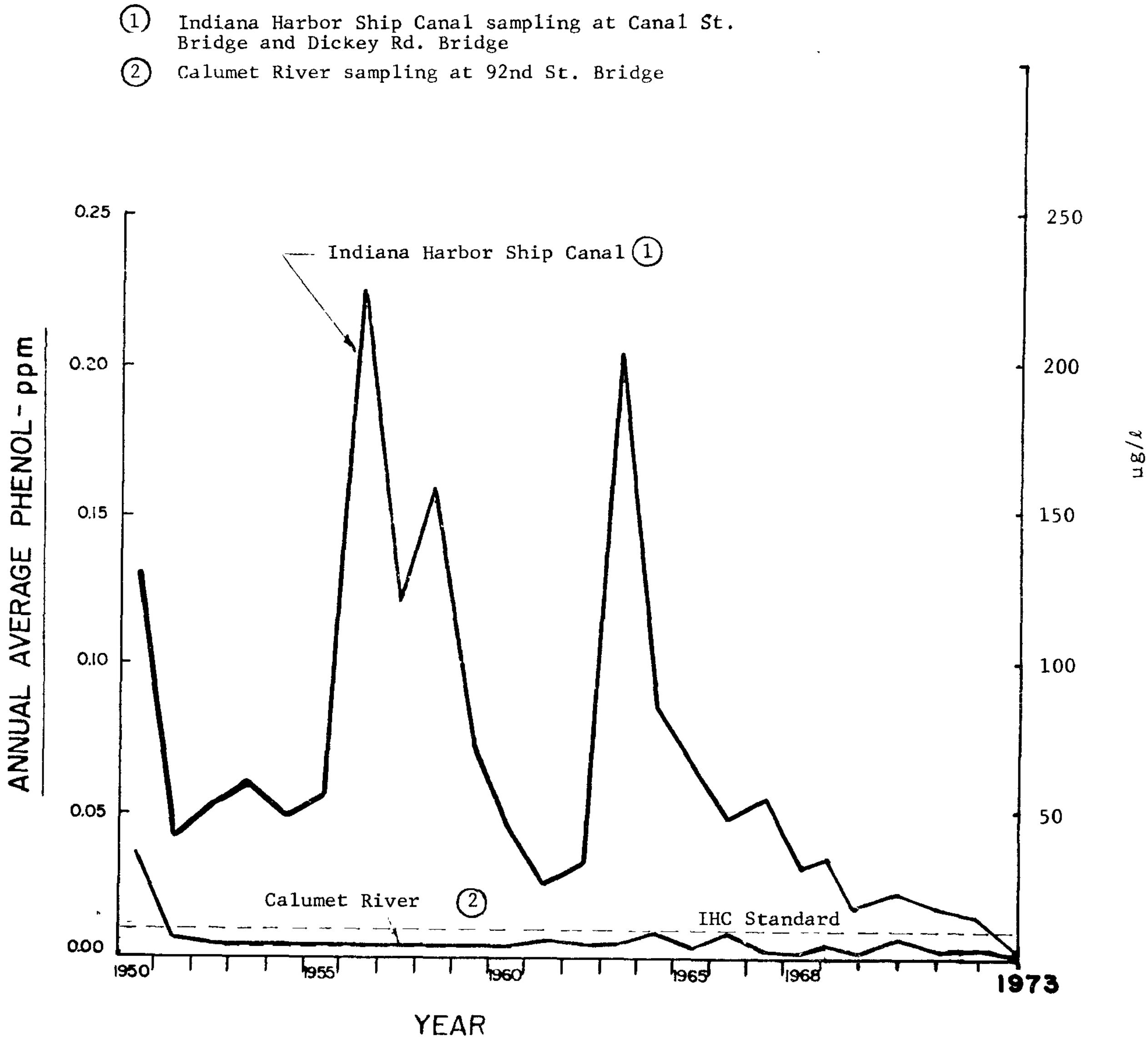

Figure 14.1

ANNUAL AVERAGE PHENOL
WEEKLY SANITARY SURVEYS
Chicago Water Department

the annual averages of weekly samples taken by the Chicago Water Dept. at Dickey Rd. on the IHC. The concentrations have dropped from a high of 200 μg/ℓ in 1963 to 3 in 1973. In 1973, the highest individual value was 13, which just exceeds the IHC standard of 10.

Of course, the Dickey Rd. station does not measure the influence of Youngstown and Inland Steel Companies, which have most of their outfalls downstream of this point.

EPA data shown in Table 14.1 indicates somewhat higher values at Dickey Rd., including a value of 21 in 1973. Values are also given at Station CAL06, at the mouth of IHC, and these are lower because of dilution there. Table 14.2 gives some values measured by the State of Indiana at IHC stations. The 1973 average at Dickey Rd. was 4, in agreement with Chicago Water Dept.

14.3 Water Quality Data

Figure 14.2 shows results of phenol measurements at stations in Lake Michigan by the Chicago Water Dept. There were violations at most of the stations in 1972, but no violations of average values in 1973. A few individual readings of 3 were measured, which just meet the Indiana individual value standard for the Lake.

Figure 14.3 from the Chicago Water Dept. Radial Survey shows a few peaks in 1972 which could be attributed to the IHC. The data for 1973 show no peaks.

Historical records of phenol peaks at water intakes in the Lake are shown in Storet plots, Figures 14.4 to 14.9. These records also indicate recent improvements in phenol concentrations.

An unpublished report from the Chicago Water Dept. indicates a severe taste and odor problem at the end of 1973. This suggests

Table 14.1

PHENOL, $\mu g/\ell$

Annual Averages
Storet Data, U.S. EPA

Station		Year 1971	1972	1973	1965-1971
CAL17	Chicago SWFP	0.062			1.1
CAL16	Hammond WFP	1.4			2.2
CAL15	East Chicago WFP	1.1			2.0
CAL14	Gary WFP	1.0			1.4
CAL13	Calumet Harbor	1.6			1.8
CAL06	IHC Mouth	8.58	8.17	6.0	21.8
CAL02	IHC 151 St.	49.7	16.0	57.0	163.
CAL03	IHC Dickey Rd.	58.	6.5	21.	67.

Table 14.2

IN-STREAM WATER QUALITY
from Indiana State files
Combinatorics (1974)

Description	Phenols		
Water quality standard	0.10 mg/ℓ		
Monitoring stations	72 Average	73 Average	72-73 Maximum
GCR 41 Grand Calumet River Gary (U.S. 12)	-	0.031	0.066
GCR 37 Grand Calumet River East Chicago (Kennedy Rd.)	-	0.018	0.053
GCR 36 Grand Calumet River East Chicago (Indy. Blvd.)	-	0.501	4.800
GCR 34 Grand Calumet River Hammond (U.S. 12)	0.021	0.011	0.096
IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.)	-	0.005	0.013
IHC 3S Indiana Harbor Canal East Chicago (Dickey Rd.)	-	0.019	0.066
IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.)	0.029	0.004	0.170
IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel)	-	0.008	0.017

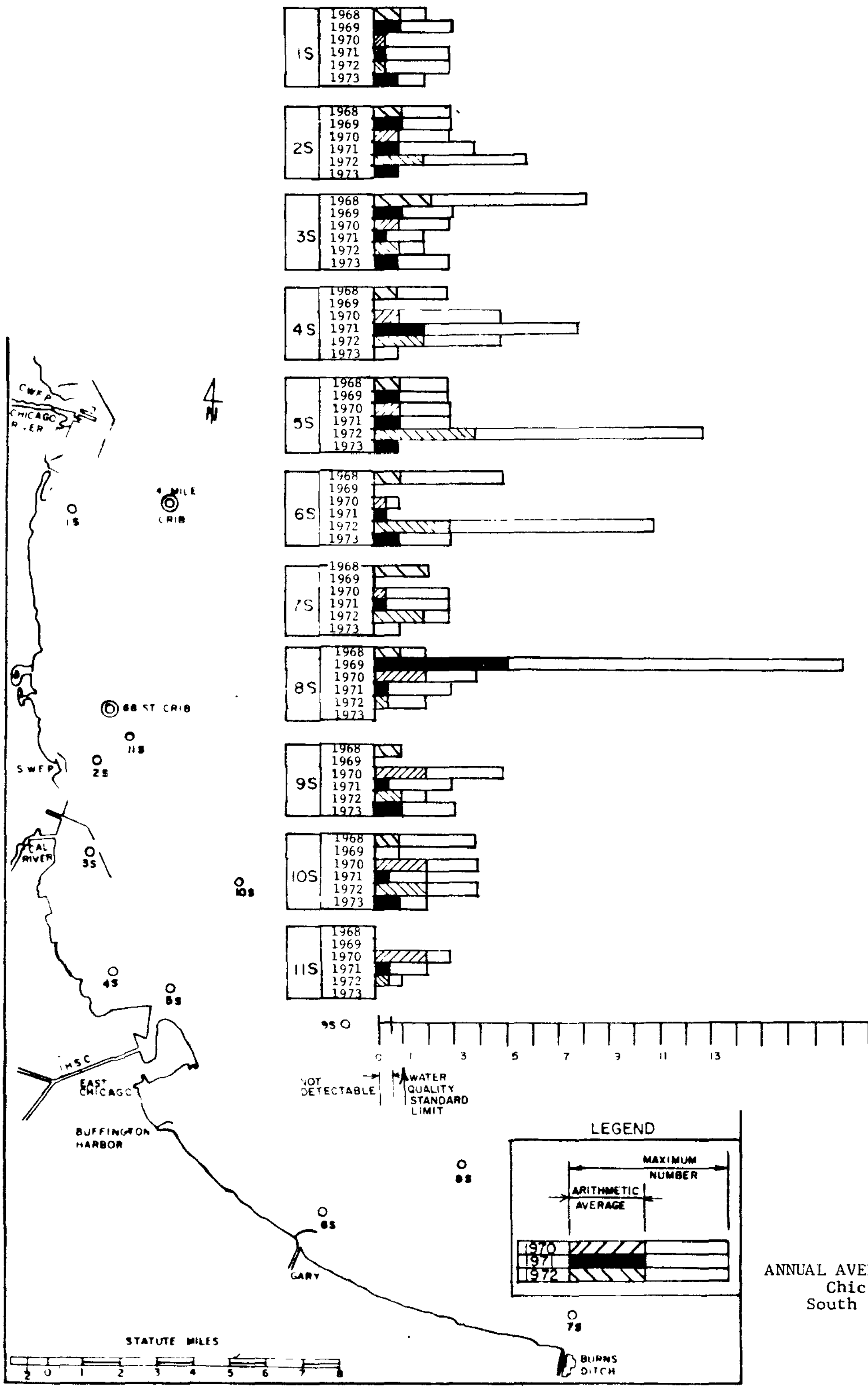

Figure 14.2

PHENOL
ANNUAL AVERAGE AND MAXIMUM, μg/l
Chicago Water Dept.
South Shore Lake Survey

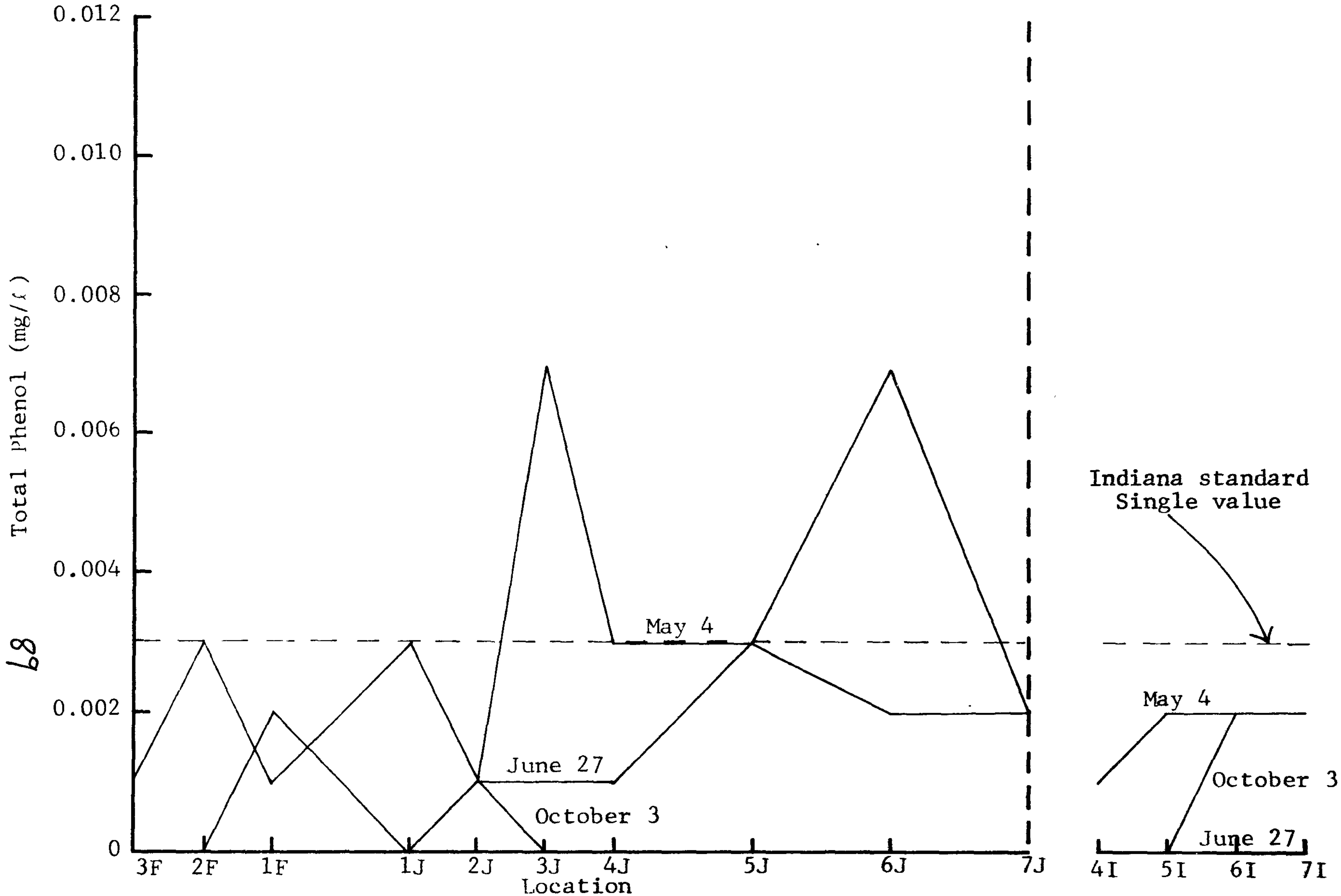

Figure 14.3

RADIAL SURVEY OF PHENOL CONCENTRATION - 1972
Chicago Water Dept.

that peak values of phenol or other chemical substances may periodically issue from the IHC. The tastes were associated with ammonia, which as we have seen comes mainly from the IHC.

14.4 Effluent Loads

Table 14.3 lists the discharges of phenol into the IHC. The quantities given would result in much greater concentrations than were actually measured at Dickey Rd or at the mouth of the IHC. It appears that phenol effluents have been reduced below the amounts given in this table. The table reflects permit application data.

14.5 Conclusions and Recommendations

Phenol levels have been reduced to the point where they are not usually a significant problem, but peak values may still cause taste and odor problems. The load allocations should be decreased to reflect this current situation, so that they are not more permissive than current performance.

Table 14.3

DISCHARGES OF PHENOL INTO THE IHC
Source: Combinatorics (1974)

				Phenols		Water Quality Standard .01 mg/l		
Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
U. S. Steel								
GW-1	19.9	28.9	40.7	4.82	10.18	.020	.030	
GW-2	10.9	16.4	23.0	17.80	30.30	.130	.158	
GW-2A	1.4	2.2	3.9	1.84	15.30	.100	.470	
GW-3	2.7	3.8	4.5	2.30	2.66	.064	.071	
GW-3A	0.4	1.7	3.7	.42	5.61	.030	.182	
GW-4	0.5	0.7	0.9	.01	.01	.001	.001	
GW-5	82.4	87.7	95.3	234.50	302.00	.320	.380	
GW-6	23.4	29.5	39.4	1.47	2.63	.006	.008	
GW-7	5.8	10.6	16.9	.44	2.68	.005	.019	
GW-7A	93.3	120.1	146.0	35.10	51.18	.035	.042	
GW-9	24.7	34.7	39.7	.58	2.64	.002	.008	
GW-10A	26.3	34.6	47.2	1.13	3.94	.004	.010	
GW-11A	81.3	94.7	115.6	1.58	2.89	.002	.003	
GW-13	1.8	2.9	4.8	.24	.48	.010	.012	
ST-14	0.8	1.8	3.3	.01	.01	.001	.001	
ST-17	20.1	30.0	39.3	22.45	47.85	.090	.146	
GSTP	44.0	52.7	62.0	1.76	5.16	.004	.010	
E.I. duPont								
001	0.5	1.8	2.4	.01	.01	.001	.001	
002-004	7.24	10.31	11.66	.10	.12	.001	.001	
005	0.07	0.08	0.12	-	-	.001	.001	
006-010	0.89	2.24	2.98	.01	.01	.001	.001	
U.S.S. Lead		0.36		-	-	-	-	
HSTP	35.0	40.7	44.0	1.47	3.67	.004	.010	
ECSTP	10.0	14.0	20.0	18.58	432.00	.159	2.590	
Union Carbide	0.05	0.07	0.11	-	-	.001	.001	
ARCO		5.04	6.77	2.90	8.06	.070	.143	
Amer. St. Foundries	0.09	0.15	0.27	.02	.11	.003	.005	

Table 14.3 (cont.)

Phenols — Water Quality Standard .01 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
Youngstown								
001 YS-20	8.46	13.70	23.60	1.14	3.06	.010	.015	
002 YS-2	1.50	3.62	7.50	.03	.06	.001	.001	
003 YS-4	0.53	0.98	1.40	.01	.01	.001	.001	
004 YS-8	1.03	1.40	1.75	.01	.01	.001	.001	
005 YS-11	1.19	1.60	3.00	.01	.02	.001	.001	
006 YS-12	3.30	5.70	8.40	69.30	114.00	1.520	2.480	
007 YS-13	6.30	14.00	18.90	303.00	3040.00	2.590	26.000	
008 YS-22	3.00	5.00	11.70	14.10	606.00	.290	12.500	
009 YS-14	34.00	48.70	60.00	.41	.51	.001	.001	
010 YS-15	36.60	58.00	67.00	8.23	12.77	.017	.023	
011 YS-18A	107.80	121.60	138.70	11.20	17.20	.011	.017	
Inland								
001 IE-2		.14	.29	-	-	.001	.001	
002 4E-1		190.00	228.00	17.40	179.00	.011	.094	
003 5E-1		7.20	8.60	.06	.07	.001	.001	
004 5E-2	8.60	0.86	1.04	.01	.01	.001	.001	
005 5E-3		8.60	10.40	.07	.09	.001	.001	
006 6E-1		0.65	1.30	.01	.01	.001	.001	
007 7E-1		21.60	25.90	6.32	8.21	.035	.038	
008 10E-1	Unknown & Highly Variable							
011 13G-1	126.96	158.70	190.44	10.00	16.00	.008	.012	
012 13H-1	67.68	50.80	70.00	29.60	432.01	.070	.740	
013 14H-TT	85.52	106.90	128.28	51.60	532.93	.058	.500	
014 15H-TT	85.52	106.90	128.28	57.00	748.90	.064	.700	
015 16H-1	17.28	21.60	25.92	.18	.22	.001	.001	
016 16H-2	7.20	9.00	10.80	.07	.09	.001	.001	
017 16H-3	115.28	144.10	172.92	1.20	1.44	.001	.001	
018 16F-1	119.76	149.70	179.64	1.25	1.50	.001	.001	

CAL17
Chicago SWFP Intake
EPA data

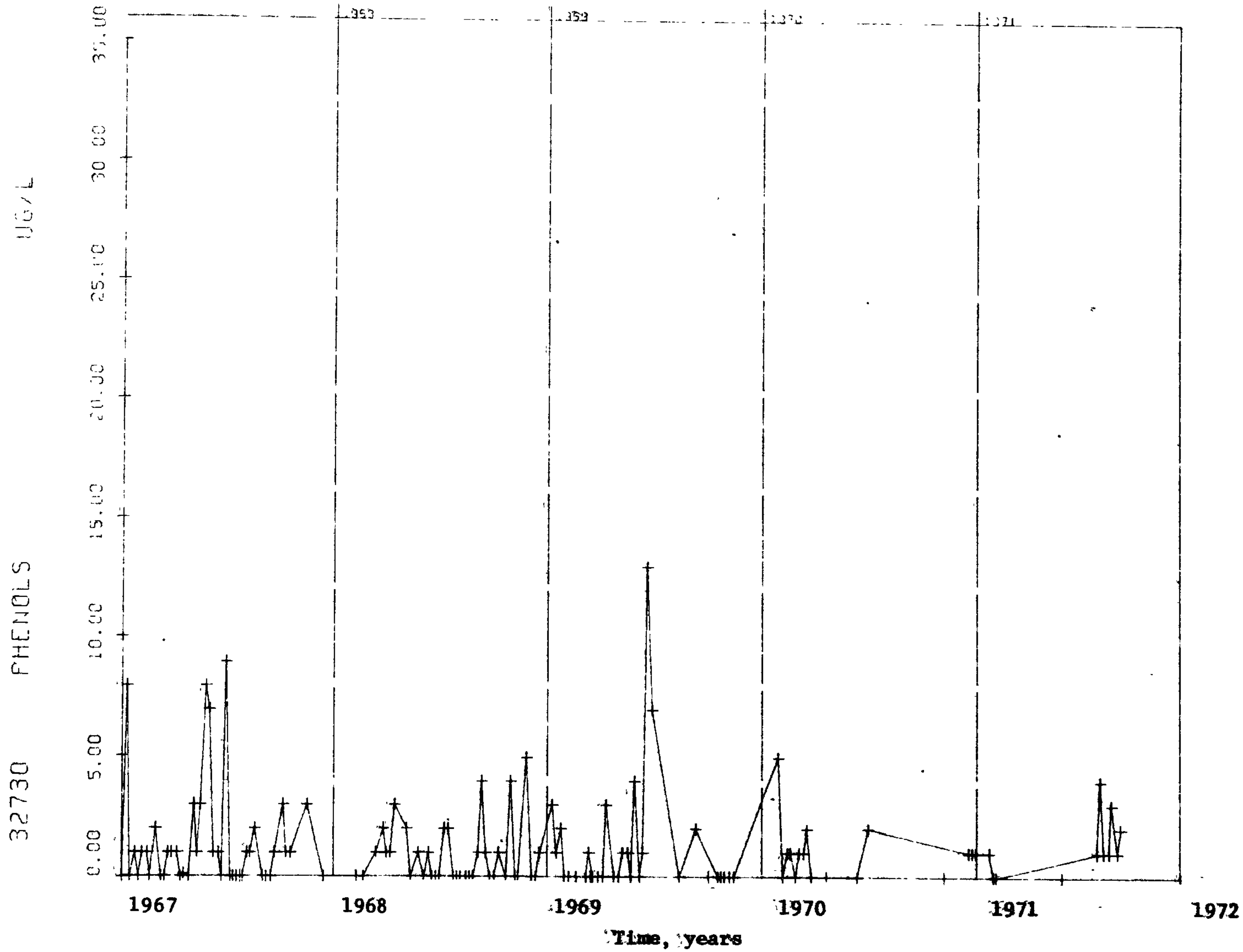

Figure 14.4

STORET WATER QUALITY PLOT

CAL13
Calumet Harbor
EPA data

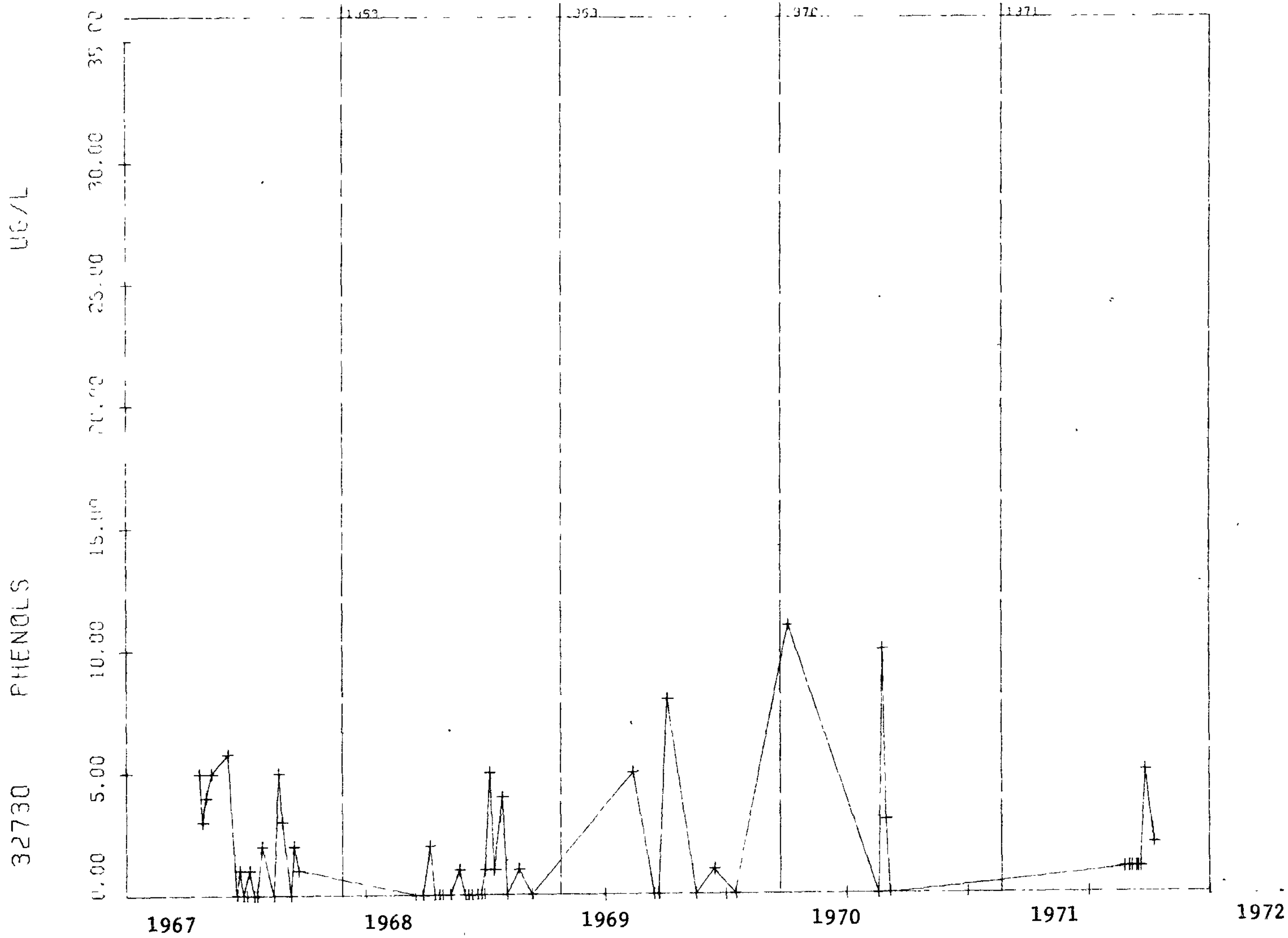

Figure 14.5

STORET WATER QUALITY PLOT

CAL16
Hammond Water Plant Intake
EPA data

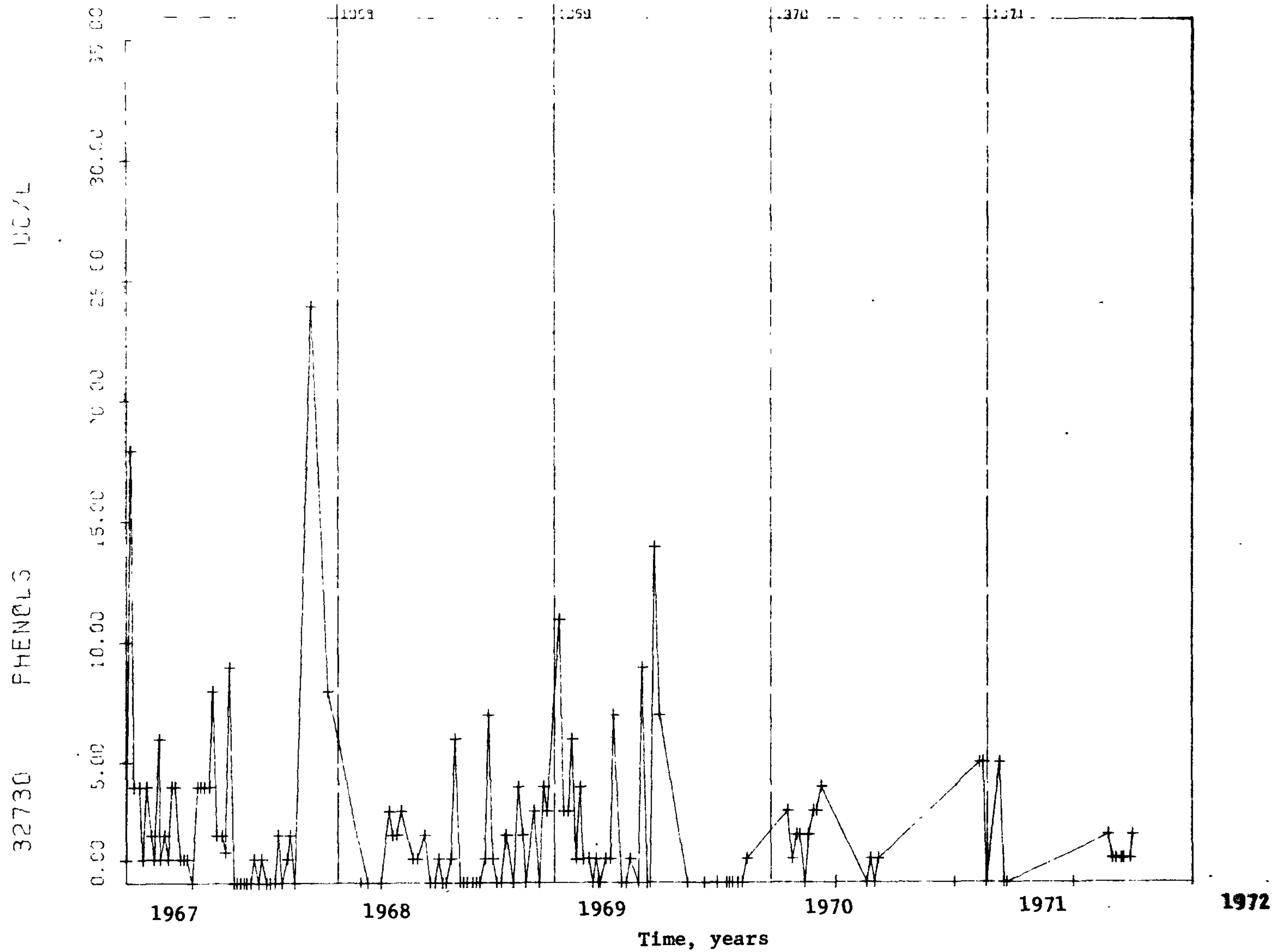

Figure 14.6
STORET WATER QUALITY PLOT

LM W
Whiting Water Plant Intake
Indiana data

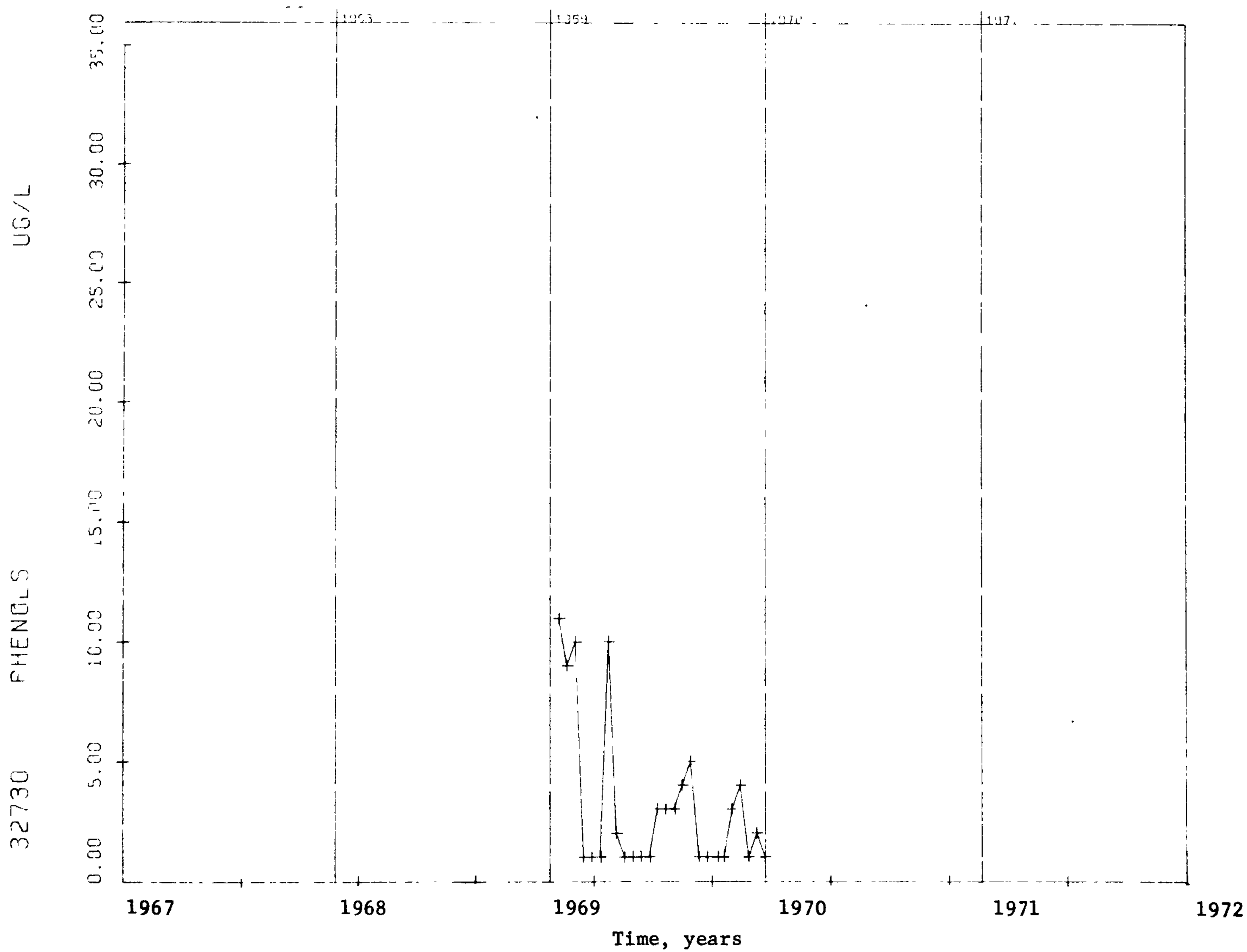

Figure 14.7

STORET WATER QUALITY PLOT

CAL15
East Chicago Water Plant Intake
EPA data

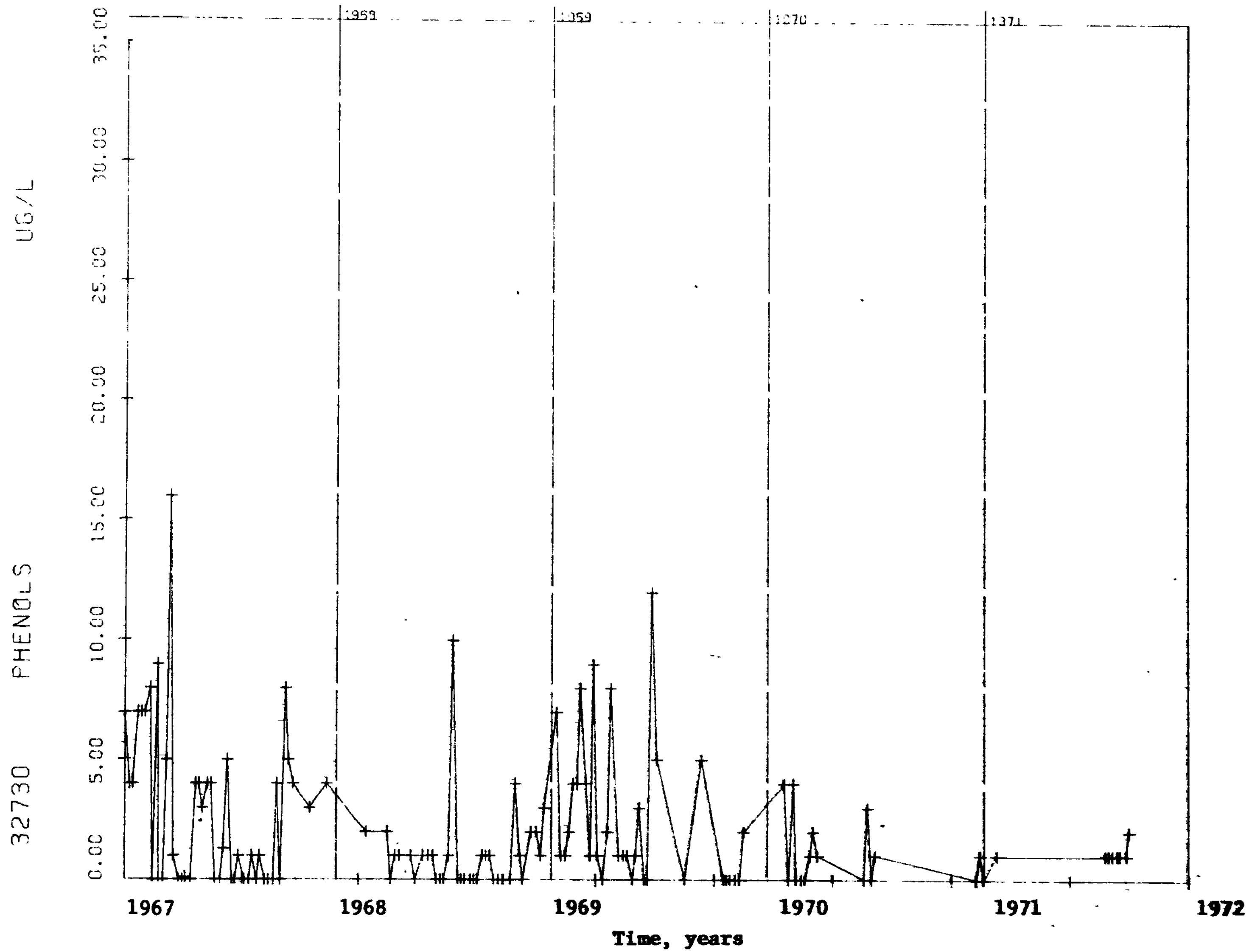

Figure 14.8

STORET WATER QUALITY PLOT

CAL14
Gary Water Plant Intake
EPA data

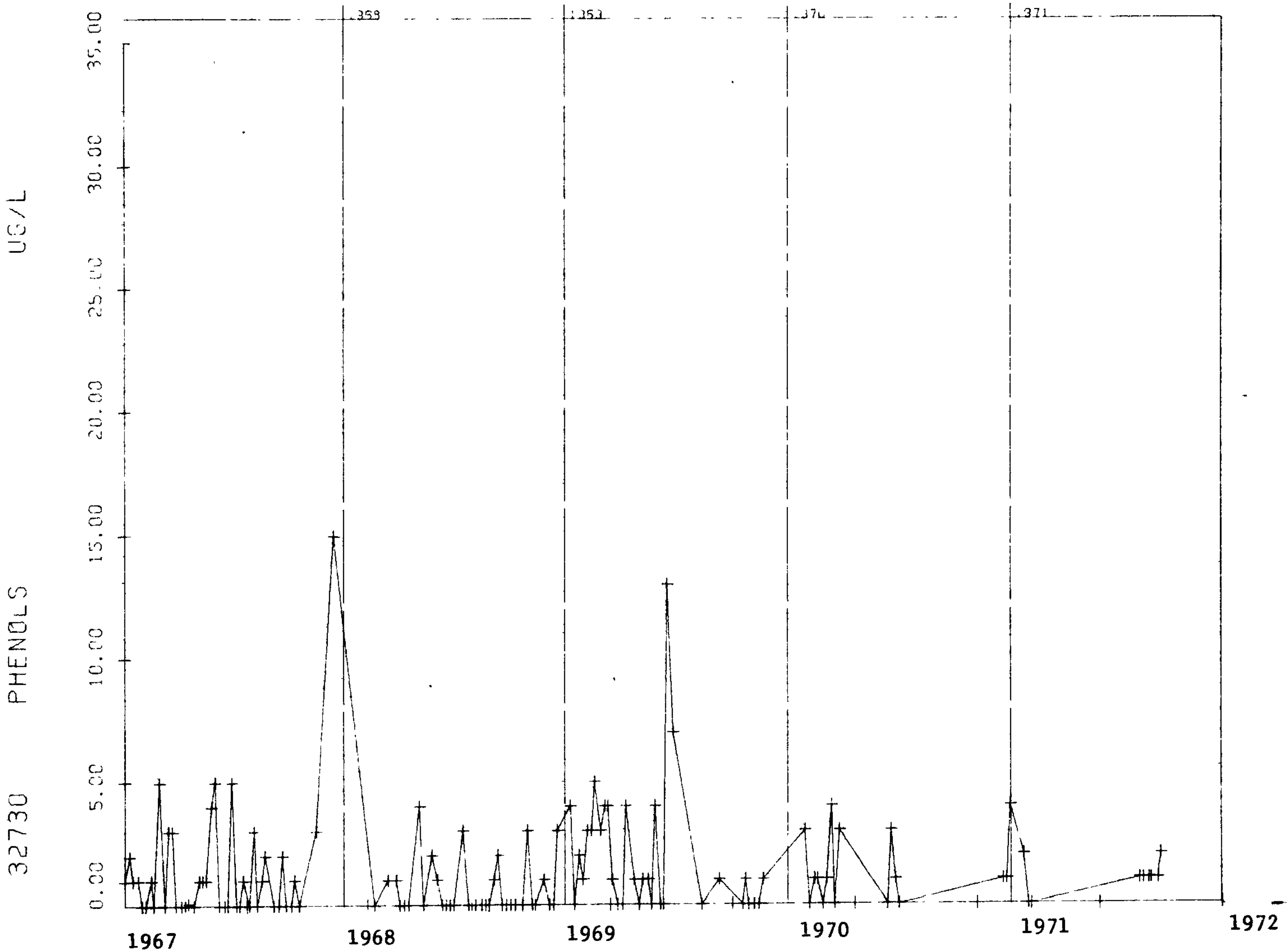

Figure 14.9

STORET WATER QUALITY PLOT

15. OIL AND GREASE

Available data on oil and grease in Calumet area waters is obtained from Storet and presented in Table 15.1. The values in IHC generally fall within the Indiana Standard of 5 mg/ℓ; however, there are daily oil spills and emissions into the IHC, which we documented by aerial photos during our sampling program. Oil slicks are practically always observable in the Lake coming from IHC, and they are blown by the wind many miles.

Oil can also be carried into the bottom sediments with solid particles, and the oozy bottom of IHC and the inner harbor have been observed to contain a large fraction of oil (see Table 7.1.) Visual observations of oil on the surface and bottom of the IHC and along its banks constitutes a violation of the practical standards of Indiana for the IHC.

The Corps of Engineers (1968, Appendix V) report summarizes the following harmful effects of oil pollution: "Oil pollution is a deterrent to industrial and domestic use of water as well as being detrimental to the marine environment. Oil films interfere with gas exchange, exert a toxic action on some organisms, and interfere with the natural marine life cycle by coating both plankton and bottom. If oils become adsorbed on sediments they then are available for later release with agitation. Oils impart a disagreeable taste and odor to domestic water supplies and are detrimental in industrial food and beverage preparation."

The Technical Committee (1970, Table 3) estimated total effluents of oil to the IHC at 100,000 lb/day, with an additional 20,000 lb/day going direct to Lake Michigan outfalls. The Corps of Engineers study (1968, p. 103) estimated that oil and grease removed from the IHC in dredging spoils in 1967 amounted to 1750 tons (3,500,000 lb, or the equivalent of 175 days accumulation). Combinatorics (1974) did not report the industrial load of oil and grease, but the loads can be estimated from outfall flows and permit effluent data given in Appendix C, at least for the three major steel companies. The loads in Table 15.2 total

48,000 lb/day to the IHC. The BOD_5 loadings from steel mills and ARCO in Table 15.2 agree very well with the oil and grease loadings; this checks the estimates since oil and grease should comprise most of the organic effluents from these industries. Appendix C does not contain sufficient data to calculate the loads from the petroleum refineries on the IHC, but the Technical Committee (1970, Table 3) indicated that the Mobil and Sinclair (now ARCO) refineries contributed 500 and 1700 lb/day of oil respectively in 1968. Thus the total load has been reduced from 100,000 to 50,000 lb/day since 1968, according to the permit data.

Loads direct to Lake Michigan are computed from permit data as follows: American Oil 1870 lb/day; Union Carbide 1125 lb/day; U.S. Steel Gary 3700 lb/day, for a total of 6700 lb/day.

Although there may have been an improvement in oil loads, harmful effects of oil pollution are still evident in the IHC and the Lake. We recommend that either the oil or the BOD_5 allocations be reduced as a means to require the steel mills to drastically reduce the amount of oil they discharge into the IHC. Until this is done the IHC will remain an inhospitable place for aquatic life, and the impact on aquatic life of the Lake will continue to be substantial (Howmiller, Appendix A).

Table 15.1

OIL AND GREASE, mg/ℓ

Annual Averages
Storet Data, U.S. EPA

Station		Year 1971	1972	1965-1971
CAL17	Chicago SWFP	4.8		1.7
CAL16	Hammond WFP	5.57		1.8
CAL15	East Chicago WFP	4.9		1.7
CAL14	Gary WFP	5.3		1.7
CAL13	Calumet Harbor	5.6		2.3
CAL06	IHC mouth	6.1	5.0	3.5
CAL02	IHC 151 St.	5.9	5.0	4.76
CAL03	IHC Dickey Rd.	8.8	5.0	21.5

Table 15.2

SUMMARY OF EFFLUENT LOADS, IHC
lb/day, existing averages

Discharger	Oil[a]	BOD_5[b]
U.S. Steel	10,200	10,488
Gary		12,100
E. I. duPont de Nemours		100
U.S. Lead		5
East Chicago S.D.		11,100
Hammond S.D.		7,800
Union Carbide		1
ARCO		400
American Steel Foundry		1
Youngstown	9,970	9,233
Inland	27,500	27,620

[a]Appendix C [b]Combinatorics (1974)

CAL02
IHC and 151st St.
EPA data

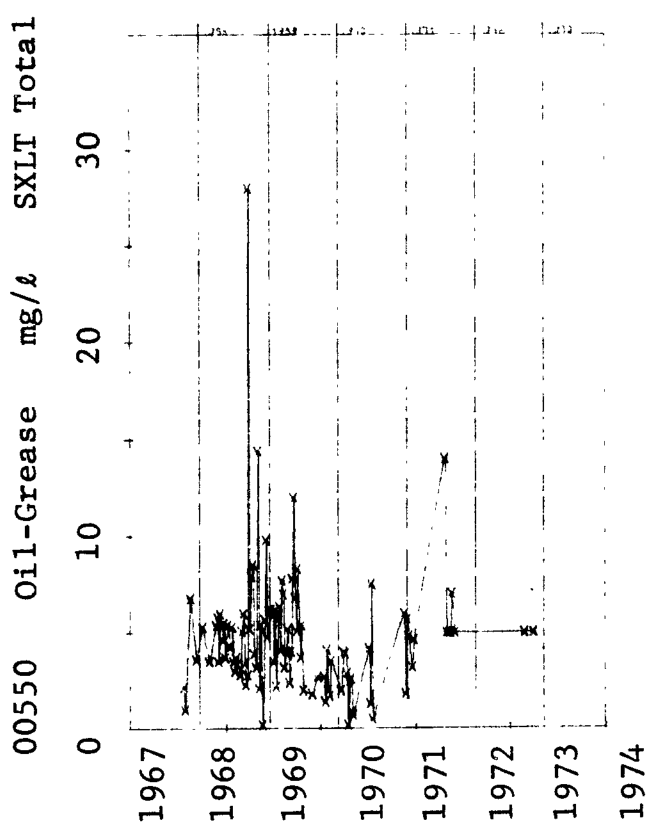

Figure 15.1

STORET WATER QUALITY PLOT

CAL06
IHC mouth
EPA data

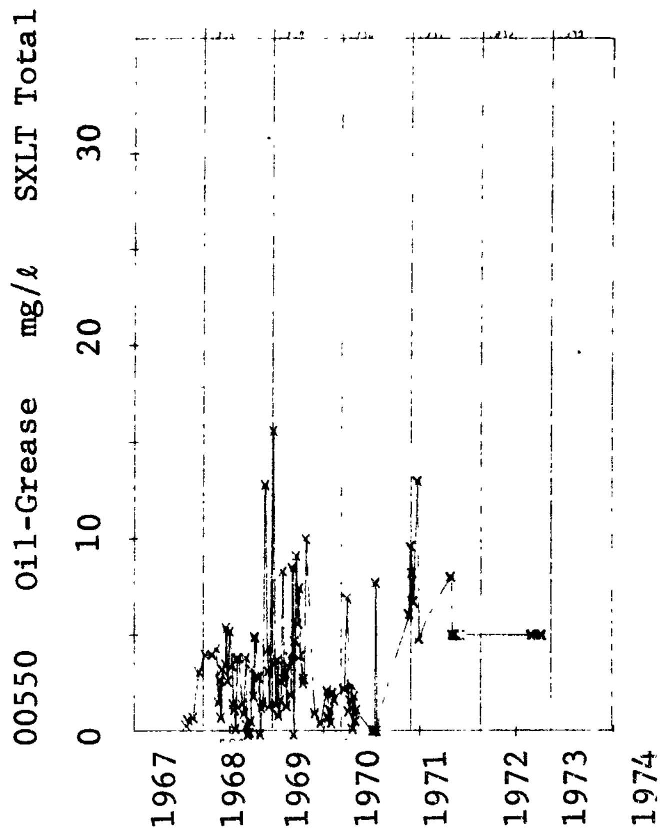

Figure 15.2

STORET WATER QUALITY PLOT

CAL11
Calumet River mouth
EPA data

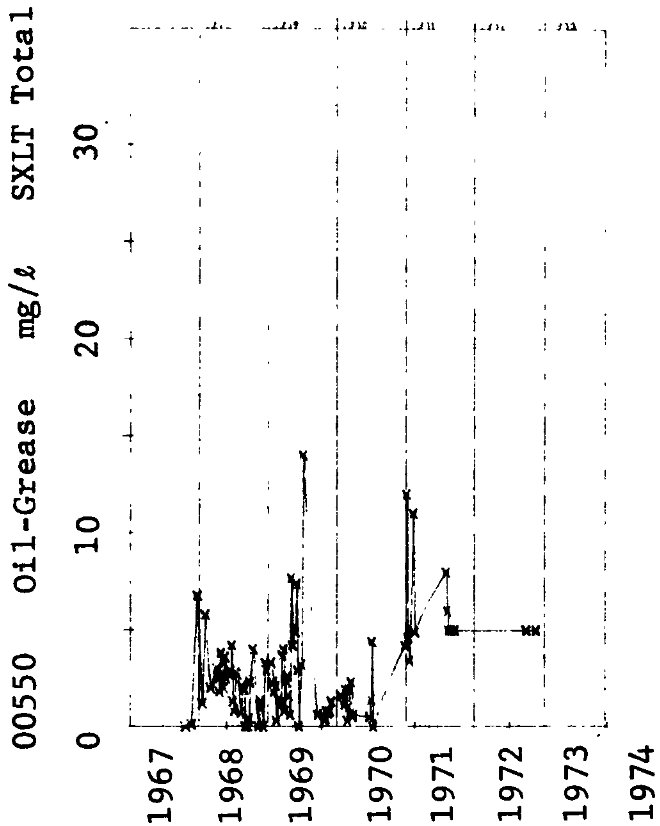

Figure 15.3

STORET WATER QUALITY PLOT

CAL13
Calumet Harbor
EPA data

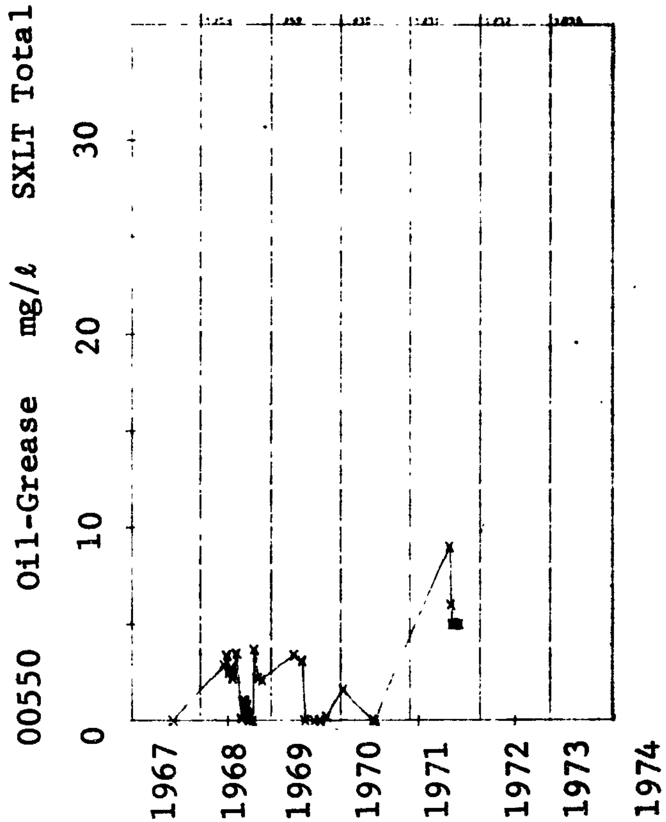

Figure 15.4

STORET WATER QUALITY PLOT

CAL16
Hammond Water Plant Intake
EPA data

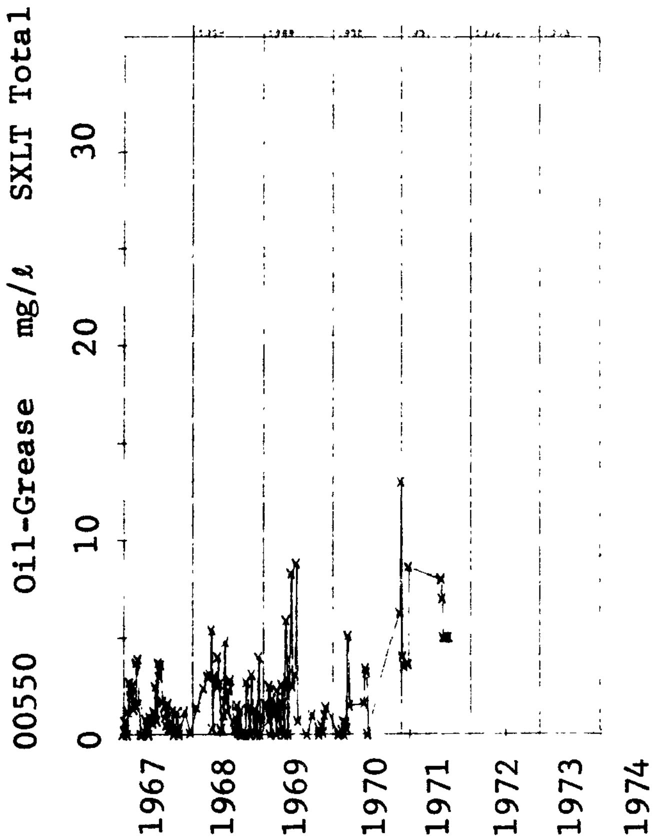

Figure 15.5

STORET WATER QUALITY PLOT

CAL17
Chicago SWFP Intake
EPA data

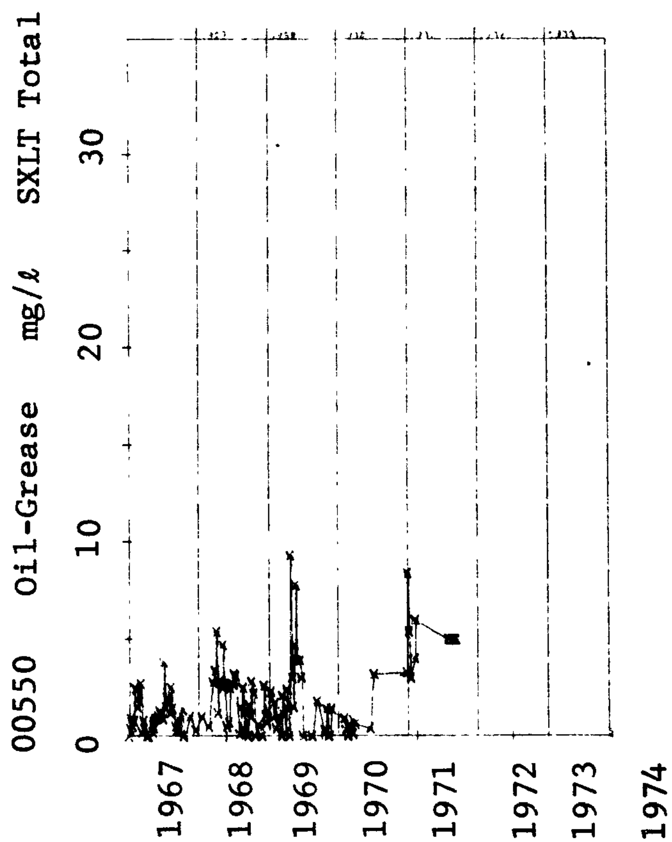

Figure 15.6

STORET WATER QUALITY PLOT

16. BACTERIAL POLLUTION

16.1 Introduction and Summary

Human uses of the Calumet area of Lake Michigan have been severely restricted by bacteriological contamination of the near-shore waters. These restrictions have included greater water treatment costs to achieve potable quality water and a restriction on bathing at beaches in this area of the Lake (Technical Committee 1970).

Bacteriological contamination measured in the form of total coliform, fecal coliform and fecal streptococci comes into this area of the Lake from many sources. Municipal sources such as combined sewer overflows discharge directly to the Lake as well as to tributary streams. Incompletely treated effluents from municipal treatment plants are the other major contributors. Substantial investments of capital and effort have been applied to eliminate the combined sewer overflow problem. The Hammond Robertsdale outfall and the Whiting Front St. outfall are now supposed to be inoperative, but our observations suggest that this is not yet the case. (See Section 16.5.) The three major sewage treatment plants (Hammond, East Chicago, and Gary) have been upgraded. Although improved, they are still the major sources of coliform bacteria discharged into this area of the Lake. Industrial discharge of coliform material appears to be only a minor contributor to the coliform pollution, based on permit application data.

Data presented in the following sections show that there has been little improvement in coliform pollution in this part of the Lake in the past five years, in spite of attempts to upgrade the sewage treatment plants. The reasons for this are discussed and steps to bring about improvement are recommended.

16.2 Water Quality Standards

Different standards apply to different areas of southern Lake Michigan and its influent streams. The Indiana and Illinois standards for fecal coliform and their area of application are given in Table 16.1. Illinois standards apply only to the open Lake while Indiana has standards for the open Lake, Harbor areas, the beaches and Indiana Harbor Canal.

The U.S. EPA (1973) has proposed fecal coliform standards of 10,000/100 mℓ for fresh water used as a source of public water supply. No applicable standards have been promulgated for total coliform or fecal streptococci by Illinois or Indiana. The U.S. EPA (1973) has proposed standards for total coliform of 2,000/100 mℓ for wildlife water uses and 10,000/100 mℓ for fresh water public water supply uses. The International Joint Commission (1972) established the specific objective of 1,000 total coliforms per 100 mℓ and 200 fecal coliforms per 100 mℓ for the boundary waters area of the Great Lakes. Of course, this does not include Lake Michigan.

16.3 Water Quality and Violation of Standards in Lake Michigan

Howmiller (Appendix A) reviews published data on the bacterial flora of Lake Michigan. Most of the measurements have been made at water intakes and beaches, and have concentrated on bacteria of sewage origin. The trends of beach pollution in the past decade are reviewed, and it appears that problems at the Calumet area beaches are not new. Coliform densities in the IHC were even higher a decade ago than now; values as high as 25,000,000 per 100 mℓ were recorded. Twenty-three pathogenic strains of salmonellae were found regularly in the Grand Calumet River.

The most extensive data on water quality are those obtained from Lake Surveys conducted by the Chicago Water Department. Data on fecal coliform from the South Shore Survey are summarized for the years 1968-1972 in Figure 16.1. These show that while there is extensive violation of the open Lake water quality standards of 20/100 mℓ, only sample station 5S, located immediately

Table 16.1

WATER QUALITY STANDARDS
FECAL COLIFORM (MPN or MF/100 mℓ)

Agency	Regulation	Lake Michigan: Open water	Lake Michigan: Inner harbor	Lake Michigan: Beaches	IHC
ISPCB	SPC 4-R	20	1,000 (2,000)*	200 (400)*	-
ISPCB	SPC 7R-2	-	-	-	1,000 (2,000)*
Ill. EPA	Chap. 3, Part 2 Paragraph 206	20	-	-	-
U.S. EPA	Proposed+		2,000 (secondary contact)	200	
IJC	Annex 1, 1.(a)	200	-	-	-

*maximum not to be exceeded in more than 10% of the samples.

+Proposed criteria for water quality, October 1973, U.S. EPA. (As required by Section 304(a) of the 1972 Water Quality Act Amendments.

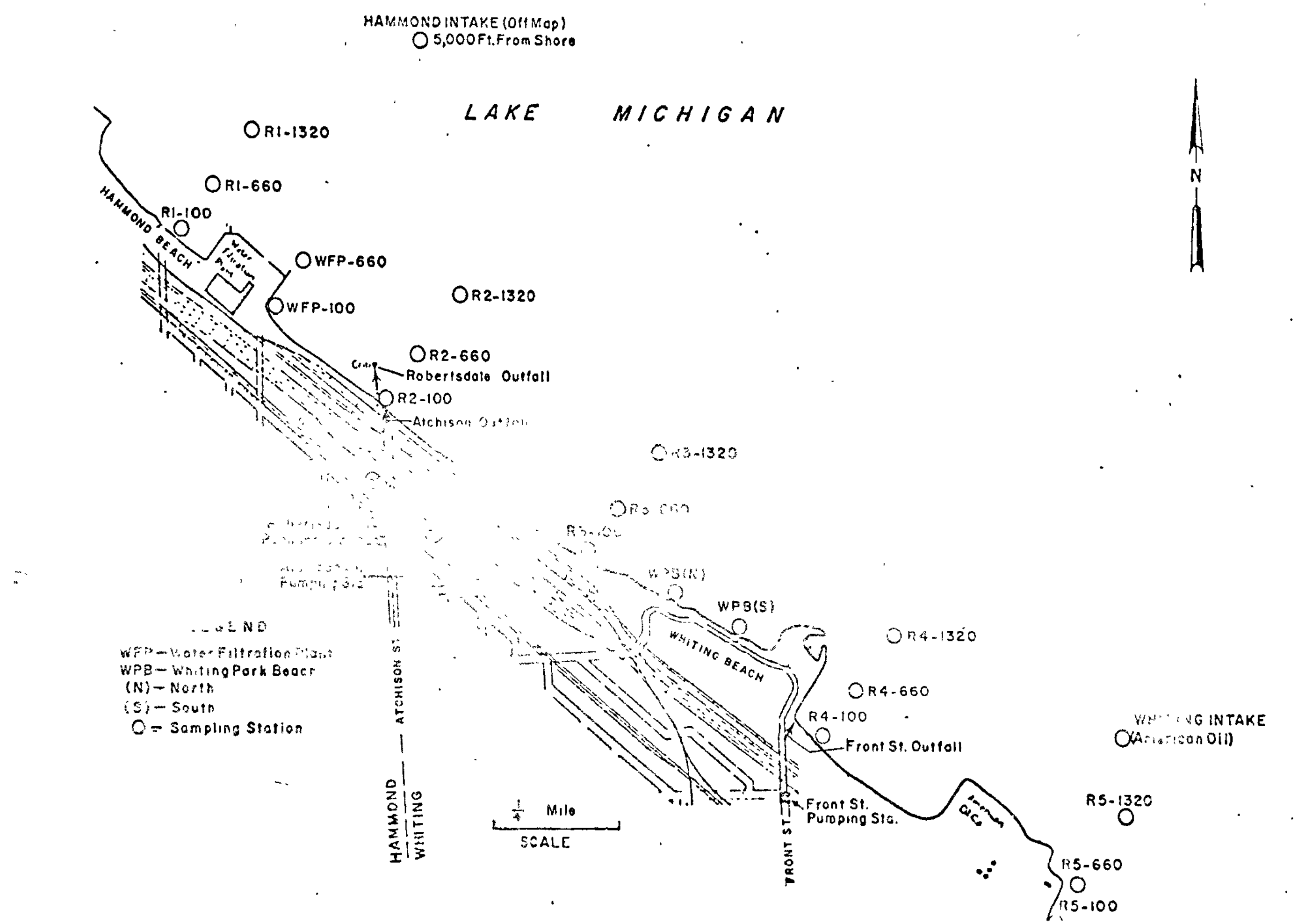

Figure 16.2

HAMMOND AND WHITING BEACH SAMPLING STATIONS
SHOWING LOCATION OF THREE COMBINED SEWER OUTFALLS
(from unpublished U.S. EPA Report, 1972)

north of the entrance to the Indiana Harbor Canal violated (1969) the inner harbor water quality standards of 1,000/100 mℓ. The fecal coliform count at the near-shore stations of 3S, 4S, and 5S frequently exceeded the Indiana beach standard of 200/100 mℓ.

During the past five years, the fecal coliform concentration in the Calumet area has not shown any significant change, as indicated by Chicago Water Department Surveys in Figure 16.1.

Analysis of the intake water quality data for the Whiting and Hammond public water supply plants for the years 1967-1972 show frequent instances of 20,000 to 180,000 total coliforms/ 100 mℓ (Chicago Water Dept, Calumet Area Surveys 1967-1970).

During the period June 13 to July 20, 1972, the Illinois District Office of U.S. EPA conducted bacterial analyses at eight near-shore locations (Figure 16.2) from the Hammond Beach to the American Oil Company at Whiting. Their results in Table 16.2 show that on certain dates various sample stations had very high total and fecal coliform and fecal streptococci counts; while on other dates the counts were close to the background level for this area of the Lake. These incidents of local high bacterial counts were suspected to be due to combined storm and sanitary sewer overflows from the Robertsdale and Front St. outfalls shown in Figure 16.2.

Table 11.3 indicates that bacterial pollution from the IHC was measured by IITRI at station LM102, five miles out in the Lake on November 14, 1973. The total coliform count was 1,000/ 100 mℓ. This indicates that sewage effluents from the IHC can exceed sanitary standards over a large region of the Lake.

16.4 Sources of Bacterial Pollution

In this section it will be shown that the main source of bacterial pollution in the Calumet area is the IHC, and that the main bacterial discharge sources on the IHC are the three municipal sewage treatment plants and the combined sewer outfalls. The other important sources on the Lake are three combined sewer

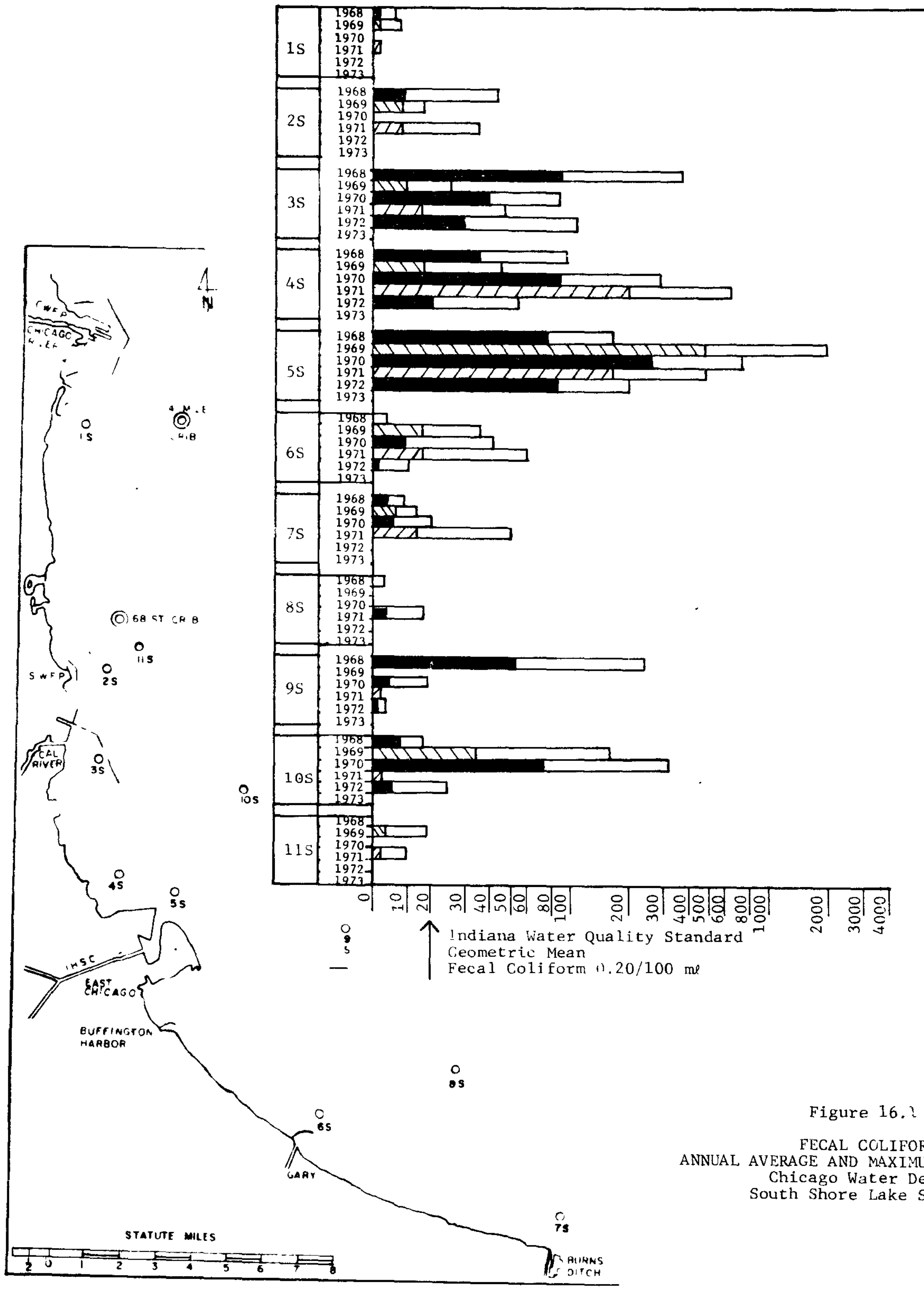

Figure 16.1

FECAL COLIFORM
ANNUAL AVERAGE AND MAXIMUM, No./100 ml
Chicago Water Dept.
South Shore Lake Survey

Table 16.2

BACTERIA COUNTS AT HAMMOND AND WHITING BEACHES IN 1972
Data from U.S. EPA unpublished survey
Selected dates showing high counts

Date	Station	Bacteria: Total coliform	Fecal coliform	Fecal Streptococci
June 01, 1972	R1-1320	>3,000	770	
	R1-660	>3,000	670	
	R1-100	11,000	2,100	
June 29, 1972	R2-1320	200	2	<2
	R2-660	70,000	60	550
	R2-100	96,000	86	270
	R3-1320	2,000	4	24
	R3-660	130,000	110	550
	R3-100	260,000	240	230
	WPB(N)	370,000	230	1,300
	WPB(S)	310,000	250	1,100
July 03, 1972	R2-1320	150,000	130	860
	R2-660	390,000	8,500	22,000
	R2-100	1,200,000	2,300	9,400
July 14, 1972	R2-1320	110,000	180	380
	R2-660	210,000	1,200	740
	R2-100	230,000	2,200	1,500
	R3-1320	260,000	460	380
	R3-660	270,000	110	940
	R3-100	300,000	360	1,700
	WPB(N)	280,000	720	590
	WPB(S)	330,000	930	700
July 18, 1972	R2-1320	540,000	640	1,000
	R2-660	3,300,000	4,800	11,000
	R2-100	3,300,000	4,200	10,000
	R3-1320			
	R3-660			
	R3-100	2,700,000	3,700	8,000
	WPB(N)	1,700,000	1,900	5,600
	WPB(S)	1,000,000	1,200	3,500
July 24, 1972	R2-1320	1,000	<10	20
	R2-660	18,000	20	190
	R2-100	13,000	200	700

outfalls from Hammond and Whiting. The Calumet River also contributes some bacterial pollution, but it is much less than the IHC (we estimate it amounts to 1% of the IHC).

During IITRI's sampling program in November-December 1973, the total coliform bacteria count in the IHC at Columbus Drive (station IHC3S) averaged 200,000/100 mℓ, and the maximum was 360,000. At the mouth of the IHC (CAL06) total coliform averaged 20,000. The Chicago Water Department's weekly Calumet Area survey samples at Dickey Rd. bridge on the IHC show total coliform counts of 500,000 to 5,000,000/100 mℓ (Figure 16.3). The current values are less than the highest values encountered more than five years ago.

The sources of bacterial pollution on the IHC are the three municipal sewage treatment plants, and combined sewer outfalls. The average discharge flows from these plants are known, but the plants do not measure their bacterial contents. On the average, the Hammond, East Chicago and Gary STP's discharge 94.5 mgd to the Grand Calumet River, and this usually flows to the Lake via the IHC. (Table 5.1, Chapter 5). The flow rate of combined sewer overflows is known only for Hammond; it amounts to 17 mgd, or approximately 50% of the 36 mgd flow from the Hammond STP. Seventy-four percent of the Hammond combined sewer overflow goes to the Lake via the IHC (Table 5.6). Table 5.5 is an estimate of all the combined sewer overflows.

In 1972 and 1973, the State of Indiana measured the fecal coliform concentration in the east and west branches of the Grand Calumet River and the Indiana Harbor Canal. Average values for these two years are shown in Table 16.3. The location of the monitoring stations may be obtained by reference to Figure 6.2. Data in Table 16.3 show that the most consistently high fecal coliform counts were obtained from the west branch of the Grand Calumet River at stations on either side of the Hammond STP (stations GCR 34 and GCR 36).

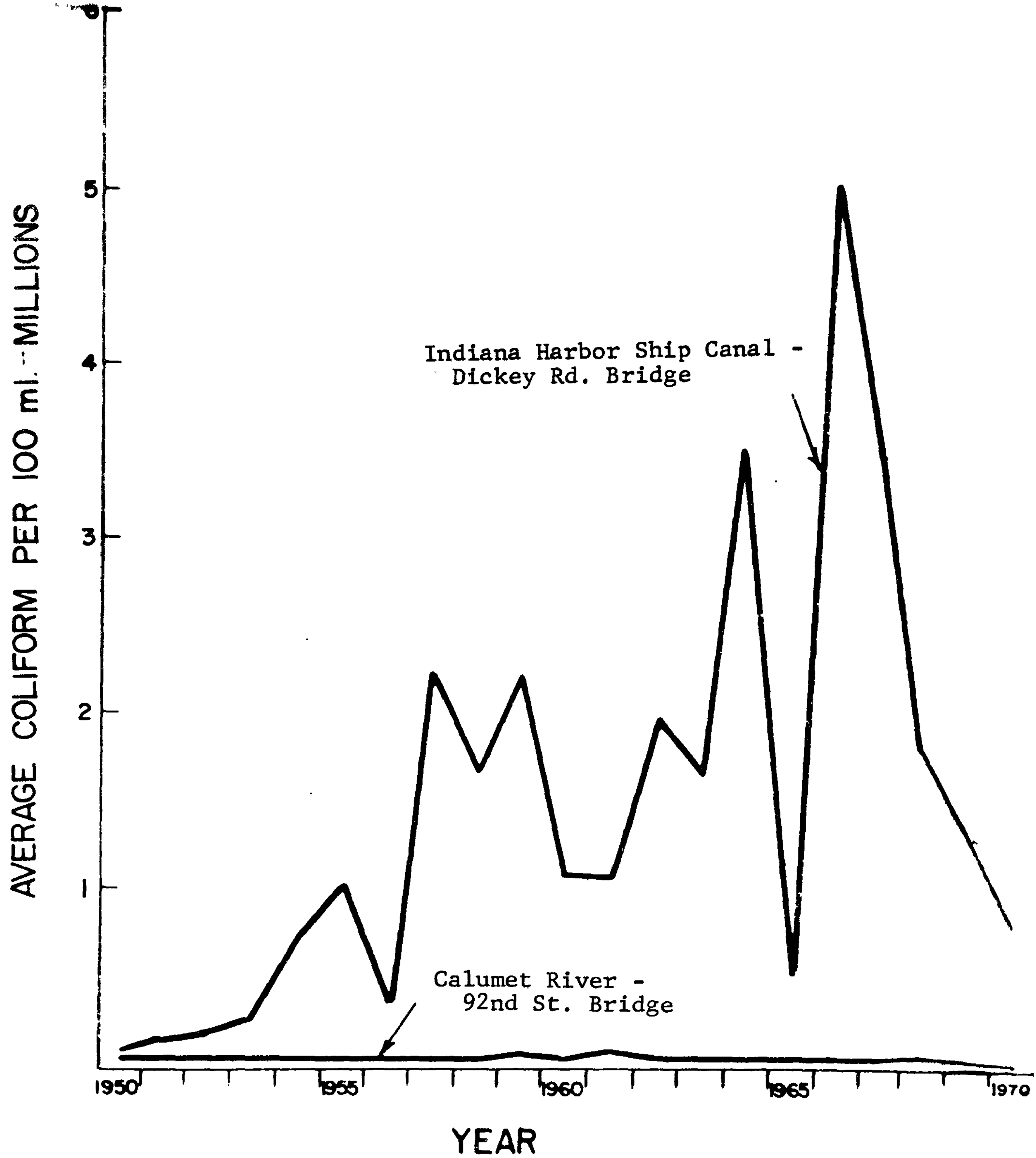

Figure 16.3

ANNUAL AVERAGE COLIFORM ORGANISMS PER 100 ML
WEEKLY SANITARY SURVEYS

Chicago Water Department

Table 16.3

IN-STREAM WATER QUALITY - FECAL COLIFORM, 1973
from State of Indiana Files
Combinatorics (1974)

Description	Fecal coliform		
Water quality standard	Geometric mean 1000/100 mℓ except during storm runoff		
Monitoring stations	72 Average	73 Average	72-73 Maximum
GCR 41 Grand Calumet River Gary (U.S. 12)	6,733	1,861	39,000
GCR 37 Grand Calumet River East Chicago (Kennedy Rd.)	3,919	1,340	33,000
GCR 36 Grand Calumet River East Chicago (Indy. Blvd.)	306,171	64,665	1,300,000
GCR 34 Grand Calumet River Hammond (U.S. 12)	619,242	43,189	3,300,000
IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.)	2,952	1,138	16,000
IHC 3S Indiana Harbor Canal East Chicago (Columbus Drive)	4,050	4,160	30,000
IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.)	26,858	1,293	63,000
IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel)	-	971	2,300

IITRI conducted sampling in the Grand Calumet River on November 29, 1973, in an attempt to locate the major bacterial sources. This was necessary because the STP only measures the residual chlorine in their effluent and not the bacterial concentration. We used the stations defined by Combinatorics (1974) as follows:

HSTP2B	downstream from Hammond STP
ECST-1	upstream from East Chicago STP
ECST-2	downstream from East Chicago STP
USL-1A	downstream from Gary STP, near junction with IHC.

Our data are given in Table 16.4. These show that the East Chicago STP was the largest source of total coliform count at that time. Chapter 5 indicates that Hammond STP increased the amount of its chlorination in 1973, reducing the bacterial pollution in the adjoining part of the Grand Calumet River.

The appearance of the Grand Calumet River near the Hammond STP outlet is that of an open sewer, with floating sewage debris, fungal growths, and anaerobic bottom conditions. Some self-purification is evident downstream towards the East Chicago STP, but the appearance again deteriorates below the East Chicago STP. On the east branch of the Grand Calumet River the flow is much larger, and the influence of the Gary STP is less evident, although the bacterial count is substantial.

The BOD removals of the three STP's are (from Chapter 5):

Sewage treatment plant	%
Hammond	80% (1972)
East Chicago	63% (1973)
Gary	77% (1973)

Table 16.4

WATER QUALITY MEASUREMENTS NEAR MUNICIPAL SEWAGE TREATMENT PLANTS
IITRI data, November 30, 1973

Parameter	Storet No.	Units of measurement	HSTP 2B	ECSIP -1	ECSIP -2	USL 1A
Temperature	00010	°C	16.5	15.0	14.0	18.0
Conductivity	00095	μmho/cm	910	820	1,010	350
pH	00400	pH units	8.2	7.4	7.0	7.6
Turbidity	00075	Jackson	16.0	9.1	9.0	14.0
Dissolved oxygen	00300	mg/ℓ				
Chloride	00940	mg/ℓ	103	120	170	40
Fluoride	00950	mg/ℓ	0.45	0.54	0.82	0.93
Ammonia-nitrogen	00610	mg/ℓ	4.5	7.6	21.0	2.6
Total phosphorus	00665	mg/ℓ	1.66	1.83	1.26	0.48
Total coliform	35501	MFIM ENDO 100 mℓ	200	18,000	520,000	25,000
Total organic carbon	00680	mg/ℓ	31.	27.	36.	10.
Total solids			665	507	757	216
Nonfilterable residue (suspended solids)	00530	mg/ℓ	26.1	16.9	11.1	19.2
Chlorophyll	-	mg/ℓ	-	-	-	-
Volatile solids	00505	mg/ℓ	22.9	12.6	10.1	6.0
Iron (total)	00680	mg/ℓ	0.66	0.53	0.55	0.67
Iron (dissolved)	00681	mg/ℓ	0.11	0.10	0.11	0.09

The Technical Committee (1970) recommended that the quality of effluent from the East Chicago STP must be improved. Little improvement is evident. (See Appendix D). The reason for its poor performance is discussed in Chapters 5 and 13, and is primarily due to upsets in the biological treatment process due to inputs of industrial effluents from Youngstown Sheet and Tube and Inland steel Mills. Excess lime from ammonia stripping, large amounts of ammonia, and probably other toxic materials impair the biological oxidation process at this STP.

The ammonia alone is a sufficient explanation for the high effluent bacteria concentrations, since excess ammonia prevents effective chlorination of the effluent. Improvement of performance of this plant will require more effective pretreatment by the steel industries. (See Chapters 5 and 13 where this is discussed.)

16.5 Combined Sewer Overflows

There are 31 combined sewer overflows which can contribute to the pollution of the Calumet area (Figure 5.2, Chapter 5). The sources are:

Hammond Sanitary District	15
Metropolitan Sanitary District of Greater Chicago	1
Gary Sanitary District	8
Whiting Sanitary District	2
East Chicago Sanitary District	5

There are additional overflows for storm water only. The Robertsdale outfall of the Hammond Sanitary District was supposed to be discharging only chlorinated storm water as of May 1973; however, on November 30, 1973, we observed a large area containing a black colored discharge that came directly from the Robertsdale outfall. This indicates that improper discharges may still be entering this "storm water only" system. The city of Whiting is responsible for two combined sewer outfalls to Lake Michigan. These three lake-side outfalls, shown in Figure 16.2, are most probably primarily responsible for the near-shore and beach bacterial pollution referred to in Section 16.3.

The raw water samples at the Whiting water plant (LM047A) typically show total coliform counts of 500 to 1000 (Table 11.3) and on November 14, 1973, the count was 40,000. The currents were not in the proper direction to attribute these high coli values to discharge from the IHC. The Amoco refinery seems an unlikely source for coli. The high counts suggest continuing discharges from the three outfalls shown in Figure 16.2. The problem from Whiting outfalls may be solved by present construction of a larger sewer, to carry Whiting sewage to the Hammond system. In the past, the size of this connection has been said to limit the flow, resulting in overflow to the Lake whenever it rained.

16.6 Conclusions

The main conclusions that can be drawn from this study of the bacterial pollution of the southern end of Lake Michigan are:

- There continues to be frequent violation of the Indiana Water Quality Standards for the Harbor, Beach and Open Water areas of this part of the Lake.
- The main source of coliforms is the Indiana Harbor Canal. Discharge from the Calumet River is of much less significant, although it is badly contaminated.
- Effluent from the East Chicago STP appears to be the main coliform source to the IHC. The relative contributions from the Hammond STP and Gary STP are less. The reasons why the East Chicago STP does not function effectively were discussed in Chapters 5 and 13.
- Until flow meters are installed on the Gary and East Chicago combined sewer overflows, their contribution to the total bacterial

contamination will not be assessible. The volume of the Hammond Sanitary District combined sewer overflow averages about half of the treatment plant discharge. Information on the strength of its bacterial contamination is not available.

- We were able to detect total coliforms, traceable as originating in IHC discharge, five miles out into the Lake on November 14, 1973, at station LM102.

- High levels of bacterial contamination along the Hammond and Whiting beaches appear to be caused by combined sewers discharging to the Lake at Robertsdale and Front St. The Robertsdale outfall is supposed to be only chlorinated storm water.

CAL16
Hammond Water Plant Intake
EPA data

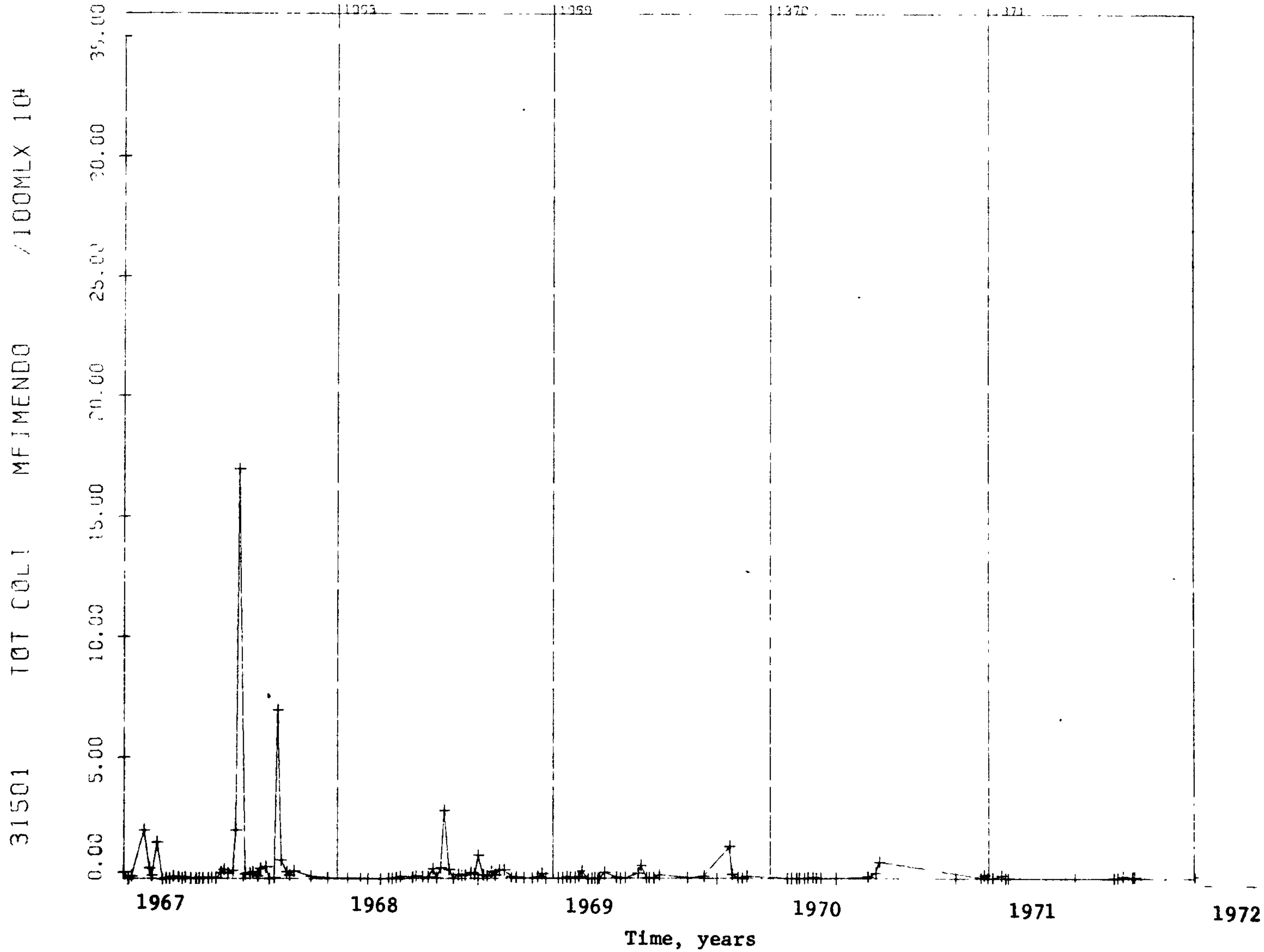

Figure 16.4
STORET WATER QUALITY PLOT

LM W
Whiting Water Plant Intake
Indiana data

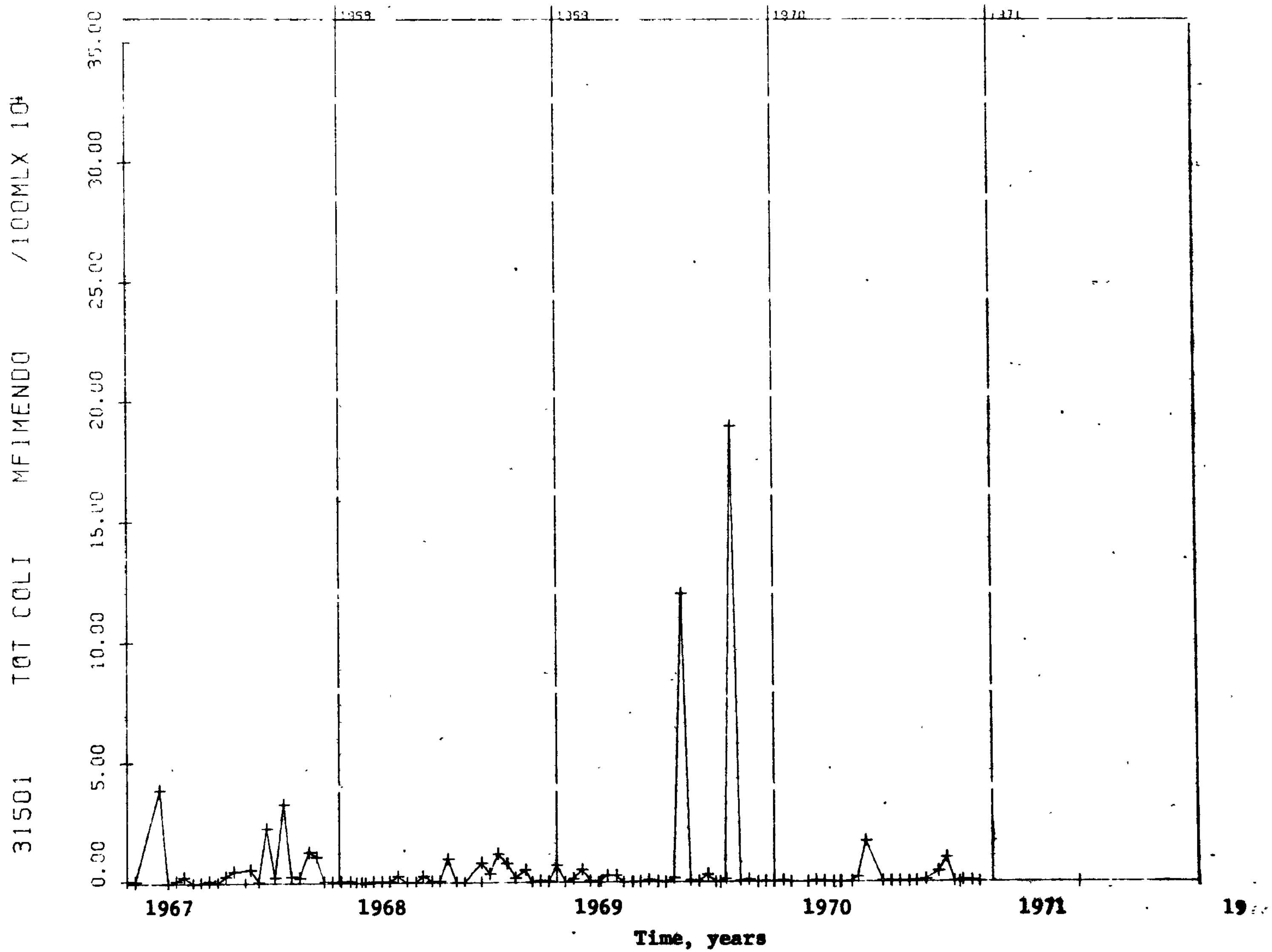

Figure 16.5

STORET WATER QUALITY PLOT

17. PHOSPHORUS

17.1 Introduction

Phosphorus represents one of the most serious pollution problems in the Calumet area of Lake Michigan. Phosphorus concentrations are relatively high in the near-shore waters of the Calumet area. The consensus of biologists is that these high levels are responsible at least in part for the observed eutrophication of near-shore waters (Phosphorus Technical Committee 1972; Thomas, Hartwell and Miller 1972; and Schelske and Roth 1973). Control of phosphorus would limit eutrophication (Schindler 1974).

Phosphorus is one of the most important pollutants in Lake Michigan because its concentration controls one of the most evident effects of pollution, namely the growth of algae. The harmful effects of various kinds of algae in clogging of water intakes, forming unpleasant deposits on beaches and detracting from the enjoyment of the water are discussed in Chapter 8 and in Appendix A. Although Lake Michigan is not yet affected to the extent of Lake Erie, the deterioration of near-shore conditions in Lake Michigan in the last 15 years is alarming. As discussed below, we do not have sufficient knowledge about the phosphorus cycle in the Lake to predict reliably the length of time needed for the Lake to recover after phosphorus inputs are reduced. For these reasons the information in this chapter is important, as well as the recommendations for further phosphorus control.

Our analysis of available data shows that the long-range trend of phosphorus in the Calumet area has increased in the past 15 years.

Control methods by the State of Indiana have lowered phosphorus from the IHC since 1970, and this may be responsible for a slight decrease that is noted in near-shore concentrations. We recommend further inspections to insure that controls are properly carried out, so that phosphorus effluents can be further reduced to the levels recommended by the Phosphorus Technical Committee (1972). Further control efforts should also be carried out by Michigan, Illinois and Wisconsin to achieve the recommended reductions.

17.2 Effluent and Water Quality Standards

The Phosphorus Technical Committee (1972) of the Lake Michigan Enforcement Conference stated that a phosphorus reduction of more than 80% was needed. It was decided that this could best be achieved by setting a limitation of phosphorus concentration in municipal and industrial effluents of 1 mg/ℓ, and this has now been embodied in Indiana standards.

Water quality standards also exist for various waters, and they are given in Table 17.1.

The Illinois limit is substantially lower than the Indiana standards. The International Joint Commission (1973) (for other Great Lakes) recommends that phosphorus levels be limited to values that will prevent nuisance growths of algae, weeds and slimes, but does not give a numerical value. The Phosphorus Technical Committee (1972) quotes Vollenweider (1968) who specifies a value of 0.01 mg/ℓ dissolved phosphorus to prevent nuisance algal blooms. The Committee considers 0.02 to 0.03 total P to be an equivalent goal for Lake Michigan.

17.3 Water Quality and Violations of Standards in Lake Michigan

The most extensive data on water quality are those obtained from Lake surveys conducted by the Chicago Water Department. Data from the Shore surveys are summarized in Figure 17.1. Most of the values exceed the Illinois standard and the recommendation of the Phosphorus Technical Committee, and some exceed the Indiana standards.

A striking increase is noted in 1973, but we do not believe it represents a trend. The difference from previous years is due to one sampling run done in May 1973 when very high values were found at all stations. Knight, Schmeelk and Lue-Hing (1972) reported a similar high sampling run in May 1970, 1000 ft off North Avenue, Chicago, and 5000 ft off Zion, Illinois. These individual high values appear to be unusual or sporadic events, and we cannot conclude from them that there is an upward trend in 1973. Excluding the May run, the 1973 values would average about 0.02 mg/ℓ.

Table 17.1

WATER QUALITY STANDARDS
PHOSPHORUS, TOTAL, mg/ℓ AS P

		Lake Michigan					
		Open water		Inner harbor		Indiana Harbor Canal	
Agency	Regulation	Average	Single value	Average	Single value	Regulation	Single value
Indiana	SPC 4R	0.03	0.04	0.03	0.05	SPC 7R-2	0.10
Illinois	206		0.007				
Phosphorus Technical Committee		0.02 (recommendation)					

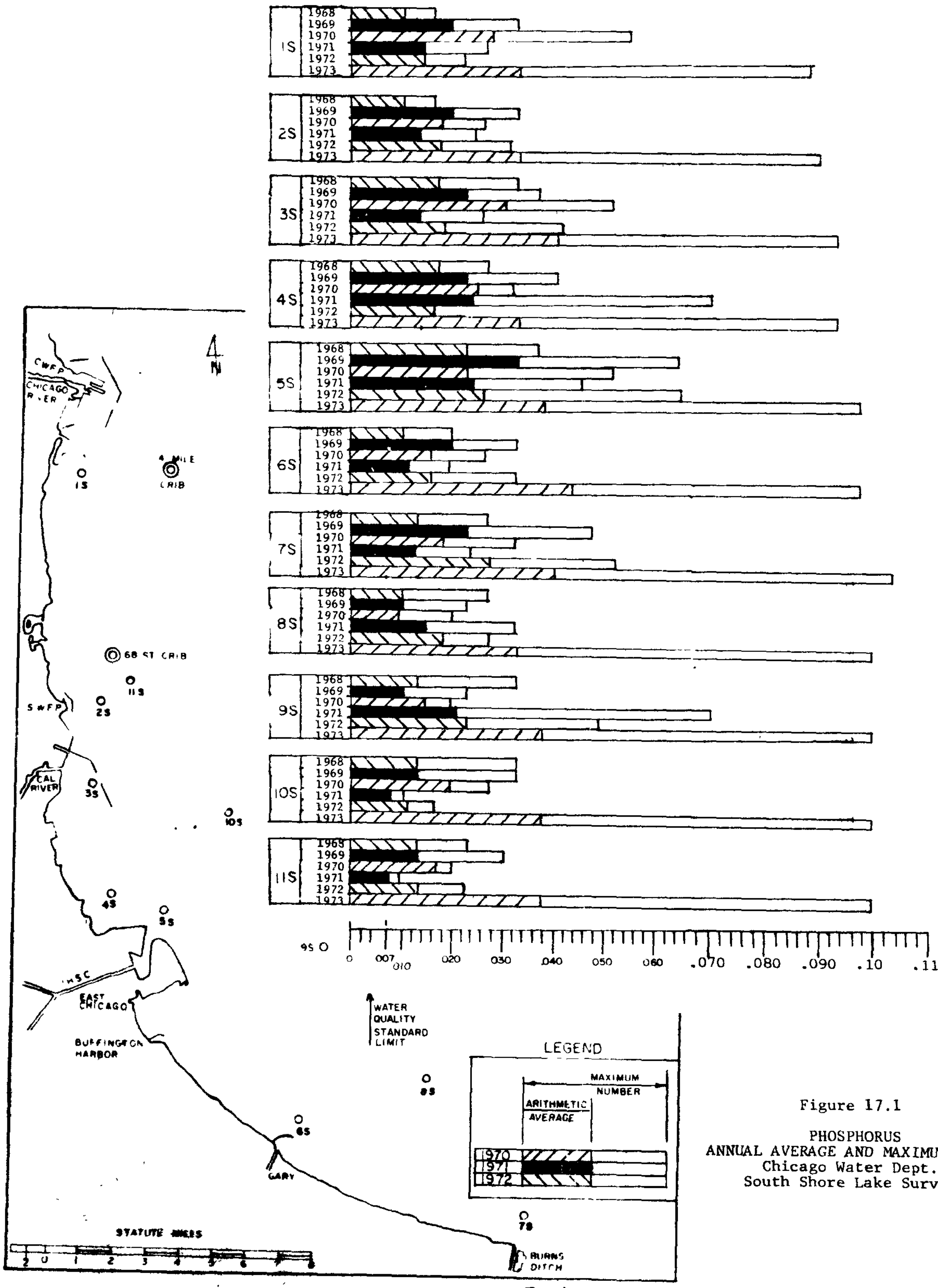

Figure 17.1

PHOSPHORUS
ANNUAL AVERAGE AND MAXIMUM, PPM
Chicago Water Dept.
South Shore Lake Survey

The data in Figure 17.1 from the South Shore survey show little correlation with position in the Lake, indicating that the general phosphorus level in near-shore waters cannot be directly traced to a local source; however, on three dates the Radial Surveys of the Chicago Water Department plotted in Figures 17.2 to 17.4 clearly show peaks of phosphorus concentration at stations 5J to 6J in the usual path of the plume from IHC. This indicates that the contribution from the IHC is detectable and significant, although it does not account for the main phosphorus level throughout this part of the Lake. Other phosphorus data from the U.S. EPA and from the State of Indiana are plotted in Figures 17.7 to 17.12 (Storet data). An IITRI measurement indicating a nutrient effect from the IHC plume is described in Section 17.5.

Long-term trends of phosphorus are indicated by the data for the Chicago South Water Filtration plant intake, plotted in Figure 17.5. Although there are cyclical variations, there is a general upward trend. Since 1971 there is a slight downward trend. This will be discussed below.

The increasing concentrations of phosphorus and perhaps also of nitrogen are believed to be the cause of increasing growths of algae. A study by Thomas, Hartwell and Miller (1972) used the nutrient algal assay method to determine that Lake Michigan algal growth is primarily limited by phosphorus and secondarily by nitrogen. Increased fouling of beaches by cladophera and of water intakes by various algae are discussed in Chapter 8. These biological growths tend to reflect average nutrient levels. The increasing growths confirm that the increasing measured nutrient concentrations are real, and are not due to sampling variations.

17.4 Background Phosphorus Values

Background values of phosphorus in Lake waters far from any sources of pollution have been reported. Schelske and

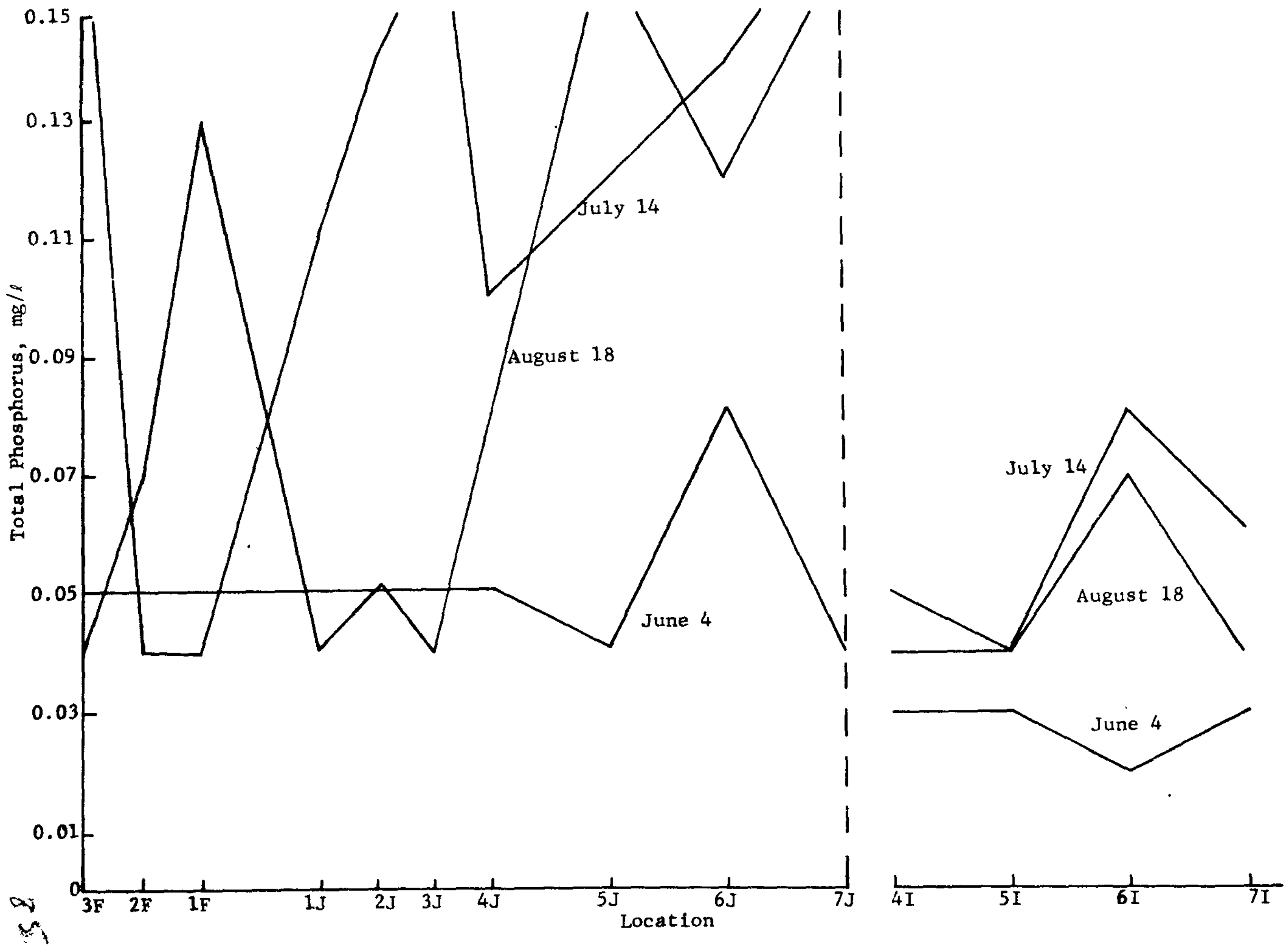

Figure 17.2

RADIAL SURVEY OF TOTAL PHOSPHORUS CONCENTRATION - 1970
Chicago South Water Filtration Plant

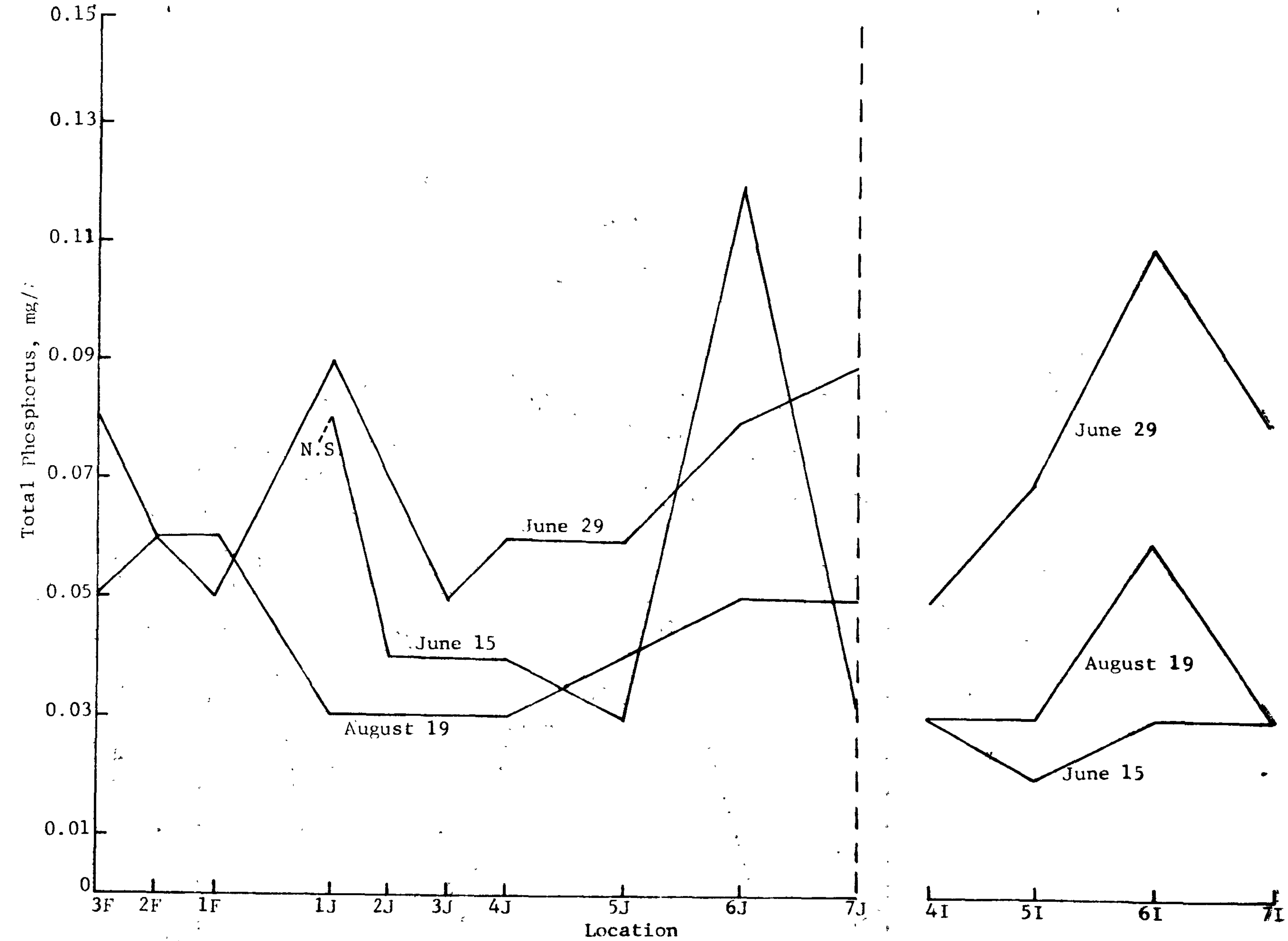

Figure 17.3

RADIAL SURVEY OF TOTAL PHOSPHORUS CONCENTRATION - 1971
Chicago South Water Filtration Plant

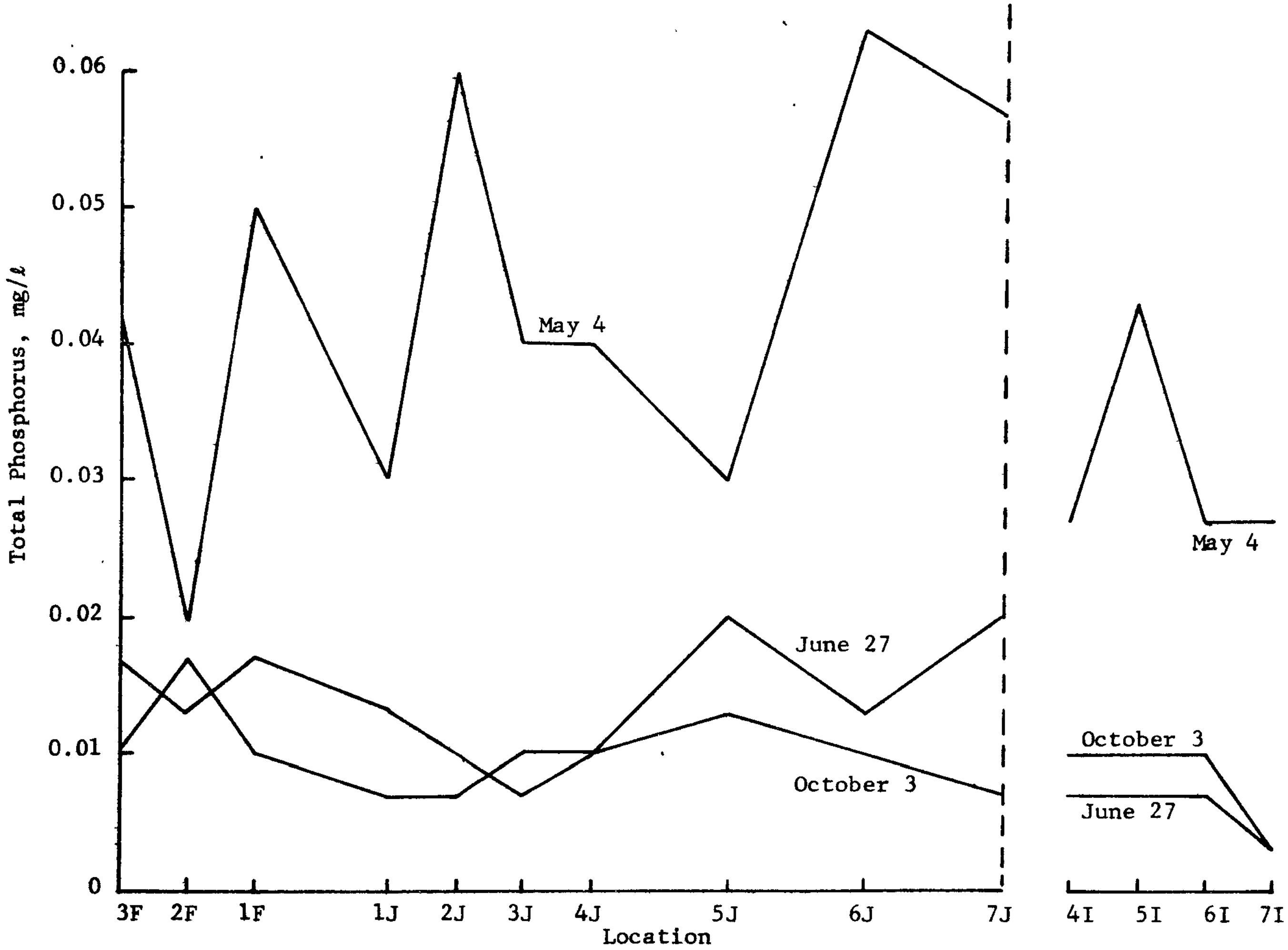

Figure 17.4

RADIAL SURVEY OF TOTAL PHOSPHORUS CONCENTRATION - 1972
Chicago South Water Filtration Plant

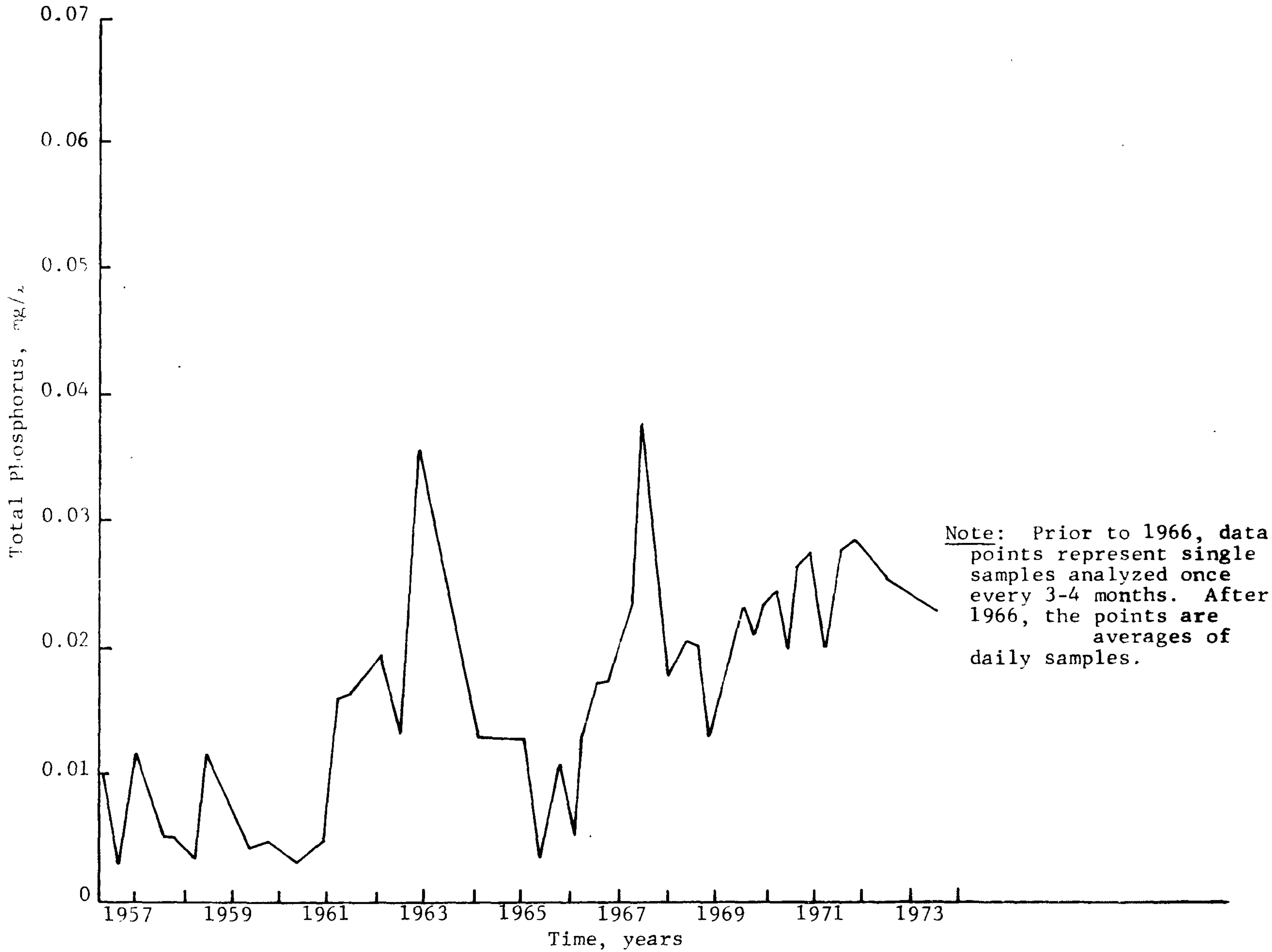

Figure 17.5

TOTAL PHOSPHORUS CONCENTRATION - 1956-1973
Chicago South Water Filtration Plant

Roth (1973) analyzed 16 samples of water from six locations and five depths in the northeast corner of the Lake, near Charlevoix, Michigan. The samples were taken in July 1970. The mean value of soluble phosphorus was 0.0017 ± 0.0012 mg/ℓ P. The smallest value was 0.0013 at 40 m depth. A greater amount of phosphorus was contained in suspended particulate matter; this form of phosphorus averaged 0.0060 ± 0.0077 mg/ℓ P. The smallest value was 0.0028 at the surface and the largest was 0.018 at 40 m depth, due to settling of particulates. Adding these two forms, the total phosphorus averages 0.008 mg/ℓ. These values compare with an average of 0.020 for the Chicago Water Department South Shore surveys. The concentrations in the Calumet area are well above those in the Charlevoix area.

Risley and Fuller (1965) reported results of surveys across the Lake at several latitudes. One survey at the latitude of Sheboygan, Wisconsin, gave phosphorus values of 0.02 mg/ℓ near shore and 0.01 in the center of the Lake. At the latitude of Calumet Harbor the values were 0.04 to 0.10, with the highest values on the Michigan side. These measurements were made in 1962-1963. There may have been interferences in the analysis of samples near shore (Fuller 1974).

Powers and Ayers (1967) summarize total phosphorus measurements in mid-Lake waters. In the northern half of the Lake the average is 0.006 mg/ℓ P, in agreement with the results of Risley and Fuller (1965). Risley and Fuller's averages at Chicago latitude are 0.013 mg/ℓ, and at the Whiting latitude they average 0.020 mg/ℓ.

Holland and Beeton (1972) measured water parameters at five locations on a transect from Milwaukee to Ludington from May 1970 to January 1971. The average value of total phosphorus was 0.0085 mg/ℓ at all stations except near Milwaukee, where the shore water had higher values. The sampling was continued to October 1971 (Rousar 1973). Again the average value of total phosphorus in the open Lake was 0.0085 mg/ℓ.

From all of the above data, we can conclude that a representative background concentration of total phosphorus in open Lake waters is 0.008 to 0.009 mg/ℓ. Concentrations in near-shore waters are generally higher, at least near sources of pollution.

17.5 Sources of Phosphorus

Table 17.2 (Phosphorus Technical Committee 1972) lists the phosphorus inputs of various rivers to Lake Michigan. The Fox River at Green Bay is the largest source, followed by the Grand and St. Joseph at the southeastern end of the Lake. The IHC contributes about 7% of the total. In addition to the rivers there are other inputs to the Lake. Table 17.3 lists other point sources, mostly municipal treatment plant outfalls. Those in northeastern Illinois and southern Wisconsin contribute another 3,500,000 lb/yr.

Shore currents might carry phosphorus effluents to the Calumet area from the St. Joseph and Grand Rivers in Michigan, as well as from sewage treatment plants on the north shore of Illinois and Wisconsin. Such shore currents are known from general circulation patterns (FWPCA 1967) and are also indicated by recent ERTS satellite photos (Photo No. E-1394-16035 401) which show sediment being carried down the eastern shore to the Calumet area. Furthermore, algal damage to eastern Lake beaches has been documented (FWPCA 1968) indicating that phosphorus nutrient effects are observed at other points along the path of travel of pollutants. Examination of the measured total phosphorus values for Calumet waters shown in Figures 17.2 to 17.4 indicates that there are some peaks due to the IHC plume, but there is also a general high phosphorus level in the area. How much of this high level is due to the IHC and how much to the more remote sources cannot be determined from the data, partly because we do not know the residence time of phosphorus in the Calumet area. The larger inputs from the remote sources, and the known currents that can carry phosphorus from remote sources

Table 17.2

TOTAL PHOSPHORUS LOADING TO LAKE MICHIGAN
TRIBUTARY CONTRIBUTIONS
Source: Phosphorus Technical Committee (1972)

Tributary	Total Drainage Area	Average Discharge	Tributary Phosphorus Discharge To Lake
	sq. mi.	cfs	1000#/yr.
Root	196	184	191
Milwaukee	845	470	379
Sheboygan	440	232	168
Manitowoc	442	195	142
West Twin	166	85	36
East Twin	140	71	30
Kewaunee	146	80	40
Fox	6,443	6,130	2,654
Pensaukee	160	144	25
Oconto	933	825	162
Peshtigo	1,155	1,010	99
Menominee	4,150	3,427	809
Big Cedar	387	309	30
Ford	468	435	25
Escanaba	920	1,104	108
Whitefish	315	386	30
Manistique	1,450	2,327	274
Boardman	347	331	123
Pine (Charlevoix)	370	396	31
Manistee	2,010	2,418	238
Pere Marquette	772	846	166
Pentwater	172	182	21
White	480	496	48
Muskegon	2,780	2,990	529
Grand	5,534	4,431	2,180
Black (Holland)	176	133	44
Kalamazoo	2,069	2,535	648
Black (S. Haven)	83	359	84
St. Joseph	4,311	5,635	2,107
Burns Ditch	330	327	199
Ind. Harbor		2,700	850*
	38,190	41,193	12,470

Unmonitored tributary non-point source contribution is taken to be 725,000 pounds per year (100 pounds of Phosphorus per square mile).

Total contribution from tributaries is thus estimated at 13.2 million pounds
*Indiana Harbor figure may include Phosphorus originally taken from lake by industrial cooling water use.

Table 17.3

ESTIMATED PHOSPHORUS SOURCES FOR LAKE MICHIGAN

Source	Load (million lb/yr)
Direct waste water sources	3.9
Indirect waste water sources	9.3
Total waste water sources	13.2
Erosion and other diffuse sources	1 to 7
Generalized total load excluding precipitation and dustfall	14 to 20
1969 total load (estimated and measured) excluding precipitation and dustfall	17.1
Combined sewer overflow	0.8
Precipitation and dustfall on surface of Lake Michigan **	1.1

*Source: Phosphorus Technical Committee to the Lake Michigan Conference (1972).

**Source: Lee (1972).

Murphy (1973) estimates that the phosphorus from rainfall amounts to 4 million lb/yr based on analysis of rainfall samples; the source of this phosphorus has not been determined.

could contribute. Correction of the Calumet eutrophication problem may require controlling these other, more distant sources, as well as the IHC.

IITRI measurements in Table 11.3 of chlorophyll in Lake samples show that the IHC effluents have a nutritive effect, and it will be shown that this can be taken as evidence that the IHC is a significant source of phosphorus as well as ammonia. For example, on November 14, 1973, the chlorophyll increased from 3 μg/ℓ at the mouth of the IHC (CAL06) to 5.4 at LM080 to 11.9 at LM102, five miles out in the Lake but still in the plume of the IHC. Locations not in the plume showed values from 1.5 to 2.0 chlorophyll on November 14. NH_3-N concentrations were also measured at these stations and are given in Table 11.2, but P concentrations were not determined. The P concentrations at CAL06 were 0.060 on November 19 and 0.070 on December 7, and these are typical IHC values according to other sources of data. Data from Industrial Biotest (1973) on November 14, 1973, indicate a phosphorus value at CAL06 of 0.044, at LM068 of 0.014, and at stations outside the plume of 0.001 mg/ℓ.

On the other two IITRI boat sampling days, the chlorophyll increases were not pronounced. November 19 was a cloudy day, and the chlorophyll values in the plume reached only 2.7 at CAL15, which value is above the values outside the plume. On December 7 the chlorophyll values were high everywhere, perhaps because phosphorus was high due to wave action stirring the Lake bottom, as described in the next section.

Chlorophyll values in the IHC itself are lower than in the Lake, and so high chlorophyll values in the plume are not due to algae flowing into the Lake from the IHC. These low values in the IHC may be due to a toxic effect, as was suggested in a similar case by Fruh, Armstrong, and Copeland (1972).

The main conclusion from these chlorophyll studies is that the IHC nutrients, when mixed with the Lake water, promote the growth of algae in near-shore waters.

The long-term trend of phosphorus input from IHC is measured by the Chicago Water Dept. at Dickey Rd. Annual averages of weekly samples are plotted in Figure 17.6. Included on the graph is one point for the average of 12 days sampled by IITRI during November-December 1973. This was done at Columbus Drive rather than at Dickey Rd., but the results of phosphorus should be the same at the two points. Additional values from the State of Indiana summer 1973 sampling taken from Table 17.4 are indicated on the graph. All these values show that phosphorus inputs from IHC have decreased in recent years. These decreases are attributed partly to phosphorus precipitation tertiary treatments installed in 1972 by two of the sewage treatment plants in the area, and parly to limitations on phosphorus content of detergents required by recent Indiana law. But from the above discussion, a further decrease is needed to prevent eutrophication of near-shore Lake waters. Also, improvement will be needed in other states bordering on the Lake.

Table 17.5 gives details of phosphorus loads from various outfalls going to the IHC, and indicates which sources are the most important. A comparison of the Combinatorics load estimates with measurements made in the IHC by IITRI indicate that the actual loads are much higher than the estimates. The comparison is given in Table 4.5, Chapter 4. This comparison suggests that the treatment plants are not performing according to their design, and is one basis for our recommendation that closer inspection should be done. See Chapter 5 and Appendix D.

17.6 Effect of Bottom Stirring on Phosphorus Concentrations

Table 17.6 shows daily phosphorus concentrations at the Chicago South Water Filtration plant intake during November-December 1973. There are occasional periods of high concentrations, and these seem to be correlated with high turbidity. We noted that the turbidity of the near-shore waters is associated with high waves and current during and after storms. Wind and

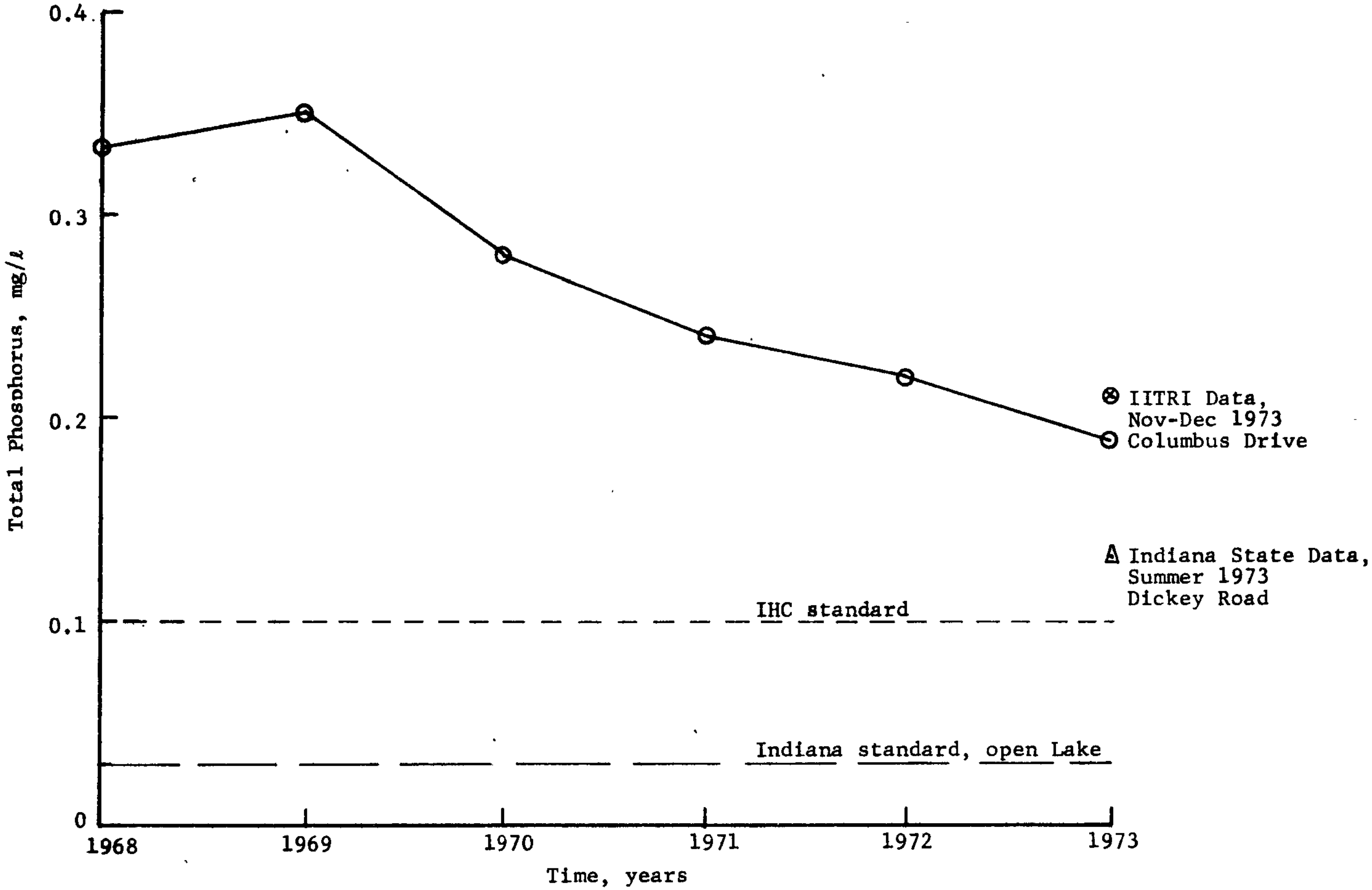

Figure 17.6

ANNUAL AVERAGE PHOSPHORUS CONCENTRATION IN INDIANA HARBOR CANAL AT DICKEY ROAD

Data Sources: Calumet Industrial Area Pollution Survey, Chicago Dept. of Water and Sewers, weekly samples

Table 17.4

IN-STREAM WATER QUALITY, 1973
Combinatorics (1974)

Description	Total phosphorus		
Water quality standard	0.10 mg/ℓ		
Monitoring stations	72 Average	73 Average	72-73 Maximum
GCR 41 Grand Calumet River Gary (U.S. 12)	1.4	0.10	6.6
GCR 37 Grand Calumet River East Chicago (Kennedy Rd.)	1.1	0.23	2.7
GCR 36 Grand Calumet River East Chicago (Indy. Blvd.)	4.5	0.85	9.9
GCR 34 Grand Calumet River Hammond (U.S. 12)	8.5	1.84	9.9
IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.)	1.2	0.19	3.3
IHC 3S Indiana Harbor Canal East Chicago (Columbus Drive)	1.1	0.23	2.5
IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.)	1.0	0.13	1.6
IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel)	-	0.10	0.16

Table 17.5

PHOSPHORUS DISCHARGES TO IHC
Source: Combinatorics (1974)

Phosphorus
Water Quality Standard .1 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
U. S. Steel								
GW-1	19.9	28.9	40.7	17.00	23.78	.05	.07	
GW-2	10.9	16.4	23.0	5.50	9.58	.04	.05	
GW-2A	1.4	2.2	3.9	.74	1.60	.04	.05	
GW-3	2.7	3.8	4.5	.95	1.90	.03	.05	
GW-3A	0.4	1.7	3.7	.57	1.50	.04	.05	
GW-4	0.5	0.7	0.9	.23	.40	.04	.05	
GW-5	82.4	87.7	95.3	65.80	87.40	.09	.11	
GW-6	23.4	29.5	39.4	12.30	23.03	.05	.07	
GW-7	5.8	10.6	16.9	8.84	21.15	.10	.15	
GW-7A	93.3	120.1	146.0	50.50	97.40	.05	.08	
GW-9	24.7	34.7	39.7	8.69	13.24	.03	.04	
GW-10A	26.3	34.6	47.2	11.53	19.70	.04	.05	
GW-11A	81.3	94.7	115.6	31.60	48.40	.04	.05	
GW-13	1.8	2.9	4.8	1.20	3.20	.05	.08	
ST-14	0.8	1.8	3.3	3.05	7.42	.20	.27	
ST-17	20.1	30.0	39.3	20.00	32.80	.08	.10	
GSTP	44.0	52.7	62.0	232.50	878.00	.53	1.70	
E.I. duPont								
001	0.5	1.8	2.4	7.00	35.00	.56	1.75	Net value
002-004	7.24	10.31	11.66	13.00	25.00	.15	.26	Net value
005	0.07	0.08	0.12	-	-	-	-	
006-010	0.89	2.24	2.98	-	-	-	-	
U.S.S. Lead		0.36		-	-	-	-	No net additio[n]
HSTP	35.0	40.7	44.0	115.30	550.00	.34	1.50	
ECSTP	10.0	14.0	20.0	35.00	162.80	.30	.10	
Union Carbide	0.05	0.07	0.11	.27		.46		
ARCO		5.04	6.77	180.30	486.00	4.30	8.60	
Amer. St. Foundries	0.09	0.15	0.27	.18		.14		

Table 17.5 (cont.)

Phosphorus — Water Quality Standard .1 mg/1

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
Youngstown								
001 YS-20	8.46	13.70	23.60	9.41		.08		Intake ave .06
002 YS-2	1.50	3.62	7.50	2.49		.08		Intake ave .06
003 YS-4	0.53	0.98	1.40	.98		.12		Intake ave .06
004 YS-8	1.03	1.40	1.75	.70		.06		Intake ave .06
005 YS-11	1.19	1.60	3.00	1.33		.10		Intake ave .06
006 YS-12	3.30	5.70	8.40	3.33		.07		Intake ave .06
007 YS-13	6.30	14.00	18.90	9.62		.08		Intake ave .06
008 YS-22	3.00	5.00	11.70	4.17		.10		Intake ave .06
009 YS-14	34.00	48.70	60.00	24.37		.06		Intake ave .06
010 YS-15	36.60	58.00	67.00	48.37		.10		Intake ave .06
011 YS-18A	107.80	121.60	138.70	60.70		.06		Intake ave .06
Inland								
001 IE-2		.14	.29	1.40		1.20		
002 4E-1		190.00	228.00	63.38		.04		
003 5E-1		7.20	8.60	6.00		.10		
004 5E-2	8.60	0.86	1.04	.29		.04		
005 5E-3		8.60	10.40	4.30		.06		
006 6E-1		0.65	1.30	.43		.08		
007 7E-1		21.60	25.90	5.40		.03		
008 10E-1	Unknown & Highly Variable							
011 13G-1	126.96	158.70	190.44	26.00	79.41	.02	.05	Maximum 24 hr. sample
012 13H-1	67.68	50.80	70.00	12.71	35.03	.03	.06	Maximum 24 hr. sample
013 14H-TT	85.52	106.90	128.28	9.00	32.09	.01	.03	Maximum 24 hr. sample
014 15H-TT	85.52	106.90	128.28	9.00	32.09	.01	.03	
015 16H-1	17.28	21.60	25.92	9.00	32.42	.05	.15	Maximum 24 hr. sample
016 16H-2	7.20	9.00	10.80	8.00	27.02	.11	.30	
017 16H-3	115.28	144.10	172.92	12.00	43.26	.01	.03	
018 16F-1	119.76	149.70	179.64	37.00	62.00	.03	.05	Maximum 24 hr. sample

Table 17.6

PHOSPHORUS CONCENTRATIONS
CHICAGO SOUTH WATER FILTRATION PLANT,
NOVEMBER - DECEMBER, 1973
AND PARAMETERS INDICATING CORRELATION WITH BOTTOM STIRRING

Date	PO_4 mg/ℓ	Turbidity, JTU	Winds	
			Direction	Speed, mph
November 1	0.06	5.3	SW	15
2	0.03	4.6	NE	14
3	0.03	5.2	N	13
4	0.03	5.9	N	17
5	0.04	8.3	W	17
6	0.04	8.9	W	13
7	0.03	7.8	S	10
8	0.02	6.5	W	14
9	0.03	8.5	NW	14
10	0.02	7.6	SW	9
11	0.02	5.3	SW	16
12	0.02	3.5	SW	18
13	0.03	3.1	SW	17
14	0.03	2.8	SW	14
15	0.04	7.4	NW	18
16	0.04	11	NW	13
17	0.03	14	S	18
18	0.04	6.9	S	17
19	0.05	6.6	NE	13
20	0.04	8.2	SE	20
21	0.03	6.3	SW	24
22	0.03	3.0	S	11
23	0.03	2.5	NE	9
24	0.03	2.4	SW	15
25	0.02	3.5	N	13
26	0.02	4.6	E	15
27	0.03	4.1	SW	6
28	0.06	13	W	25
29	0.06	14	SW	16
30	0.06	10	N	17

Table 17.6 (cont.)

Date		PO_4 mg/ℓ	Turbidity, JTU	Winds Direction	Winds Speed, mph
December	1	0.06	14.0	E	19
	2	0.05	9.6	S	23
	3	0.04	5.6	SW	16
	4	0.07	7.7	S	22
	5	0.05	8.1	SW	19
	6	0.04	5.8	SW	15
	7	0.04	8.3	S	11
	8	0.04	6.1	SW	14
	9	0.03	3.6	SW	13
	10	0.03	5.3	W	17
	11	0.04	6.9	SW	13
	12	0.04	5.9	E	12
	13	0.11	30.0	NE	33
	14	0.09	40	NE	15
	15	0.08	30.0	NE	18
	16	0.09	31.0	NE	18
	17	0.08	32.0	SW	9
	18	0.09	28.0	SE	12
	19	0.08	23.0	NE	21
	20	0.11	28.0	N	21
	21	0.07	21.0	SW	8
	22	0.03	16.0	SW	16
	23	0.03	15.0	E	16
	24	0.03	18.0	E	21
	25	0.03	16.0	SW	19
	26	0.04	13.0	NE	11
	27	0.09	14.0	W	15
	28	0.09	12.0	SW	17
	29	0.05	9.7	W	15
	30	0.04	10.0	W	11
	31	0.04	9.4	N	14

wave observations are also recorded in Table 17.6, and the correlation coefficient is 0.85. This correlation suggests that the observed phosphorus concentrations in the near-shore waters are determined largely by stirring up of bottom sediments, which Schleicher and Kuhn (1970) have shown to contain phosphorus.

Phosphorus is abstracted from the water and deposited in sediments in the detritus of organisms that die and settle, and may be subsequently stirred up. Wildung and Schmidt (1973) have reported elevated sediment phosphorus levels during late summer and early fall in lake locations having increased organic carbon and nitrogen concentrations.

Robertson and Powers (1965) measured particulate organic matter in Lake Michigan and found higher concentrations near the Chicago area than elsewhere.

The exchange of phosphorus between sediments and the water is beyond the scope of this report, but the data in Table 17.6 indicate that such relationships are important factors in determining the phosphorus levels in this part of Lake Michigan, and deserve further study.

17.7 Recent Phosphorus Trends and Models

Lee (1972) has analyzed the phosphorus sources discussed above, and assessed their probable impact on Lake Michigan. He points out that a conservative model for the build-up of P in Lake Michigan is not valid, because the rate-determining step is the deposition of P in sediments. He estimates that the apparent residence time of P in the Lake is six years. This is based on the 1971 P input rate of 18.1×10^6 lb/yr (8.2×10^{12} mg/yr) and the Lake volume of 5×10^{15} liters, together with the estimate (Phosphorus Technical Committee 1972) that the mean P concentration in the Lake is now 0.01 mg/ℓ. This is a very crude estimate, because the concentration of P in the Lake may not yet have responded to increased P inputs due to increased population and urbanization of recent years; however, it is more likely to be correct than estimates of 30 to 100 years that are based on the assumption that P is conserved in the Lake. Based on this estimate, Lee (1972) quotes a model of Sonzogni and Lee (1972) which estimates that the Lake will recover to 95% of its steady-state P concentration in 18 years after P inputs are reduced; and that a significant improvement will be seen within a few years after reductions are made in P inputs. This is based on the idea that most of the P which is deposited in sediments is permanently lost. This, of course, has not been proven.

The problems of eutrophication discussed in Chapter 8 are much more noticeable in near-shore waters than any effects in the main part of the Lake. The response of the near-shore waters to changes in P inputs should be almost immediate, except for the contribution due to the background P concentration and from sediments. The data for the Chicago water intake (Figure 17.5) show a 20% decrease in the last two years. The decrease might not be statistically significant by itself, but taken as a possible result of the 40% decrease in P from the IHC (shown in Figure 17.6) it is an encouraging sign. It indicates that P control efforts are probably having a beneficial effect in the near-shore waters, and that these efforts should be continued.

17.8 Conclusions and Recommendations

The long-range trend of phosphorus has been increasing in the Calumet area over the past 15 years. The long-range trend in the whole Lake is not so sure, because applicable data are limited. The inputs of phosphorus are large, but phosphorus is deposited in sediments, and may also be released from sediments (Wildung and Schmidt 1973). How much of the loss to sediments is permanent is not known. Although increases of phosphorus at mid-Lake locations are not certain, increases in the Calumet area are very real.

Phosphorus levels in the Lake in the whole Calumet area average at the Indiana standards (0.03 mg/ℓ P) and practically always exceed the Illinois standard of 0.007 mg/ℓ P. Furthermore, the phosphorus level is believed to be the main nutrient limiting the growths of algae that have contributed serious eutrophication in the near-shore waters in the years since 1966.

However, the trend of phosphorus loads from the IHC has been decreasing since 1970 due to improved municipal sewage treatment, including the installation of phosphorus precipitation processes in 1972. Regulation by the State of Indiana of phosphorus content in detergents is another reason for the improvement in IHC loadings. These efforts by the State of Indiana are sufficient to bring recent concentrations in the Lake outside IHC down to the Indiana standards, but they are not sufficient to achieve phosphorus standards in the IHC itself.

IITRI chlorophyll measurements on November 14 and November 19, 1973, showed a pronounced nutritive effect of IHC effluents mixing with Lake waters, causing algae to grow in the plume. This could be due to phosphorus, nitrogen, or both. These data indicate that IHC effluents are still contributing to algal fouling of water intakes and beaches.

The 80% reduction in phosphorus effluents recommended by the Lake Michigan Enforcement Conference and adopted by the states has not yet been achieved, although a reduction of 40% has been achieved in the IHC by the end of 1973. The Phophorus Technical Committee (1972) recommended that phosphorus be further controlled by setting an effluent limitation of 1 mg/ℓ total P for municipal and industrial sources. The permit application data in Table 17.5 indicate that the effluent limitation of 1 mg/ℓ is being met for most dischargers, but the measurements in the IHC (Figure 17.6) indicate that the loadings are still too high. We recommend that the control efforts be continued to further lower phosphorus entering the Lake via the IHC. This may require closer inspection and control of the operation of sewage treatment plants in the area, rather than any new methods of control. It may also require monitoring of combined sewer overflows, for which data are presently lacking.

The IHC sources comprise 7% of the total phosphorus inputs to the Lake. This figure is based on Combinatorics (1974) data from permit applications for IHC sources, and on Phosphorus Technical Committee (1972) estimates of other Lake sources. The main Lake sources are the Fox, Grand, and St. Joseph rivers, located in other parts of the Lake, as well as sewage plant effluents north of Chicago and in Wisconsin.

In conclusion it is recommended that renewed efforts be made to control the phosphorus inputs in all parts of Lake Michigan, to reverse the serious eutrophication trend that is evident in near-shore waters.

CAL02
IHC and 151st St.
EPA data

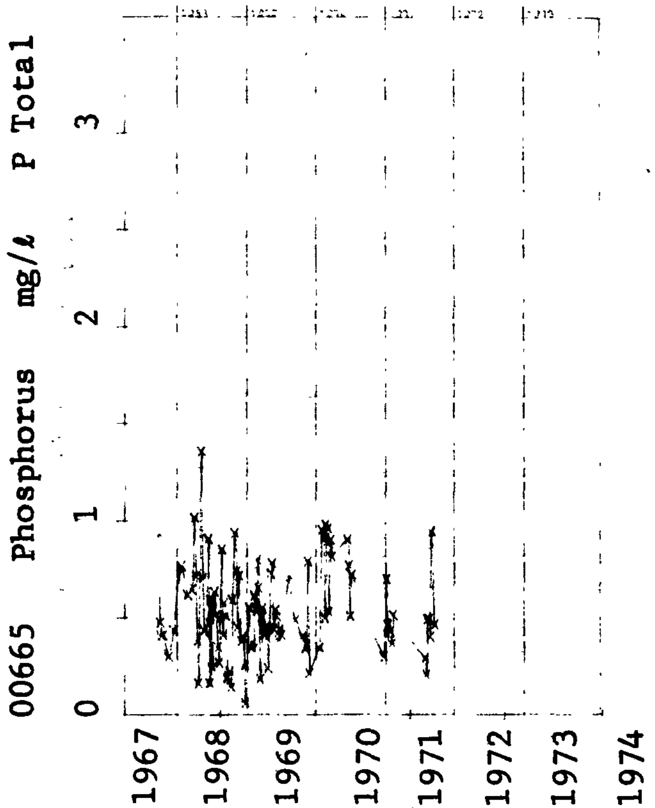

Figure 17.7

STORET WATER QUALITY PLOT

IHC 3S
IHC and Columbus Drive
Indiana data

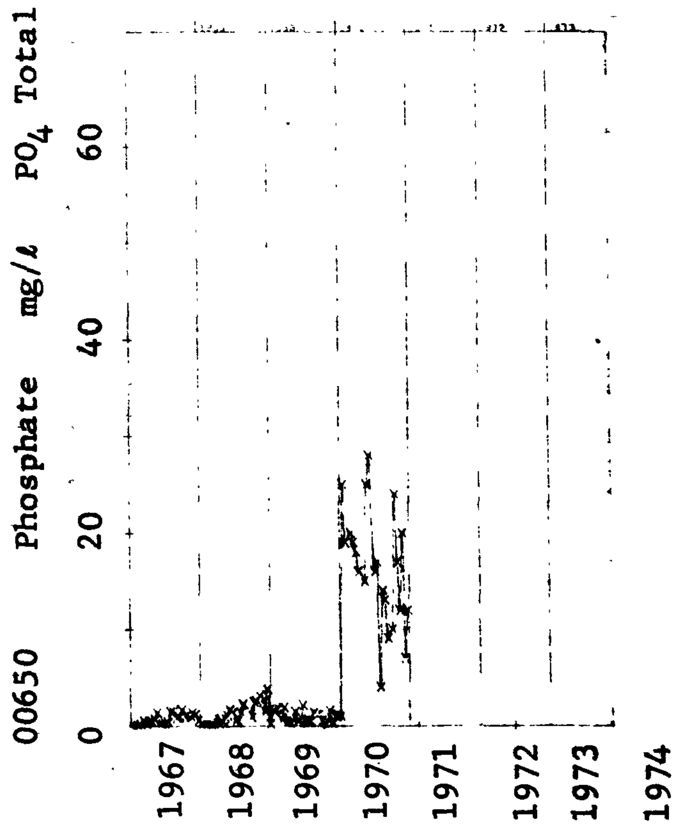

Figure 17.8

STORET WATER QUALITY PLOT

CAL03

IHC and Dickey Rd.

EPA data

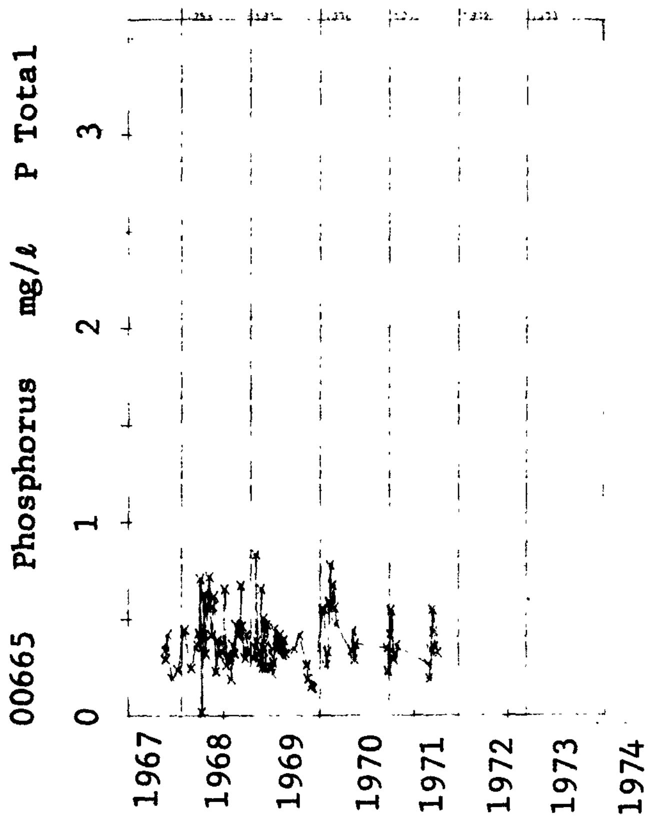

Figure 17.9

STORET WATER QUALITY PLOT

IHC 1

IHC and Dickey Rd.

Indiana data

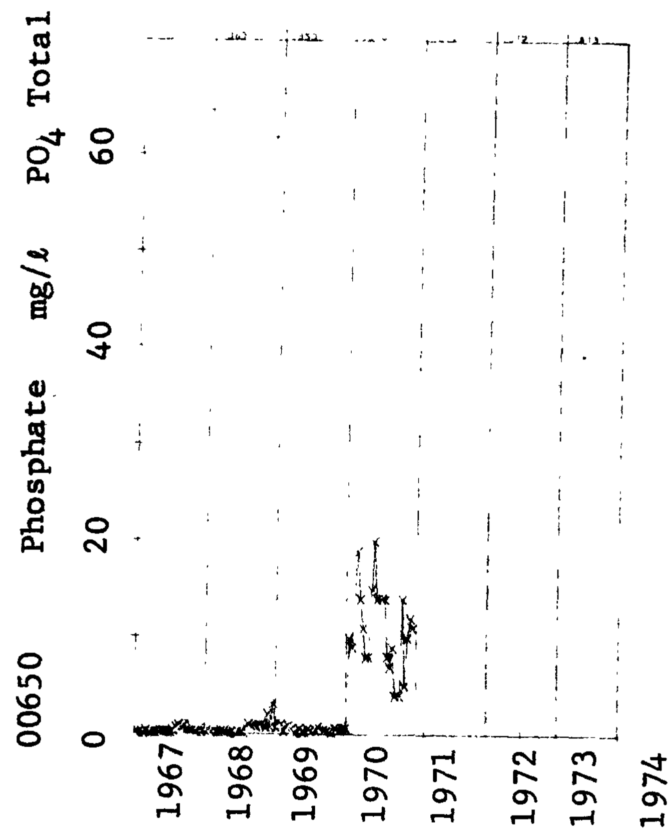

Figure 17.10

STORET WATER QUALITY PLOT

LM H
Hammond Water Plant Intake
Indiana data

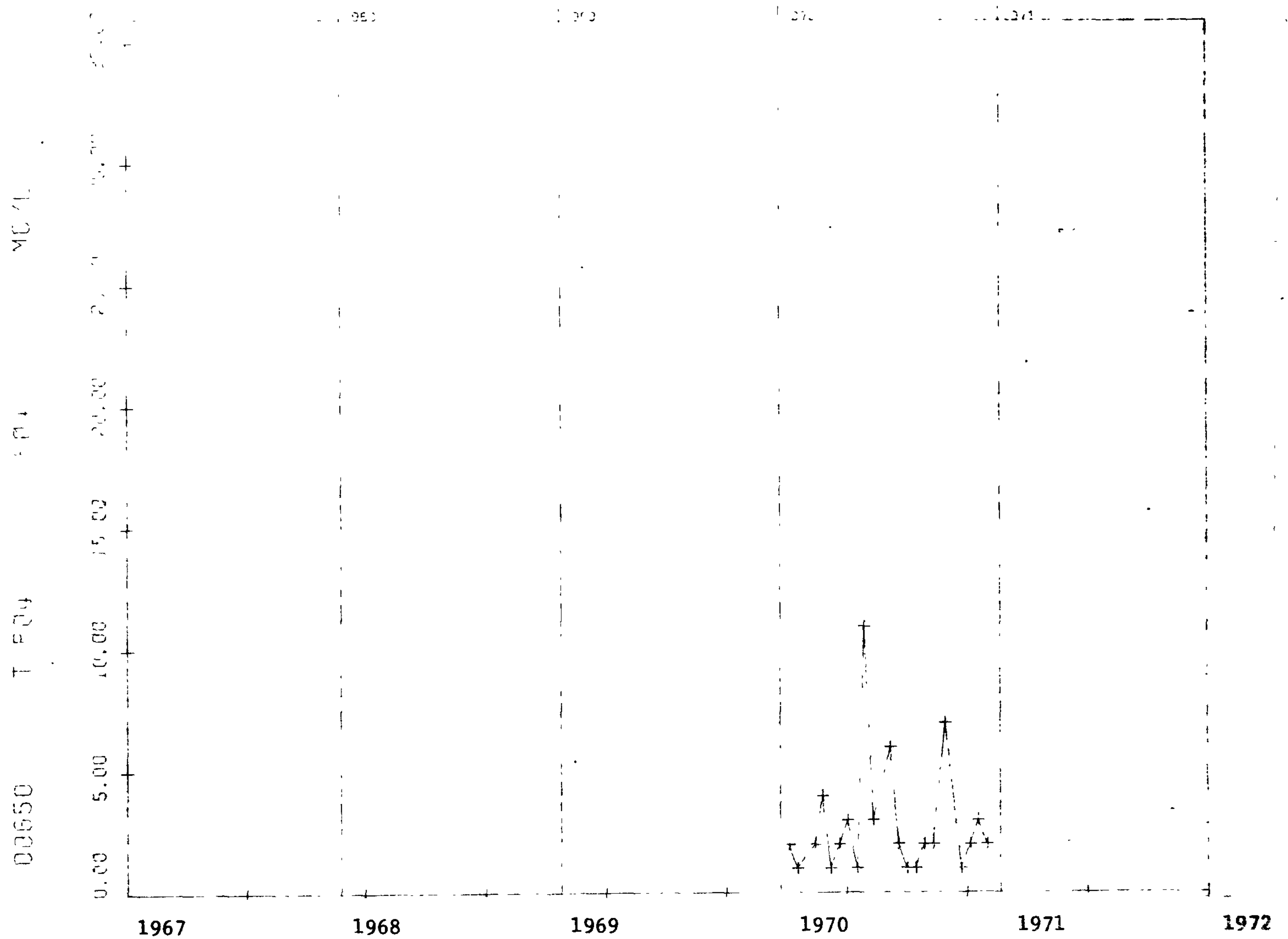

Figure 17.11

STORET WATER QUALITY PLOT

LM W
Whiting Water Plant Intake
Indiana data

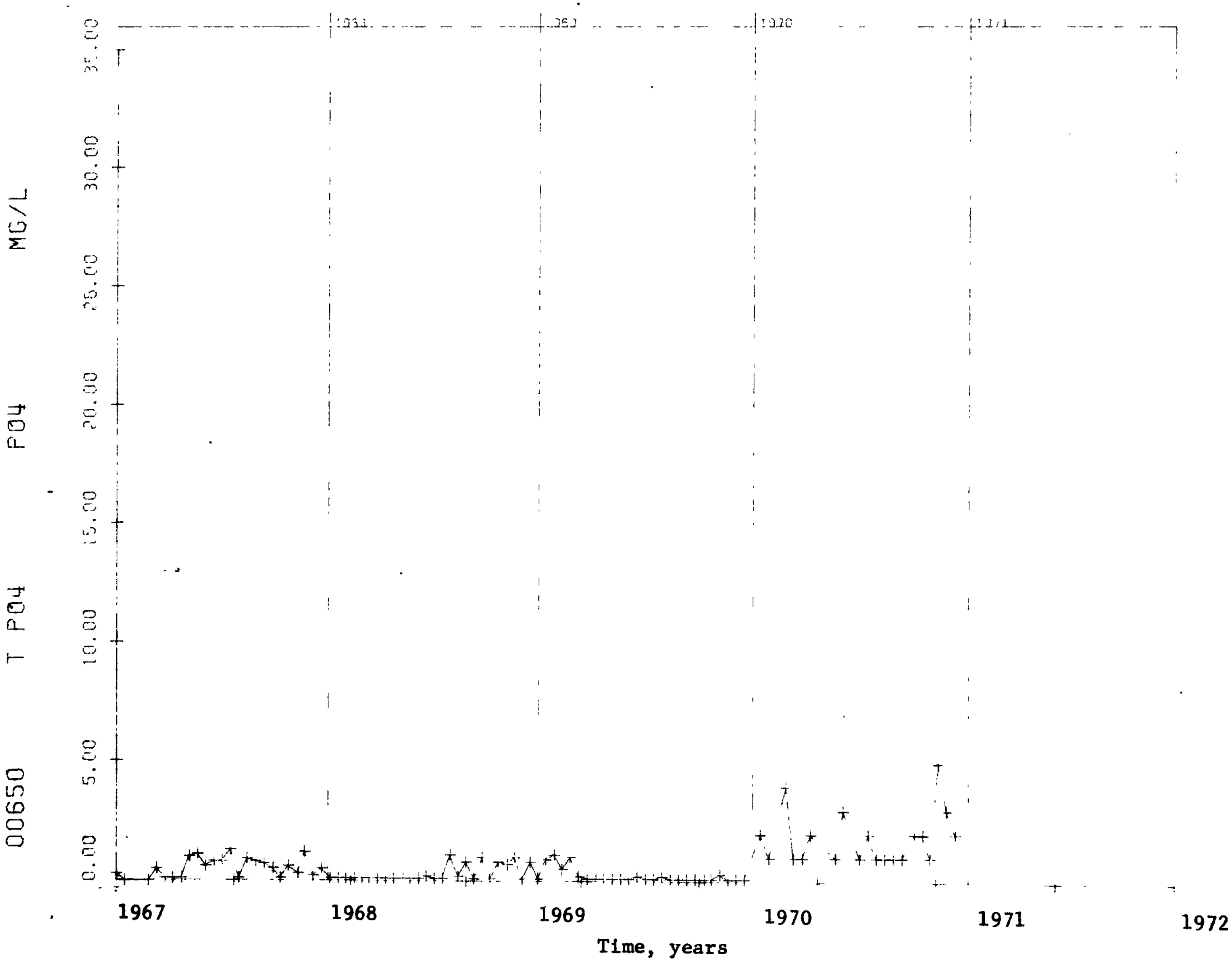

Figure 17.12

STORET WATER QUALITY PLOT

18. CHLORIDE AND SULFATE

18.1 Introduction

Chloride and sulfate concentrations in the Calumet area of Lake Michigan seldom exceed open-Lake standards; however, extensive data indicate long-term build-up of these parameters. A mixing model of the Lake shows that because of the long retention time of water in the Lake, the average concentration will rise in 20 years to exceed the standards for chloride, and probably also for sulfate. The IHC comprises 7% of the total chloride input to the Lake, and about 15% of the total industrial input. The chloride effluents from IHC are still increasing, but the sulfate levels are decreasing. Sulfate levels at water intakes in the Calumet area appear to be also decreasing, but the general Lake trend for the past three years is not known.

Control of increases of chloride would require Lake-wide control of industrial chloride effluents and of road salting.

18.2 Water Quality Standards

For chloride, the Indiana state standards for open water of Lake Michigan are 10 mg/ℓ average, and 15 single value. The Illinois state standard for Lake Michigan is not to exceed 12 mg/ℓ. Indiana standards for the inner harbor are 20 mg/ℓ average and 30 single value. Indiana standards for the IHC are 35 mg/ℓ.

For sulfate, the Indiana standards for open water of the Lake are 26 mg/ℓ and 50 single value. Illinois standard is not to exceed 24 mg/ℓ. Indiana standards for the inner harbor are 39 average and 75 single value. For the IHC the standard is 75.

Michigan has standards for total dissolved solids, which includes chloride and sulfate as well as a substantial level of bicarbonate.

18.3 Water Quality Data

18.3.1 Chloride

The long-range trends of chloride and sulfate concentrations at the Chicago South Water Filtration Plant intake are the most complete long-term records for any Lake point, and they are presented in Figure 18.1. A rapid increase in both of these parameters has taken place since 1950. Chloride is still increasing, although it appears that sulfate has peaked and is either constant or decreasing.

The values of these parameters at Chicago and other Calumet area stations is higher than in remote parts of the Lake, but the general upward trend is a Lake-wide phenomenon. Weiler and Chawla (1969) and Beeton (1971), as quoted by Schelske and Roth (1973) observe this upward trend, and attribute it to human activities.

Powers and Ayers (1967) compared chloride concentrations in mid-Lake waters with data from water intakes near the shore. The data were from their own 1962-63 measurements and those of Risley and Fuller. They concluded that the average chloride concentration in the Lake was 5 to 7 mg/ℓ in 1962. Values in the southern end of the Lake and at near-shore locations were several mg/ℓ higher. Risley and Fuller (1965) reported this north/south trend; a mean value at the latitude of Sheboygan, Wisconsin, was 6.6 with a range of 5.4 to 10 mg/ℓ across the Lake in 1962-63; at the latitude of Calumet Harbor the mean was 8 with a range of 4.2 to 22. An increased mid-Lake value was reported by Schelske and Roth (1973) who found an average of 7.22 $\pm$ 0.32 mg/ℓ for 16 samples near Charlevoix in the northeast part of the Lake.

Beeton (1965) summarized data from many sources and plotted background values of chloride and sulfate in open-Lake waters. These plots are shown in Figure 18.2. In general, they agree with the early trend of Chicago water data, Figure 18.1, but they do not extend to the time of most recent increases.

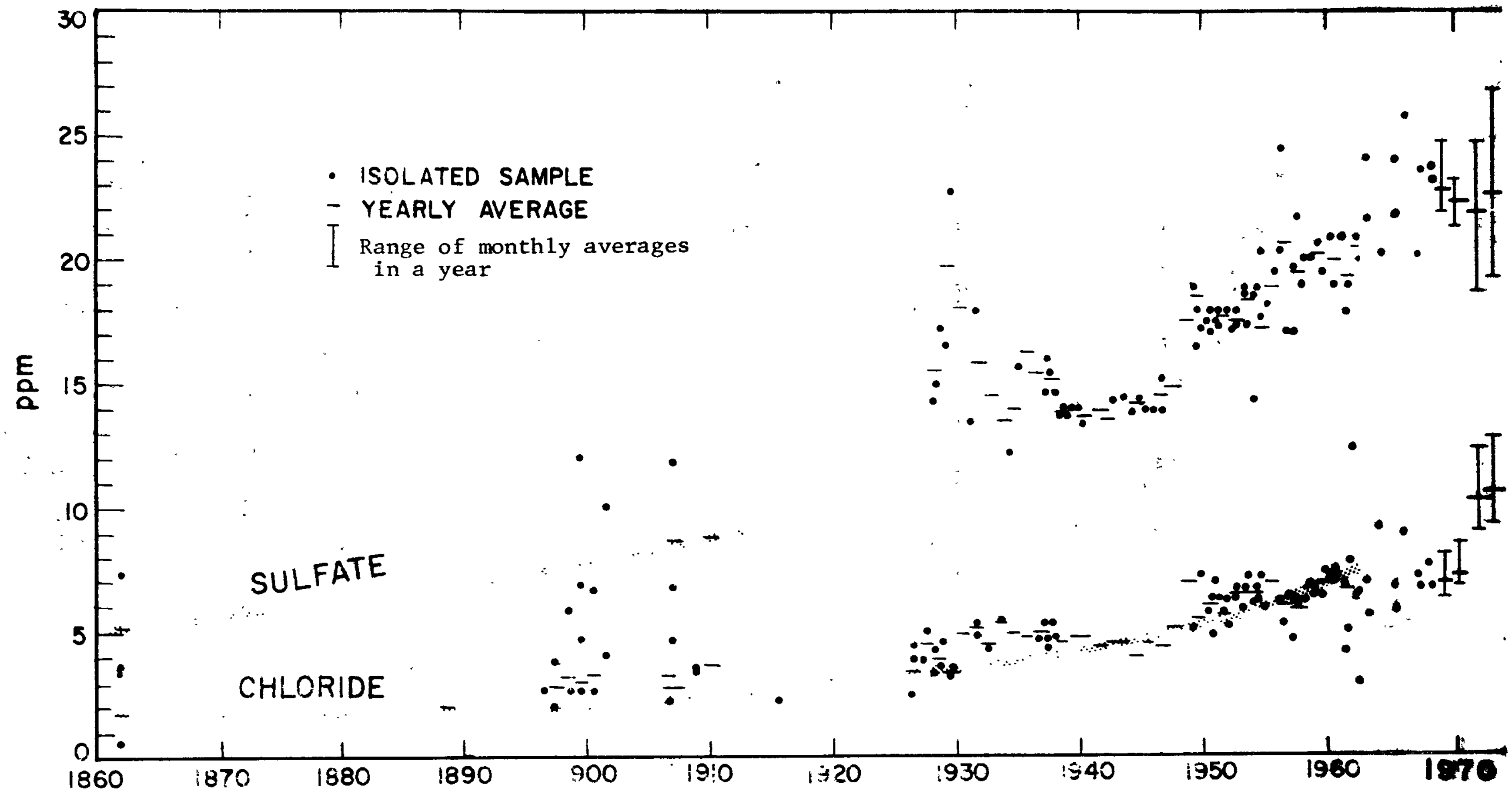

Figure 18.1

100 YEAR RECORD OF CHLORIDE AND SULFATE INCREASE AT DUNNE CRIB - 68TH st

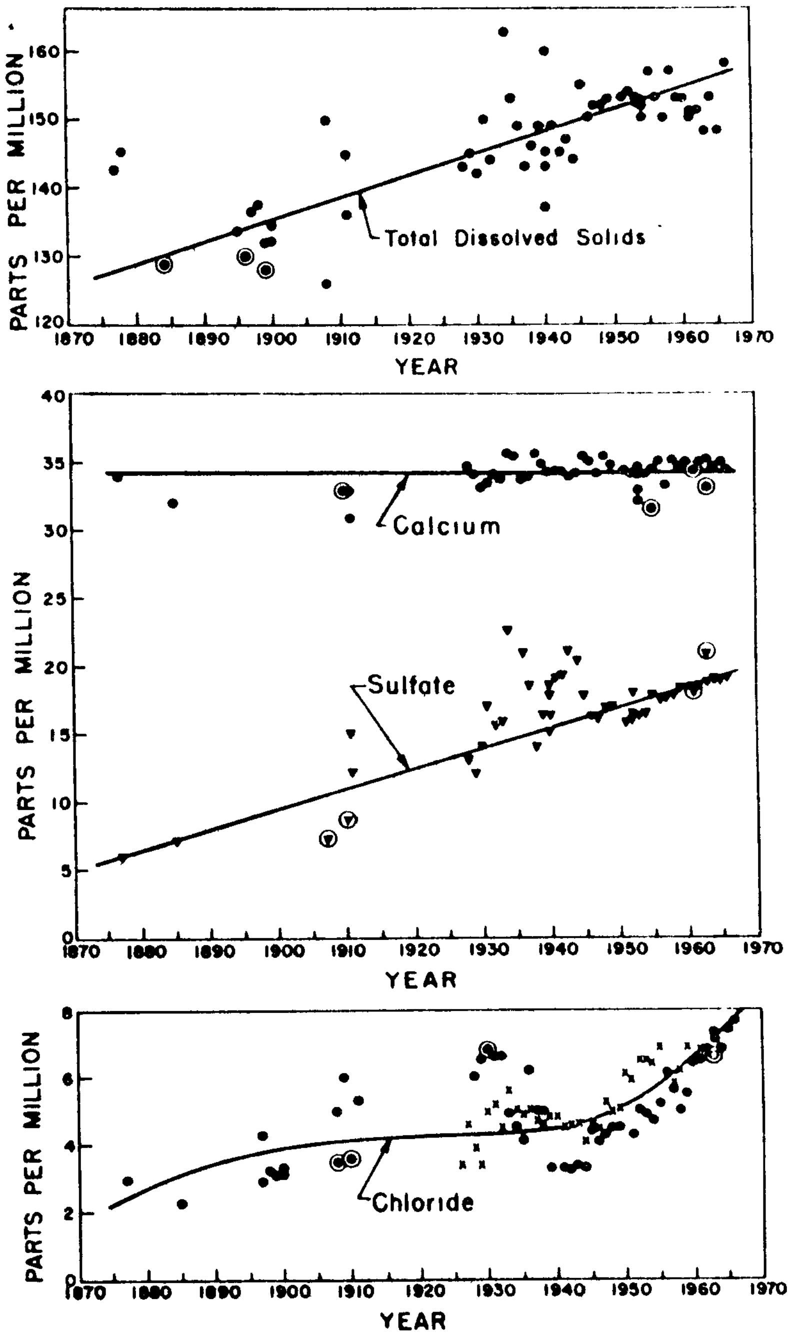

Figure 18.2

CHANGES IN CONCENTRATIONS OF DISSOLVED CHLORIDE SULFATE, CALCIUM AND TDS IN LAKE MICHIGAN

Source: Beeton (in NSF, 1969)

Circled points represent open-Lake data;
crosses are from Chicago water intake;
other points are from Milwaukee water intake.

18.3.2 Sulfate

Powers and Ayers (1967) compared sulfate concentrations in mid-Lake waters with data from water intakes near the shore. The data were from their own 1962-63 measurements and those of Risley and Fuller (1965). They concluded that the average sulfate level for the open Lake was nearly 16 mg/ℓ. The average value at the Chicago intake at that time was 18.2 mg/ℓ. Risley (1965) reported at the latitude of Sheboygan a mean of 21 mg/ℓ with a range of 10 to 49; at the latitude of Calumet Harbor the mean was 22 with a range of 15 to 57, showing little variation in north/south direction. Sulfate concentrations are higher near shore.

The data from Chicago Water Department (Figure 18.1) are a little higher than in remote regions of the Lake, but the trend of increase with years is valid for the whole Lake, at least until the last few years; however, Schelske and Roth (1973) reported a mean for 16 sulfate measurements near Charlevoix of 15.5 $\pm$ 3 mg/ℓ in 1970.

Figure 18.1 shows that the chloride values are continuing to rise, but the sulfate values are becoming constant, or perhaps decreasing from a peak of 22 in 1967. No definite trend line can be established. The data in Figure 18.1 represent daily measurements.

Storet plots of chloride data for several Lake water intake stations are given in Figures 18.9 to 18.18. Similar plots for sulfate are given in Figures 18.19 to 18.29. Both the chlorides and sulfates show similar patterns at several stations, with a significant decrease since 1967; however, there are periods of higher levels since that date. There are few indications of water quality violations. The greatest concern is not whether there are presently violations, but whether the levels will increase at the previous alarming rate.

18.4 Effluents from IHC

The Technical Committee (1970, p. 55) noted a decrease in sulfate concentration at the mouth of the IHC, at station CAL06, from a mean of 64 mg/ℓ in 1965 to a mean of 32 in 1969. This could be responsible for the decrease in Storet Lake station plots mentioned above. They attributed this improvement to conversion by the steel mills from sulfuric to hydrochloric acid pickling, and to deep well acid disposal systems.

The most complete data on concentrations in the IHC are the weekly measurements by the Chicago Water Department at Dickey Road. The annual averages of these measurements are shown in Figures 18.3 and 18.4. A decrease in sulfate concentration is noted since 1970, but the decrease is not as large as reported by the EPA. Chloride (Figure 18.4) has continued to increase. Chloride concentrations are often in violation of Indiana standards for the IHC.

Measurements by Indiana during the summer of 1973 are given in Table 18.1. The Indiana measurements fall within the standards for IHC. Recent measurements by IITRI at Columbus Drive on IHC all exceed the Indiana standard of 35 mg/ℓ for chloride.

Date	Chloride, mg/ℓ
Nov. 12, 1973	55
13	65
14	59
15	54
16	65
17	84
18	46
19	72
20	45
29	70
30	60
Dec. 07, 1973	71

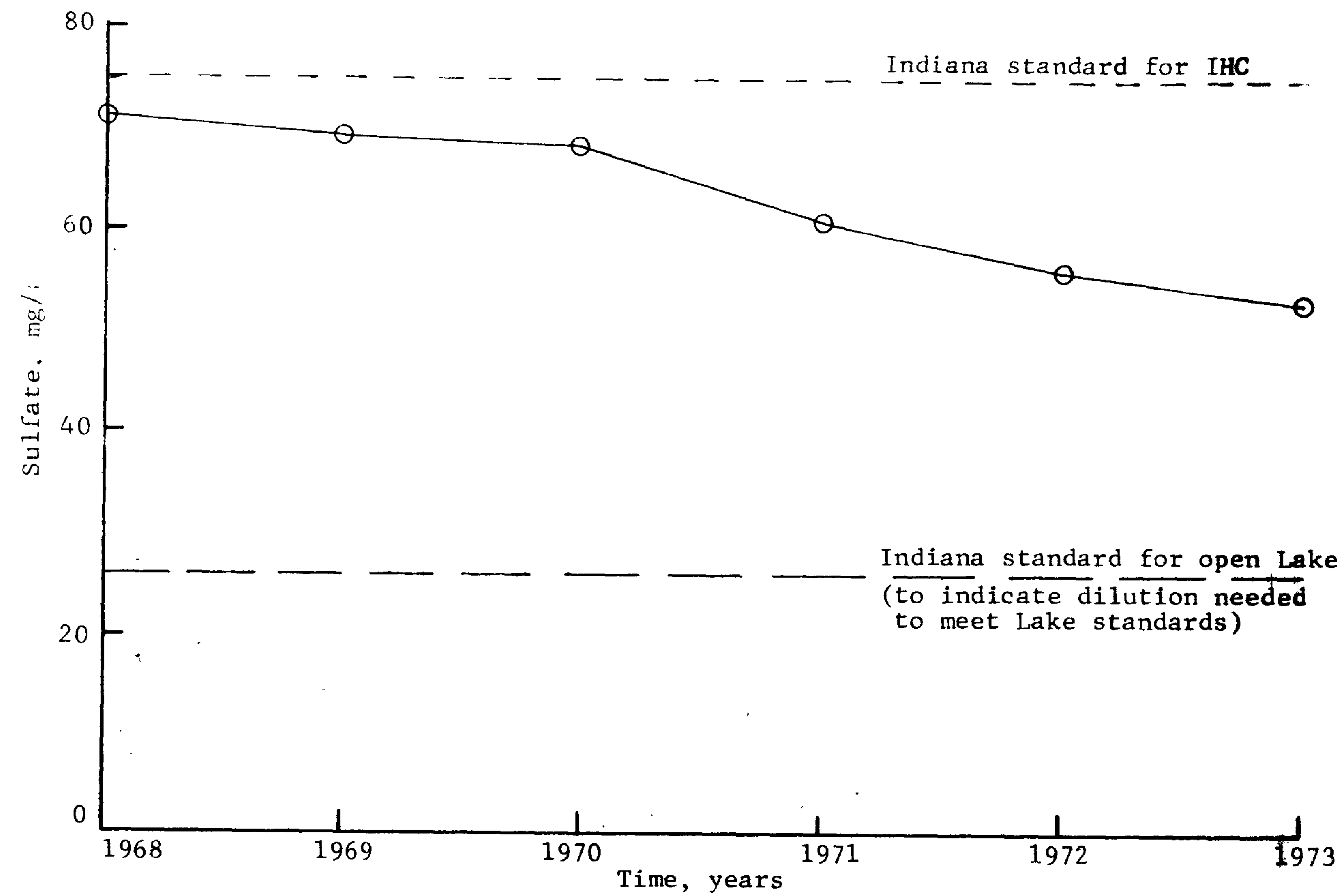

Figure 18.3

ANNUAL AVERAGE SULFATE CONCENTRATION IN INDIANA HARBOR CANAL AT DICKEY ROAD

Data source: Calumet Industrial Area Pollution Survey, Chicago Dept. of Water and Sewers

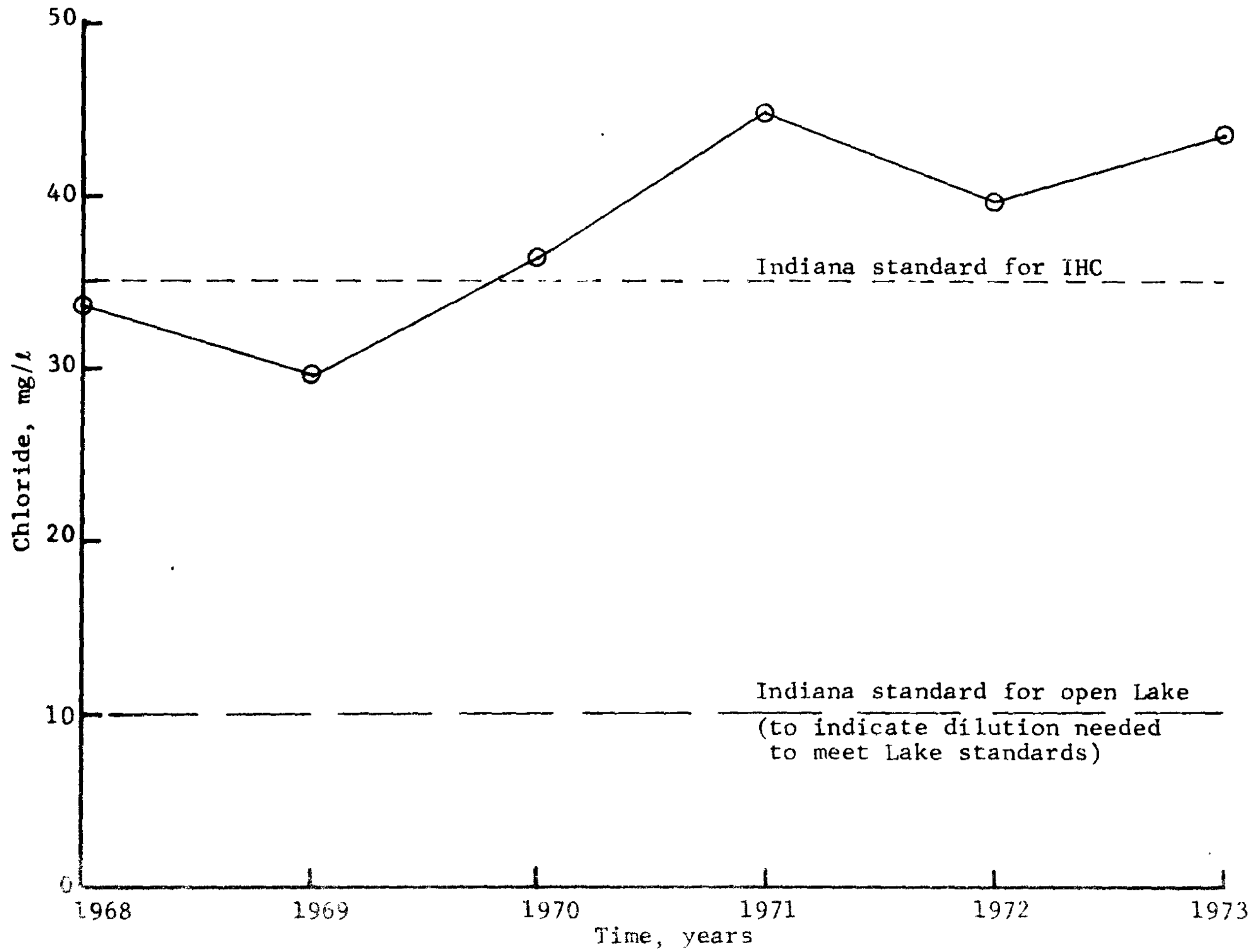

Figure 18.4

ANNUAL AVERAGE CHLORIDE CONCENTRATION IN INDIANA HARBOR CANAL AT DICKEY ROAD

Data source: Calumet Industrial Area Pollution Survey
Chicago Dept. of Water and Sewers

Table 18.1

WATER QUALITY IN IHC AND GRAND CALUMET RIVER
Data of State of Indiana, Summer 1973
Combinatorics (1974)

Description	Sulfates			Chlorides		
Water quality standard	75 mg/ℓ			35 mg/ℓ except river flow to Illinois = 125 mg/ℓ		
Monitoring stations	72 Average	73 Average	72-73 Maximum	72 Average	73 Average	72-73 Maximum
GCR 41 Grand Calumet River Gary (U.S. 12)	-	44.0	60.0	27	22	44
GCR 37 Grand Calumet River East Chicago (Kennedy Rd.)	-	53.1	115.0	31	30.6	97
GCR 36 Grand Calumet River East Chicago (Indy. Blvd.)	-	187.8	410.0	281	260.2	620
GCR 34 Grand Calumet River Hammond (U.S. 12)	147.3	139.9	223.0	155	129.9	550
IHC 3W Indiana Harbor Canal East Chicago (Indy. Blvd.)	-	86.7	123.0	59	59.7	115
IHC 3S Indiana Harbor Canal East Chicago (Columbus Drive)	-	50.3	70.0	40	33.9	125
IHC 1 Indiana Harbor Canal East Chicago (Dickey Rd.)	55.1	59.7	80.0	40	34.3	125
IHC 0 Indiana Harbor Canal East Chicago (Youngstown Steel)	-	43.6	70.0	-	25.6	37

These IITRI measurements indicate either a recent increase in effluents, or they reflect a seasonal fluctuation in chloride effluents. Season fluctuations are apparent in plots of Storet data shown in Figures 18.9 to 18.18. The reason for seasonal fluctuations might be the use of salt on roads in winter in the Calumet area; however, the timing is not right; for instance, there was no snow during the period of IITRI's sampling. No other reason is known.

18.5 Water Quality Violations

It appears that there are violations of chloride standards in IHC due to increases in the last few years. At some times of the year, the concentrations are just below the standards. Violations occur in the Grand Calumet River due to its lower flow rate.

There is no evidence of sulfate violations in IHC.

Violations of chloride standards in Lake Michigan are quite rare. None were observed during IITRI's sampling near the mouth of IHC during Nov-Dec 1973. The Storet data in Figures 18.9 to 18.18 indicate occasional violations, and so do measurements of Chicago's 68th St. water intake crib. The main reason for concern is not the occational violations at present, but the persistent increase over time shown in Figure 18.1. Future increases are predicted by model calculations below.

18.6 Sources of Effluents

Table 4.5 shows that the sum of reported chloride effluents into the IHC totals 393,537 lb/day, as determined by Combinatorics Inc. (1974) from permit data. IITRI measurements at the mouth of the IHC are higher than this, by a factor of 1.5 to 2. A further check is given by comparing the effluents with the loads measured by IITRI at Columbus Drive on the IHC; this comparison is given in Table 4.4 . Again the IITRI measurements are higher than the Combinatorics totals of reported effluents. These higher values reflect the higher concentrations of chlorides measured by IITRI, and these were compared above with data from other sources. We can conclude that the loads are at least as high as reported by Combinatorics, and are perhaps higher sometimes.

Table 18.2 from Combinatorics (1974) lists the outfalls and their loads of chlorides. Table 18.3 is a similar list for sulfates. The major sources are the three steel companies in the Calumet area, (U.S. Steel Gary Works, Inland Steel, and Youngstown Sheet and Tube), and the municipal sewage treatment plants at Gary, East Chicago, and Hammond,

Plots of radial survey data from the Chicago Water Department in Figures 18.5 to 18.7 show some peaks at stations 5J and 6J near the mouth of the IHC, indicating that this source is strong enough to have measurable effect on local chloride content of the Lake waters, even though the background chloride concentration is relatively high compared to the ratio for other pollutants.

There are some additional sources that discharge directly into the Lake, and they are listed in Table 4.2. The values given in the table include the amount of chloride in the intake waters, so these are not net figures. Only those sources whose effluent concentrations are signficantly above Lake background chloride levels provide significant net chloride inputs. Two sources with significant net inputs of chloride are Bethlehem Steel at Burns Ditch, and Amoco at Whiting. The loads from these sources amount to 30,000 and 15,000 lb/day. These are not very large in themselves, but if chloride effluents on IHC are controlled, then these sources should also be controlled.

Table 18.2

INVENTORY OF CHLORIDE DISCHARGES ON IHC AND TRIBUTARIES
Source: Combinatorics (1974)

Chlorides
Water Quality Standard 35 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
U. S. Steel								
GW-1	19.9	28.9	40.7	2,660	5,080	11	15	
GW-2	10.9	16.4	23.0	1,913	3,260	14	17	
GW-2A	1.4	2.2	3.9	366	876	20	27	
GW-3	2.7	3.8	4.5	444	939	14	25	
GW-3A	0.4	1.7	3.7	312	895	22	29	
GW-4	0.5	0.7	0.9	58	114	10	15	
GW-5	82.4	87.7	95.3	15,380	23,100	21	29	
GW-6	23.4	29.5	39.4	2,460	4,940	10	15	
GW-7	5.8	10.6	16.9	2,210	4,510	25	32	
GW-7A	93.3	120.1	146.0	12,010	19,450	12	16	
GW-9	24.7	34.7	39.7	4,930	8,280	17	25	
GW-10A	26.3	34.6	47.2	4,910	10,610	17	27	
GW-11A	81.3	94.7	115.6	11,870	19,270	15	20	
GW-13	1.8	2.9	4.8	290	695	12	17	
ST-14	0.8	1.8	3.3	710	6,500	50	236	
ST-17	20.1	30.0	39.3	21,200	39,300	85	120	
GSTP	44.0	52.7	62.0	29,500	51,600	67	100	
E.I. duPont								
001	0.5	1.8	2.4	4,100	8,700	280	2,230	
002-004	7.24	10.31	11.66	0	0	-	-	
005	0.07	0.08	0.12	600	2,000	910	3,330	
006-010	0.89	2.24	2.98	300	1,000	161	403	
U.S.S. Lead		0.36		86	273	28.5	91	
HSTP	35.0	40.7	44.0	40,700	73,400	120	200	
ECSTP	10.0	14.0	20.0	41,600	102,300	356	675	
Union Carbide	0.05	0.07	0.11	6	14	10	15	
ARCO		5.04	6.77	12,600	25,400	300	450	
Amer. St. Foundries	0.09	0.15	0.27	1,350	3,380	1,080	1,500	

Table 18.2 (cont.)

Chlorides — Water Quality Standard 35 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
Youngstown								
001 YS-20	8.46	13.70	23.60	2,284	5,900	20	30	
002 YS-2	1.50	3.62	7.50	452	1,560	15	25	
003 YS-4	0.53	0.98	1.40	317	475	28	42	
004 YS-8	1.03	1.40	1.75	140	278	12	19	
005 YS-11	1.19	1.60	3.00	294	750	22	30	
006 YS-12	3.30	5.70	8.40	2,420	7,210	51	103	Monthly report data
007 YS-13	6.30	14.00	18.90	4,326	26,638	37	169	
008 YS-22	3.00	5.00	11.70	1,405	72,440	29	1,495	
009 YS-14	34.00	48.70	60.00	6,090	10,000	15	20	
010 YS-15	36.60	58.00	67.00	12,080	16,740	25	30	
011 YS-18A	107.80	121.60	138.70	21,291	32,444	21	32	
Inland								
001 IE-2		.14	.29	30	249	26	103	
002 4E-1		190.00	228.00	25,340	57,000	16	30	
003 5E-1		7.20	8.60	2,380	3,730	39	52	P. data high of 67
004 5E-2	8.60	0.86	1.04	86	156	12	18	
005 5E-3		8.60	10.40	788	1,560	11	18	
006 6E-1		0.65	1.30	135	282	25	26	
007 7E-1		21.60	25.90	2,160	3,240	12	15	
008 10E-1	Unknown & Highly Variable							
011 13G-1	126.96	158.70	190.44	17,200	19,800	13	15	
012 13H-1	67.68	50.80	70.00	16,099.54	39,698.4	38	68	
013 14H-TT	85.52	106.90	128.28	16,000	32,095.66	18	30	
014 15H-TT	85.52	106.90	128.28	16,000	36,375.08	18	34	High recorded in Jan.
015 16H-1	17.28	21.60	25.92	2,520	2,700	14	15	
016 16H-2	7.20	9.00	10.80	1,050	1,500	14	20	
017 16H-3	115.28	144.10	172.92	14,400	18,000	12	15	
018 16F-1	119.76	149.70	179.64	13,730	23,971.15	11	16	

Table 18.3

INVENTORY OF SULFATE DISCHARGES ON IHC AND TRIBUTARIES
Source: Combinatorics (1974)

Sulfates

Water Quality Standard 75 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
U. S. Steel								
GW-1	19.9	28.9	40.7	8,450	15,270	35	45	
GW-2	10.9	16.4	23.0	4,240	7,670	31	40	
GW-2A	1.4	2.2	3.9	459	1,140	25	35	
GW-3	2.7	3.8	4.5	1,140	1,613	36	43	
GW-3A	0.4	1.7	3.7	355	926	25	30	
GW-4	0.5	0.7	0.9	146	225	25	30	
GW-5	82.4	87.7	95.3	18,300	23,850	25	30	
GW-6	23.4	29.5	39.4	8,610	14,940	35	45	
GW-7	5.8	10.6	16.9	3,360	7,050	38	50	
GW-7A	93.3	120.1	146.0	35,350	54,700	35	45	
GW-9	24.7	34.7	39.7	11,500	14,900	35	45	
GW-10A	26.3	34.6	47.2	8,660	15,730	30	40	
GW-11A	81.3	94.7	115.6	23,670	38,500	30	40	
GW-13	1.8	2.9	4.8	1,450	4,000	60	100	
ST-14	0.8	1.8	3.3	4,620	9,640	308	350	
ST-17	20.1	30.0	39.3	48,750	75,300	195	230	
GSTP	44.0	52.7	62.0	28,600		65		Grab sample
E.I. duPont								
001	0.5	1.8	2.4	7,670	25,200	511	1,258	
002-004	7.24	10.31	11.66	15,225	64,200	177	660	
005	0.07	0.08	0.12	300	2,700	450	2,693	
006-010	0.89	2.24	2.98	31,000	50,800	1,663	2,042	
U.S.S. Lead		0.36		665	2,740	221.4	912.5	
HSTP	35.0	40.7	44.0	40,700		120		Grab sample
ECSTP	10.0	14.0	20.0	11,100		95		Grab sample
Union Carbide	0.05	0.07	0.11	9	18	15	20	
ARCO		5.04	6.77	16,900	28,200	400	500	
Amer. St. Foundries	0.09	0.15	0.27	48	113	38	50	

Table 18.3 (cont.)

Sulfates Water Quality Standard 75 mg/l

Discharges	Min. Flow (MGD)	Avg. Flow (MGD)	Max. Flow (MGD)	Avg. Load (lb/day)	Max. Load (lb/day)	Avg. Conc. (mg/l)	Max. Conc. (mg/l)	Comments
Youngstown								
001 YS-20	8.46	13.70	23.60	17,200	39,300	150	200	
002 YS-2	1.50	3.62	7.50	1,810	5,640	60	90	
003 YS-4	0.53	0.98	1.40	123	292	15	25	
004 YS-8	1.03	1.40	1.75	292	1,750	25	120	
005 YS-11	1.19	1.60	3.00	494	3,510	37	140	
006 YS-12	3.30	5.70	8.40	1,430	9,110	30	130	
007 YS-13	6.30	14.00	18.90	1,638	3,300	14	21	
008 YS-22	3.00	5.00	11.70	584	2,450	14	21	
009 YS-14	34.00	48.70	60.00	6,100	10,000	15	20	
010 YS-15	36.60	58.00	67.00	7,260	11,180	15	20	
011				55,800	75,200	55	65	
YS-18A	107.80	121.60	138.70	55,800	75,200	55	65	
Inland								
001 IE-2		.14	.29	88	180	75	90	
002 4E-1		190.00	228.00	31,600	57,000	20	30	
003 5E-1		7.20	8.60	1,800	3,590	30	50	
004 5E-2	8.60	0.86	1.04	165	261	23	30	
005 5E-3		8.60	10.40	2,150	4,340	30	50	
006 6E-1		0.65	1.30	136	433	25	40	
007 7E-1		21.60	25.90	5,400	10,800	30	50	
008 10E-1	Unknown & Highly Variable							
011 13G-1	126.96	158.70	190.44	33,000	46,300	25	35	
012 13H-1	67.68	50.80	70.00	11,015.47	21,600.6	26	37	
013								
14H-TT	85.52	106.90	128.28	25,800	53,492.76	29	50	
014								
15H-TT	85.52	106.90	128.28	25,800	45,664.00	29	41	
015 16H-1	17.28	21.60	25.92	4,323.46	11,879.5	24	55	
016 16H-2	7.20	9.00	10.80	1,875	3,152.52	25	35	
017 16H-3	115.28	144.10	172.92	28,820	43,264.53	24	30	
018 16F-1	119.76	149.70	179.64	36,190	74,809.39	29	50	

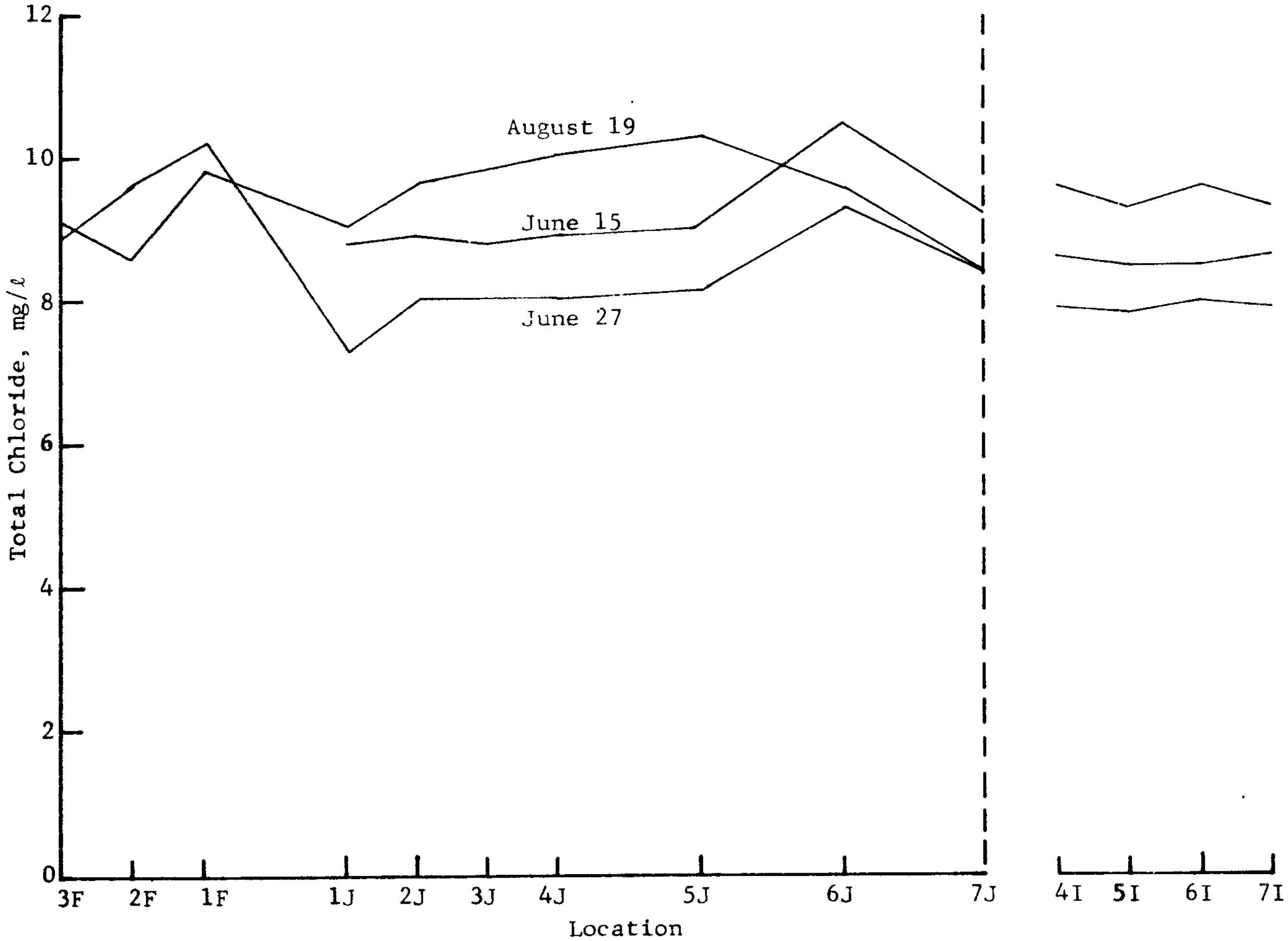

Figure 18.5

RADIAL SURVEY OF TOTAL CHLORIDE - 1971
Chicago South Water Filtration Plant

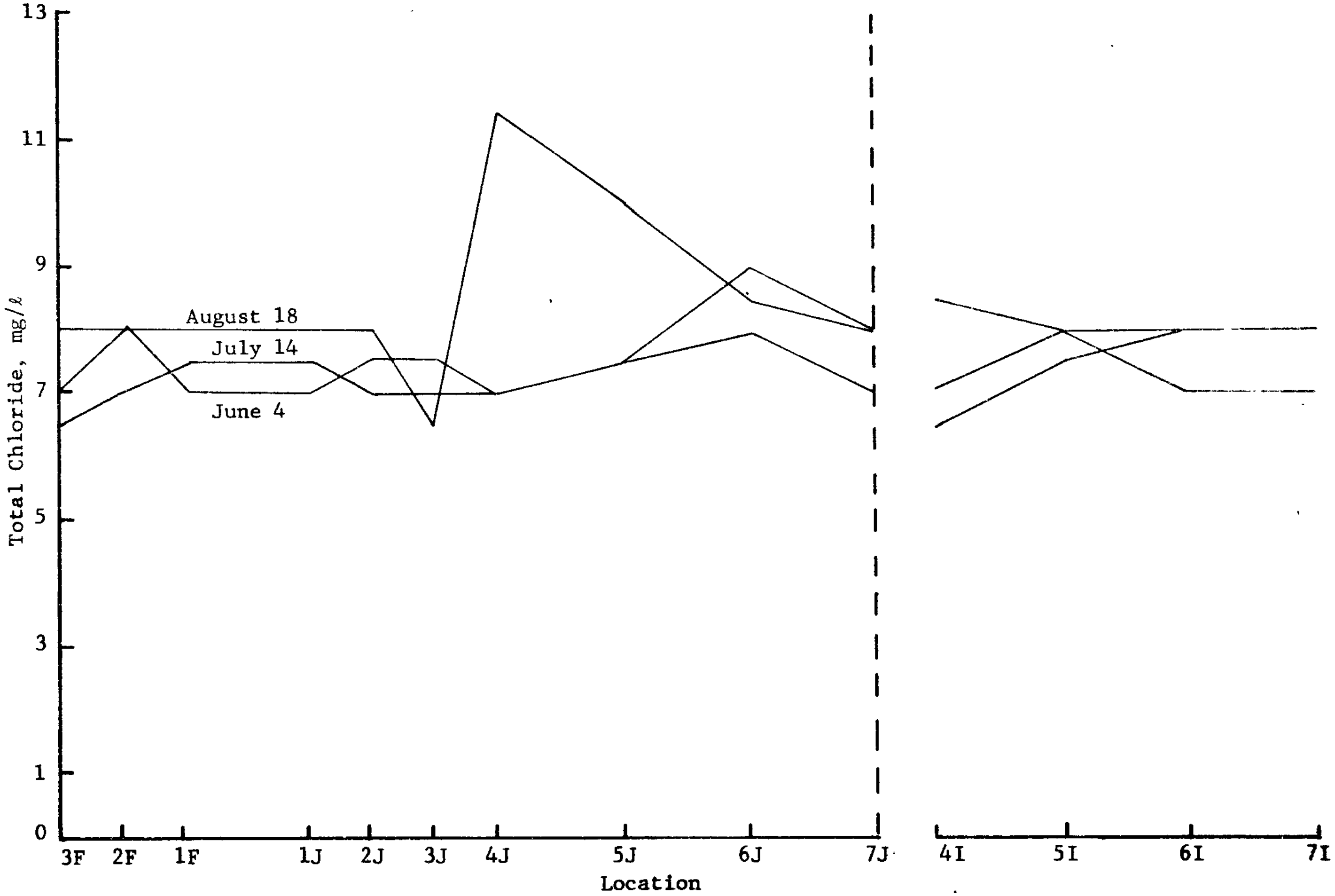

Figure 18.6

RADIAL SURVEY OF TOTAL CHLORIDE - 1970
Chicago South Water Filtration Plant

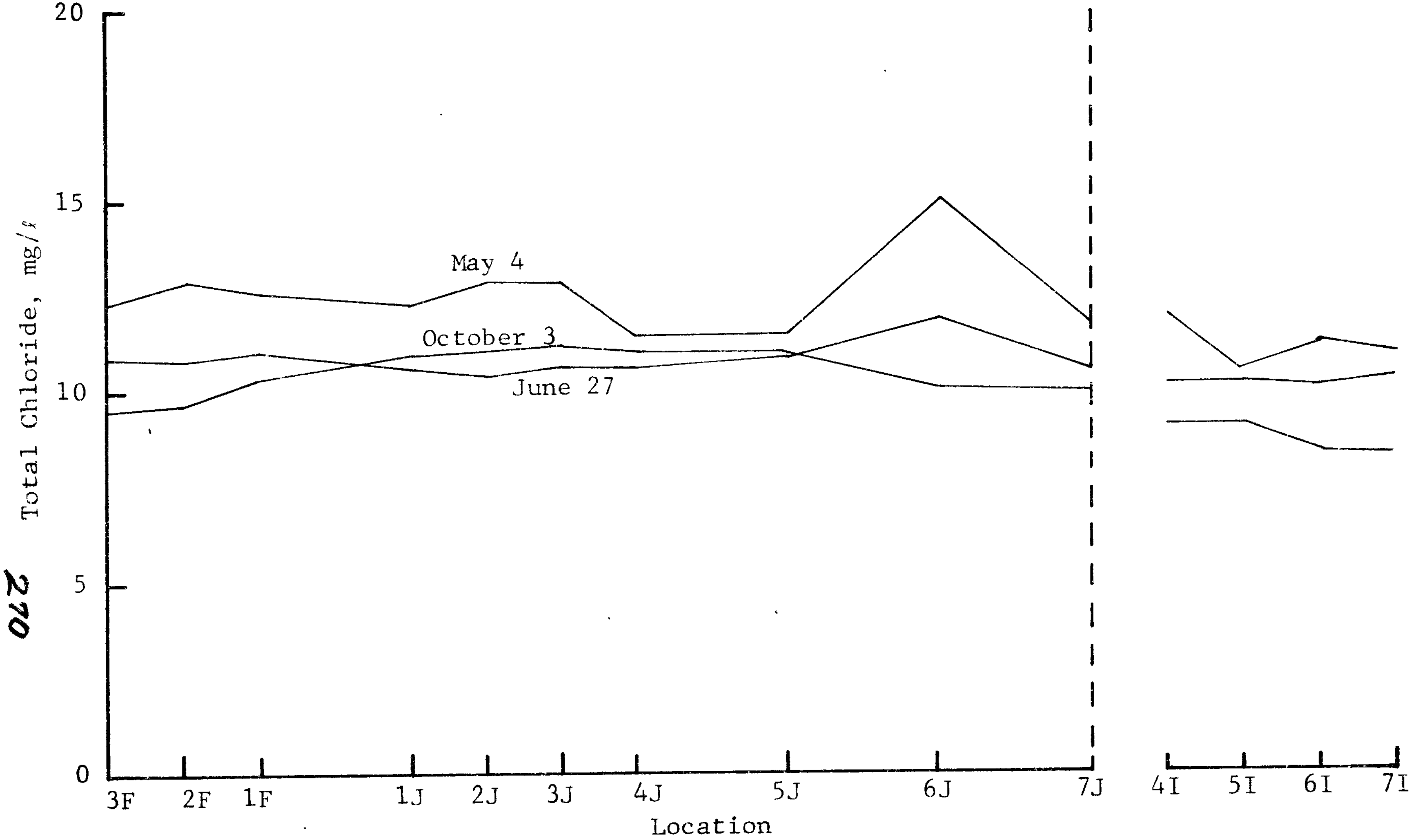

Figure 18.7

RADIAL SURVEY OF TOTAL CHLORIDE - 1972
Chicago South Water Filtration Plant

18.7 Lake Michigan Water and Chloride Model

For a conservative parameter like chloride, the Lake as a whole can be modelled by thinking of it as a well-stirred tank. The build-up of concentration is the input of chloride less the outflow (quantities are defined in Figure 18.8)

$$\frac{dC}{dt} = \frac{W}{V} - \frac{CQ}{V} \qquad (18.1)$$

This can be rearranged for integration

$$\int_{C_1}^{C_2} \frac{dC}{W/Q - C} = \int_{t_0}^{t} \frac{Q}{V}\, dt \qquad (18.2)$$

This is solved for the concentration $C_2(t)$, given the initial concentration C_1:

$$C_2 = \frac{W}{Q}\left(1 - \exp\left[- \frac{Qt}{V}\right] + C_1\left[\exp - \frac{Qt}{V}\right]\right) \qquad (18.3)$$

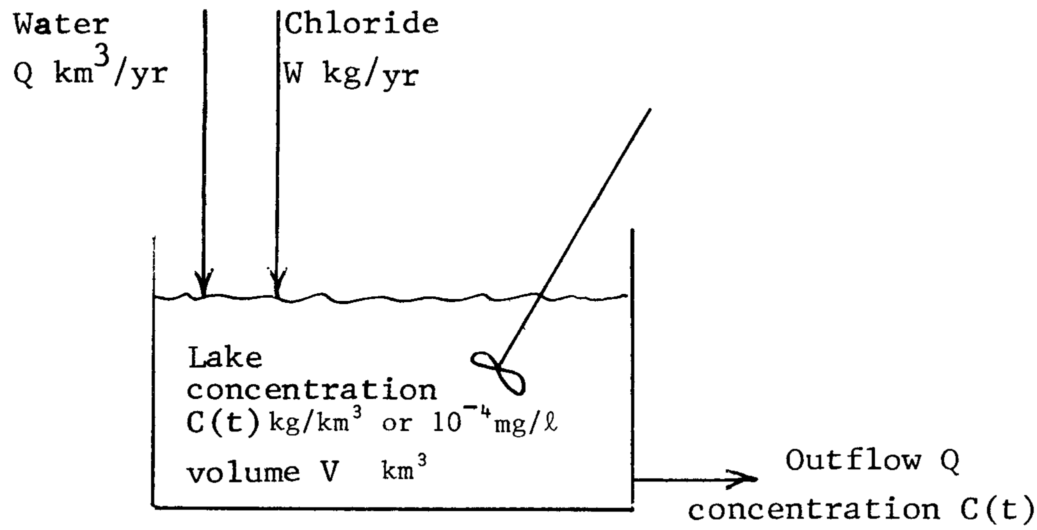

Figure 18.8

LAKE MICHIGAN MODELLED AS A STIRRED TANK
TO DETERMINE CHLORIDE BUILD-UP

The values of the flow parameters are from a Lake Michigan water balance (Chandler 1964; Schelske & Roth 1973):

		km^3/yr	1000 cfs
Inputs -	Runoff from land	35	39
	Precipitation	45	51.5
Outputs -	Evaporation	32	35
	Diversion	2.7	3.1
	Outflow	49	55
Volume		4871 km^3	1170 mi^3
Detention time, years		99	

Hence, V = 4871 km^3, Q = 49 km^3/yr.

O'Connor and Miller (1970) surveyed the available data on sources of chloride to Lake Michigan as a whole. They estimated the following inputs

	lb/day	Metric ton/year
Road salt as chloride	1,400,000	233,000
Industrial effluents	2,600,000	433,000
Municipal effluents	300,000	50,000
Other sources	1,310,000	218,000
Total (to fit model)	5,600,000	943,000

The industrial effluents comprise the largest type of source. This industrial effluent figure agrees well with a summation of industrial effluents compiled by Businessmen in the Public Interest (1972) from Rapp permit applications. The largest industrial effluents were from salt-processing industries in Manistee and Luddington, Michigan. Robbins, Lanstrom and Wahlgren (1972) also list large inputs from rivers in Michigan.

The total chloride figure given above represents the amount needed for the model to fit the observed build-up in Lake concentration. The item "Other Sources" is the difference needed to make up this total. The known sources in the list comprise 77% of the total; this 77% accounting very strongly supports the model estimates. It is therefore reasonable to use the total figure to estimate the further rate of chloride increase from 1970.

The effluents from sources on the IHC comprise 66,000 metric ton/yr (400,000 lb/day). This is 15% of the industrial input. Because the area drained by the IHC is small, road salt is expected to be a small fraction of this. Therefore, the IHC contributes a significant portion of the industrial chloride input to the Lake. The biggest sources, however, are the salt-related industries in Michigan.

From these estimates, the values of the parameters in the Lake model are

$$W = \text{chloride input rate} = 943{,}000 \text{ metric ton/yr}$$

$$W/Q = \frac{943{,}000\text{x}10^9 \text{ mg/yr}}{49\text{x}10^{12} \text{ ℓ/yr}} = 18.9 \text{ mg/ℓ}$$

$$V/Q = \frac{4871 \text{ km}^3}{49 \text{ km}^3\text{/yr}} = 99 \text{ years}$$

The mean Lake concentration of chloride in 1970 is taken to be 7 mg/ℓ. Of this, 3 mg/ℓ represents the natural background level due to leaching of the earth, and 4 represents the accumulation from human activities to date. Thus C_1 in Equation 18.3 is 4 mg/ℓ. A constant amount of 3 mg/ℓ is to be added to the equation to equal natural background. The result is in Table 18.4. The results indicate that only modest increases are expected, provided that the chloride inputs do not increase.

Another question is the actual flow, Q, used in the model. There are indications that there may be some exchange of water at the straits of Mackinac (Ayers 1959, p. 7), so that the flow Q may effectively be larger. In this case, O'Connor and Miller's estimate of the input W may be low, by less than a factor of 2. Our extrapolation from 1973 will not be affected, but use of the model to calculate other water quality parameters would be questionable.

We can conclude from Table 18.4 that as the general Lake chloride concentration increases, the frequency of violations at points in the Lake will increase. In addition, the average background level will exceed the Indiana state standard of 10 mg/ℓ in 1993.

A survey of the sulfate inputs to Lake Michigan has apparently not been done; however, the curve for sulfate growth in the Lake in Figure 18.1 parallels the chloride curve, with an increase about three times the chloride increase. The time scale for the

Table 18.4

CHLORIDE MODEL FOR LAKE MICHIGAN

Year after 1973	Concentrations, mg/ℓ			
	Accumulation of annual input, $\frac{W}{Q}\left[1 - \exp(-\frac{Q}{V}t)\right]$	Decay of previous human input, $C_1 \exp(-\frac{Q}{V}t)$	Natural background	Predicted total
1	0.189	4.0	3	7.2
10	1.89	3.6	3	8.5
20	3.5	3.3	3	9.8
50	8.1	2.3	3	13.4
100	12.0	1.4	3	16.4
200	15.5	0.5	3	19.0

two curves will be the same, and the violations of sulfate standards will occur at about the same time as chloride, if inputs are not reduced. The data presented below indicate that inputs have been decreased, but from these Calumet area data, we cannot extrapolate to the whole Lake.

CAL02
IHC and 151st St.
EPA data

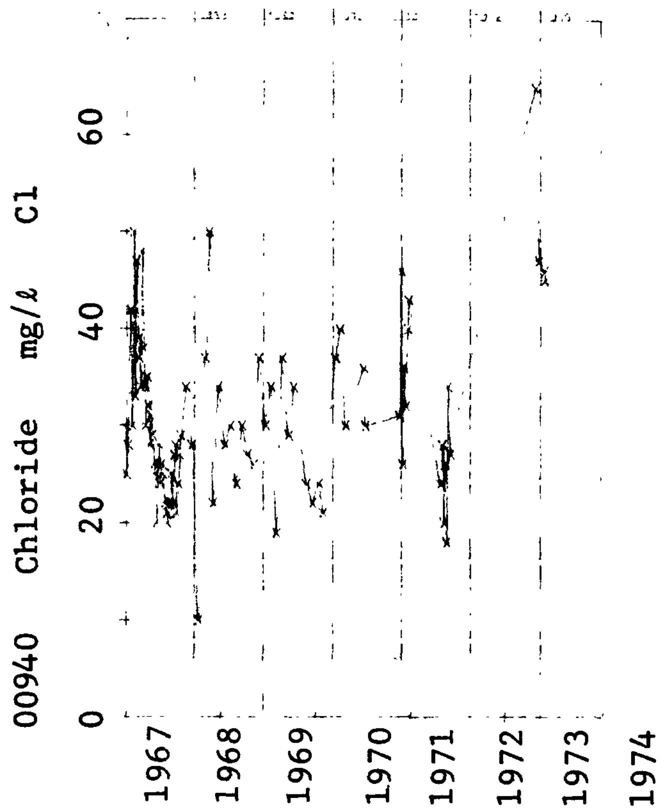

Figure 18.9

STORET WATER QUALITY PLOT

IHC 3S
IHC and Columbus Drive
Indiana data

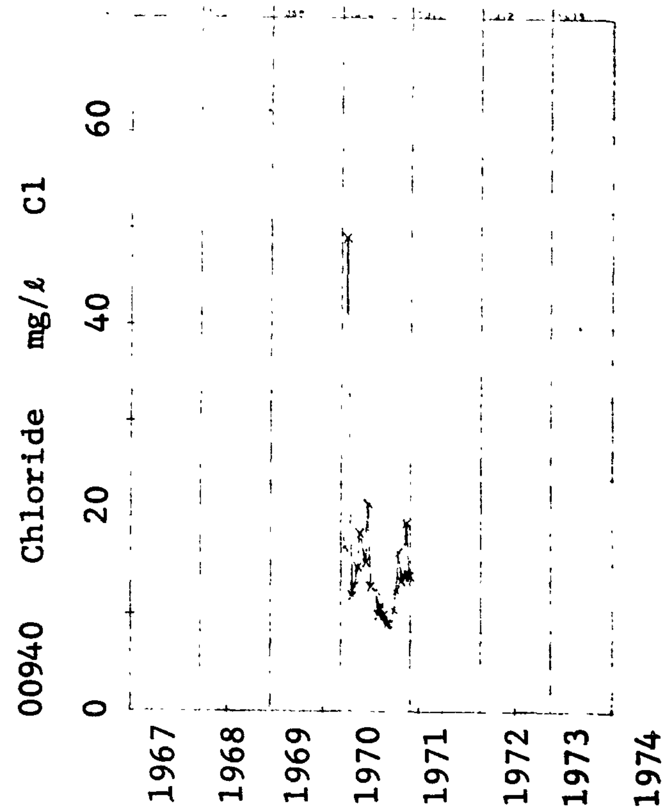

Figure 18.10

STORET WATER QUALITY PLOT

CAL03
IHC and Dickey Rd.
EPA data

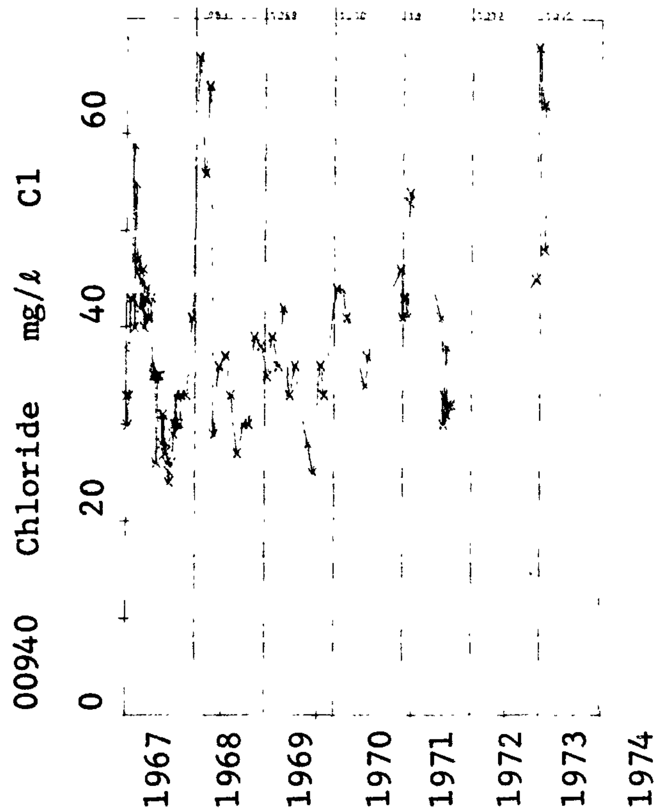

Figure 18.11

STORET WATER QUALITY PLOT

IHC 1
IHC and Dickey Rd.
Indiana data

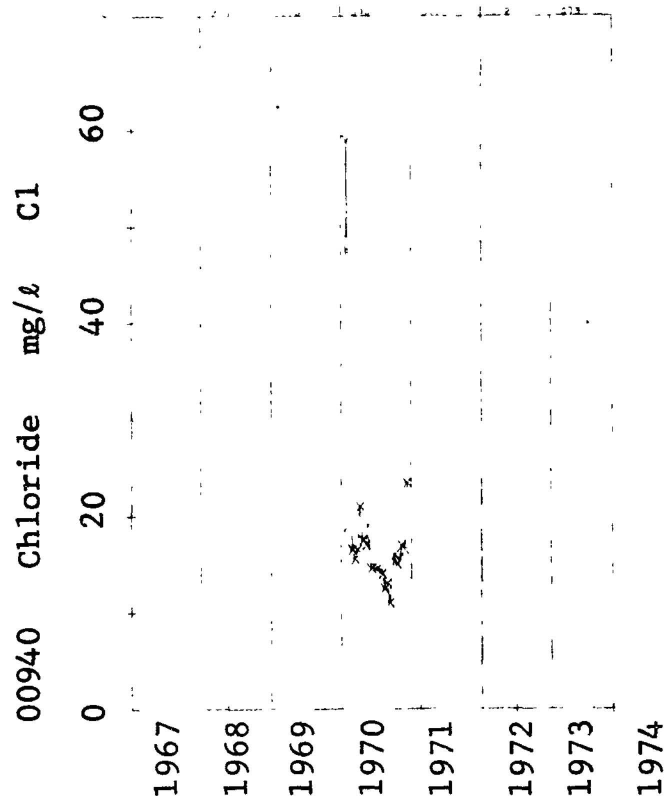

Figure 18.12

STORET WATER QUALITY PLOT

CAL17
Chicago SWFP Intake
EPA data

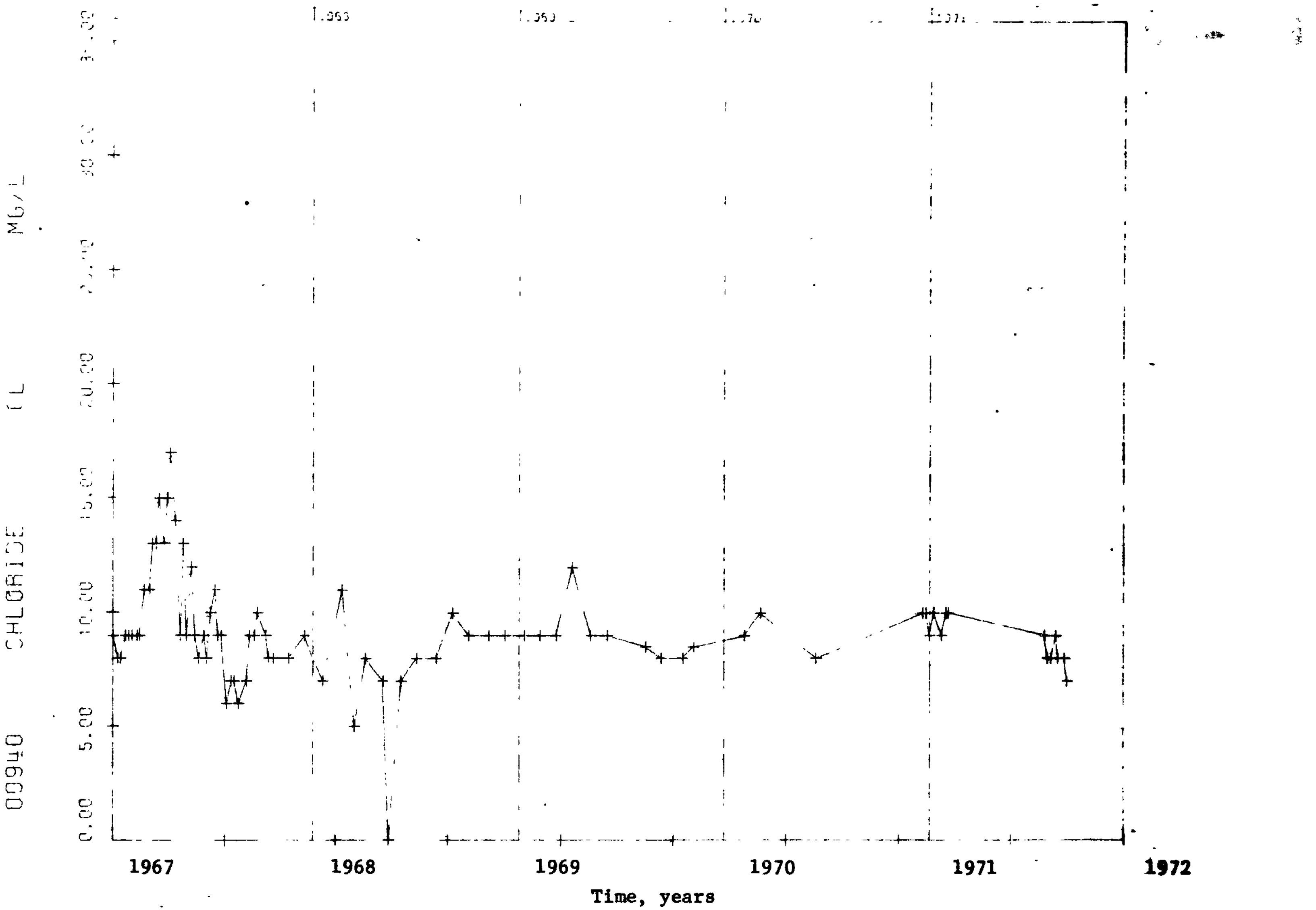

Figure 18.13

STORET WATER QUALITY PLOT

CAL13
Calumet Harbor
EPA data

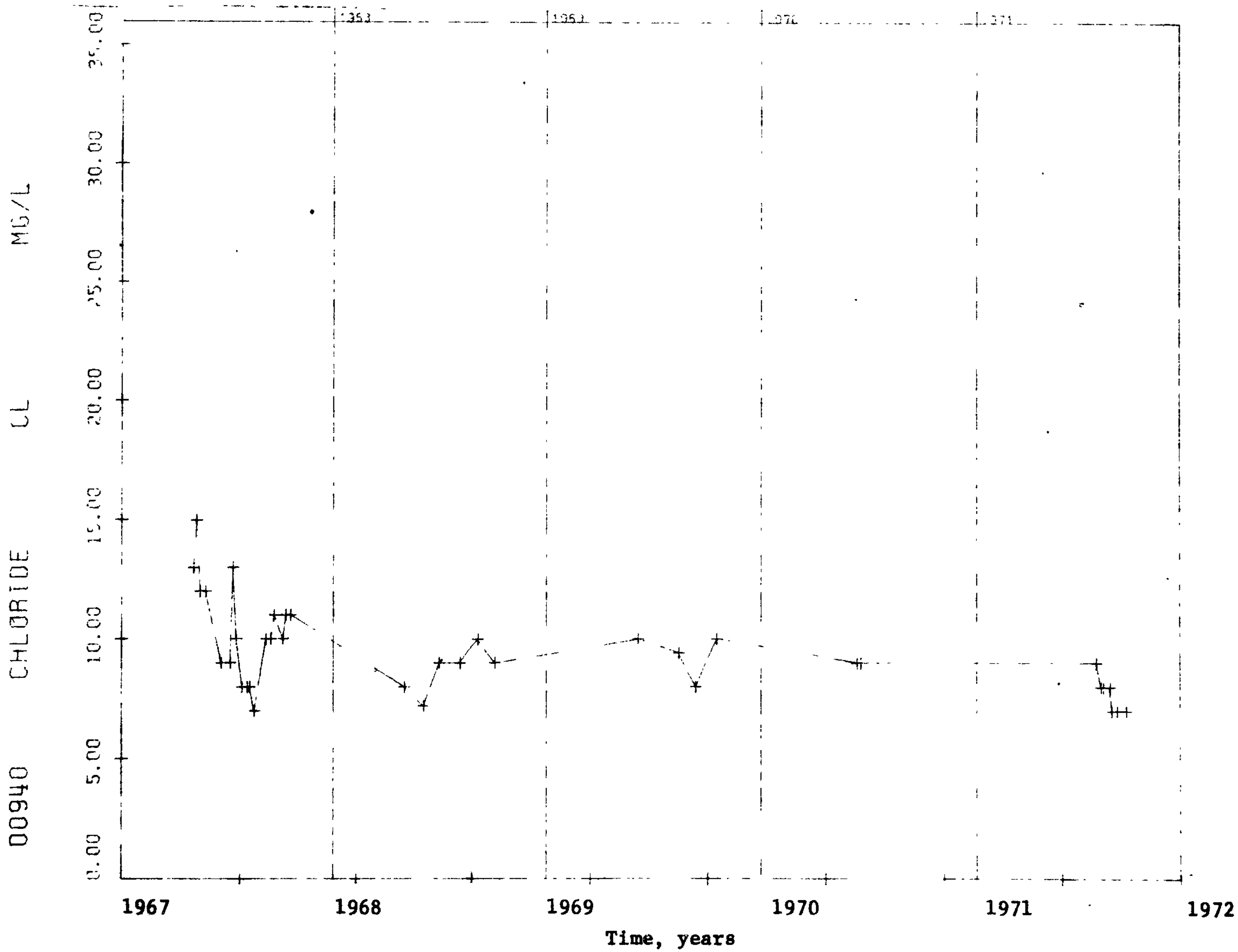

Figure 18.14

STORET WATER QUALITY PLOT

CAL16
Hammond Water Plant Intake
EPA data

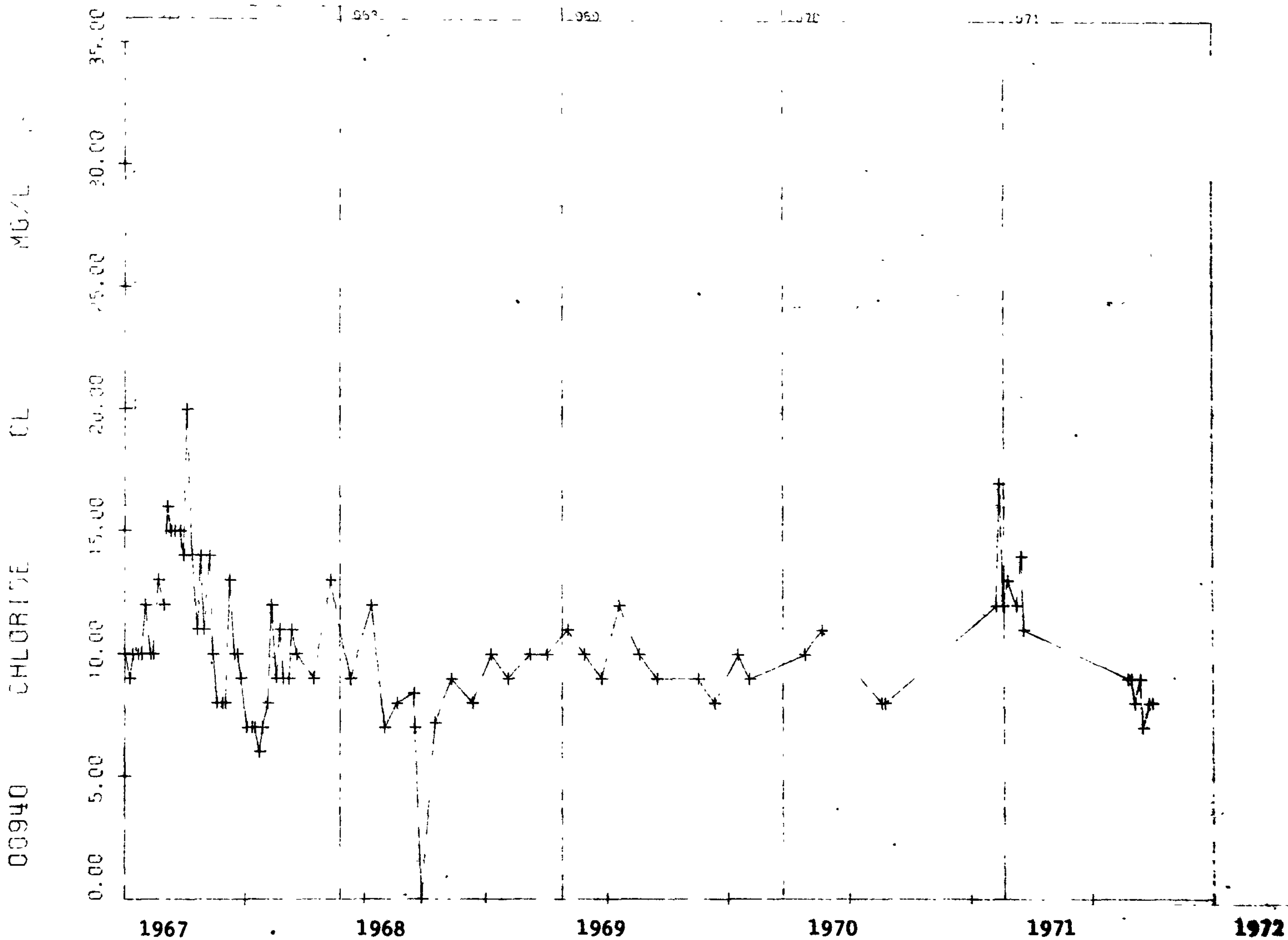

Figure 18.15

STORET WATER QUALITY PLOT

LM W
Whiting Water Plant Intake
Indiana data

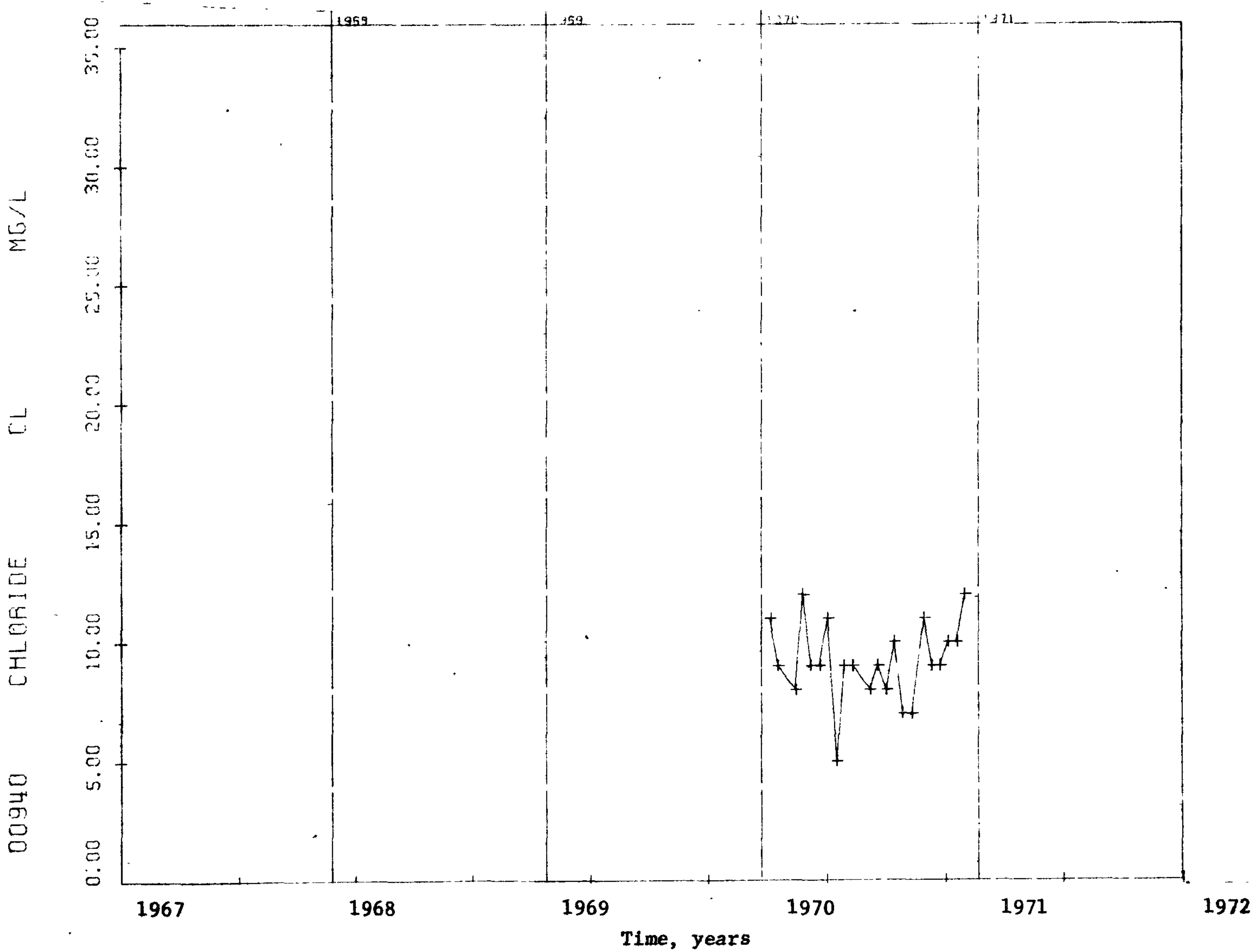

Figure 18.16

STORET WATER QUALITY PLOT

CAL15
East Chicago Water Plant Intake
EPA data

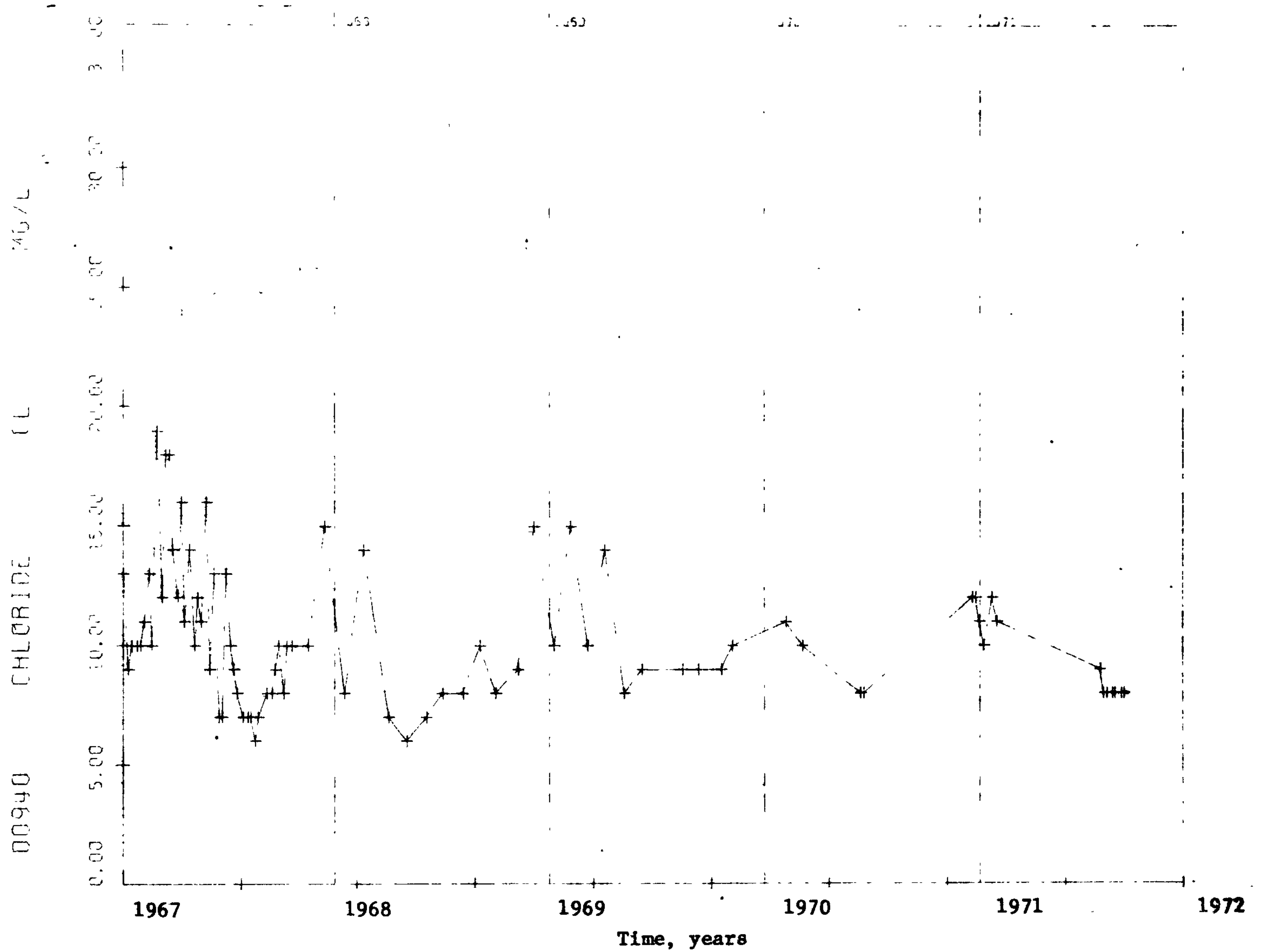

Figure 18.17

STORET WATER QUALITY PLOT

CAL14
Gary Water Plant Intake
EPA data

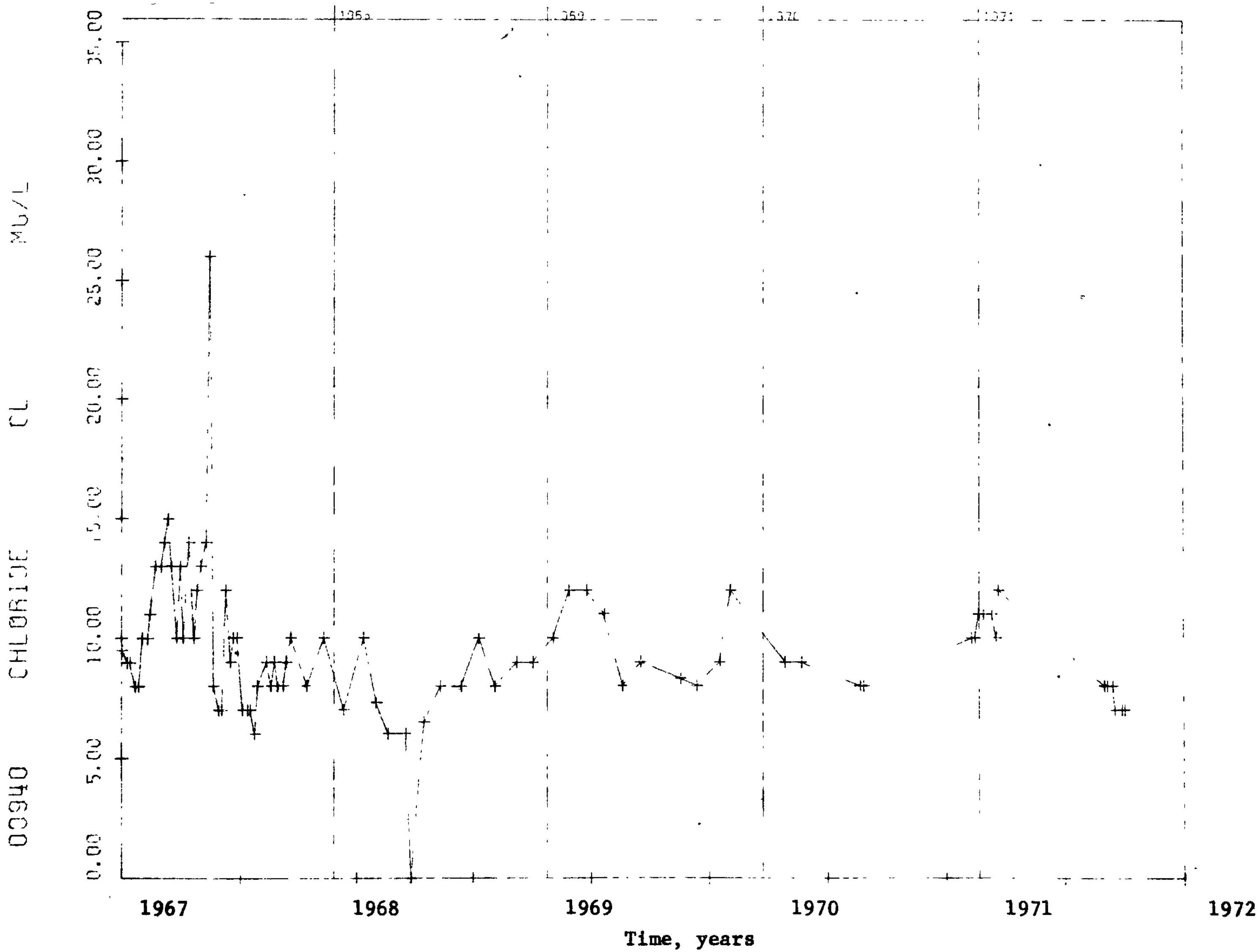

Figure 18.18

STORET WATER QUALITY PLOT

CAL02
IHC and 151st St.
EPA data

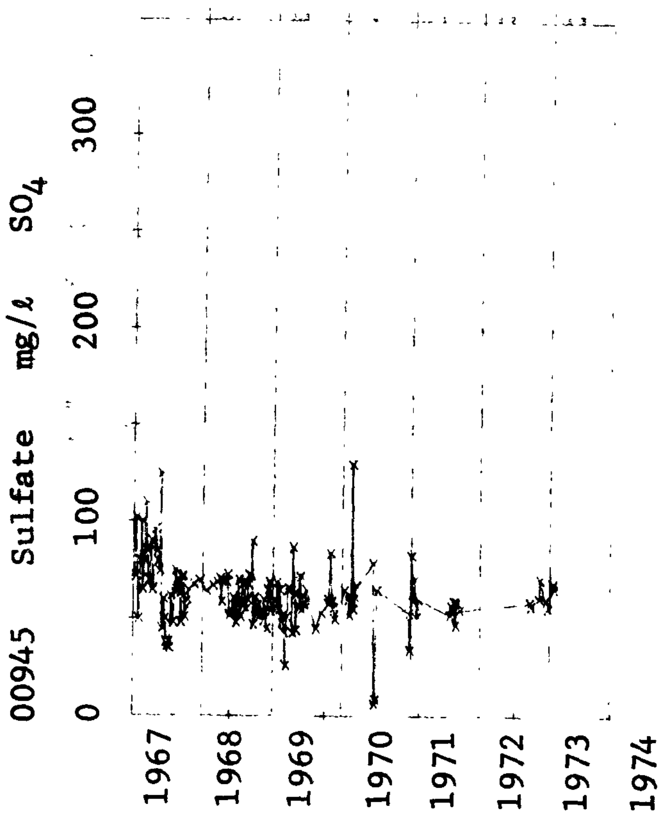

Figure 18.19

STORET WATER QUALITY PLOT

IHC 3S
IHC and Columbus Drive
Indiana data

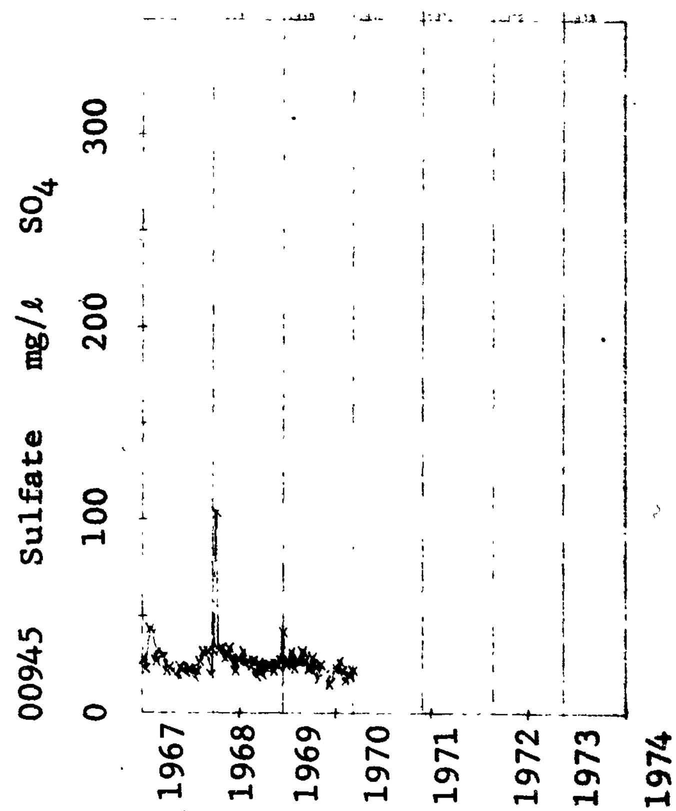

Figure 18.20

STORET WATER QUALITY PLOT

CAL03
IHC and Dickey Rd.
EPA data

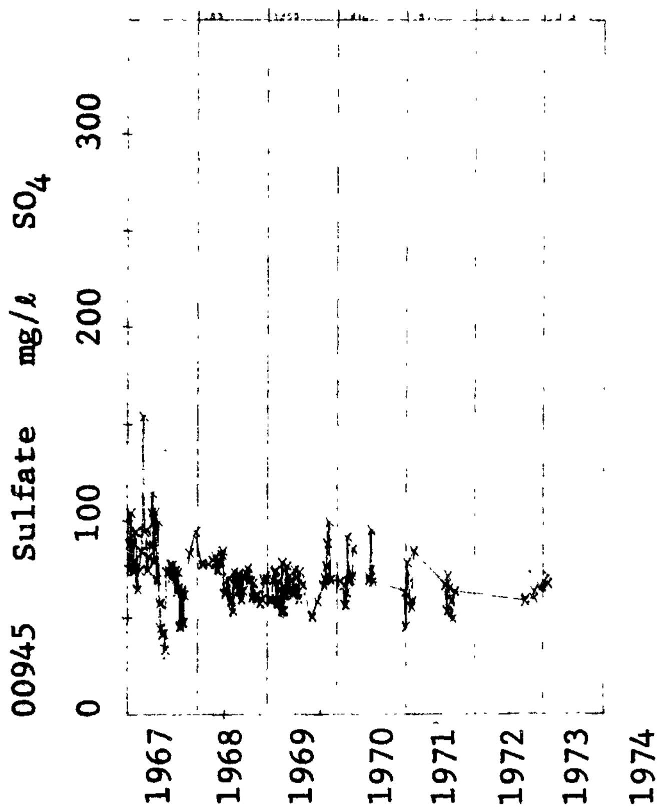

Figure 18.21

STORET WATER QUALITY PLOT

IHC 1
IHC and Dickey Rd.
Indiana data

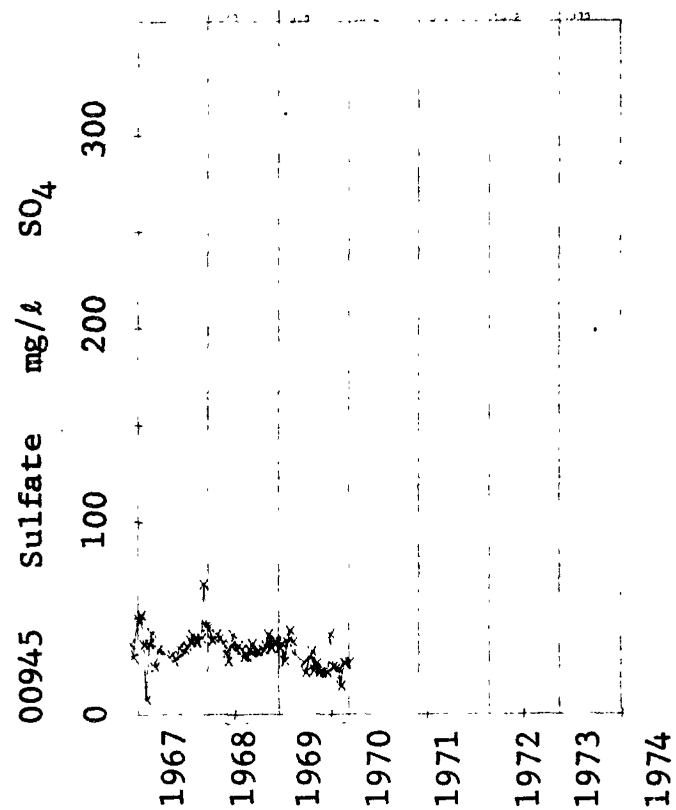

Figure 18.22

STORET WATER QUALITY PLOT

CAL06
IHC mouth
EPA data

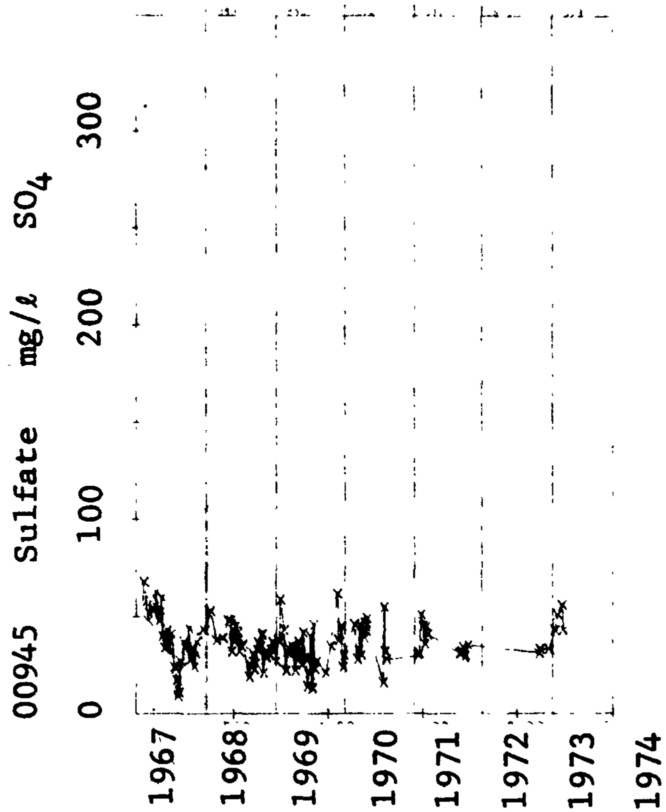

Figure 18.23
STORET WATER QUALITY PLOT

CAL11
Calumet River mouth
EPA data

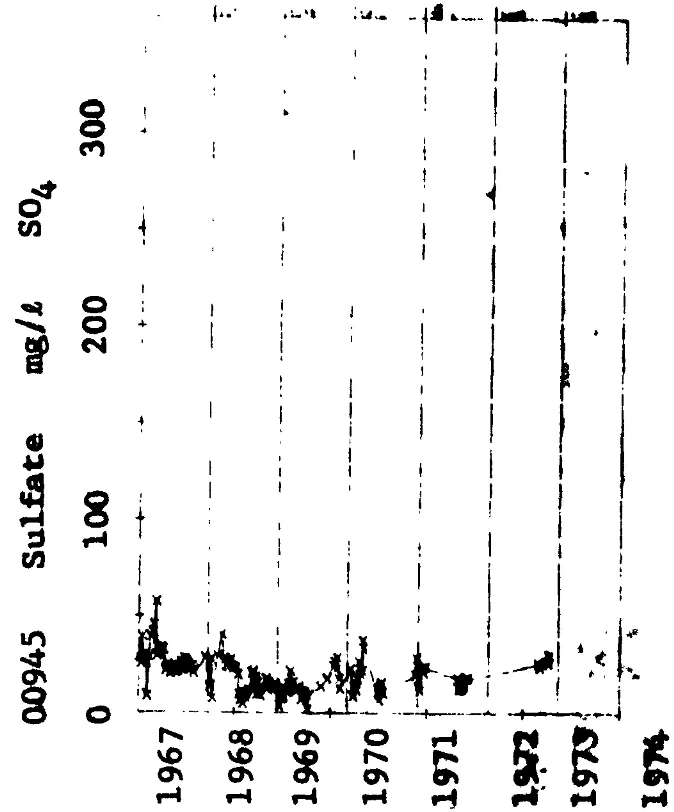

Figure 18.24
STORET WATER QUALITY PLOT

CAL17
Chicago SWFP Intake
EPA data

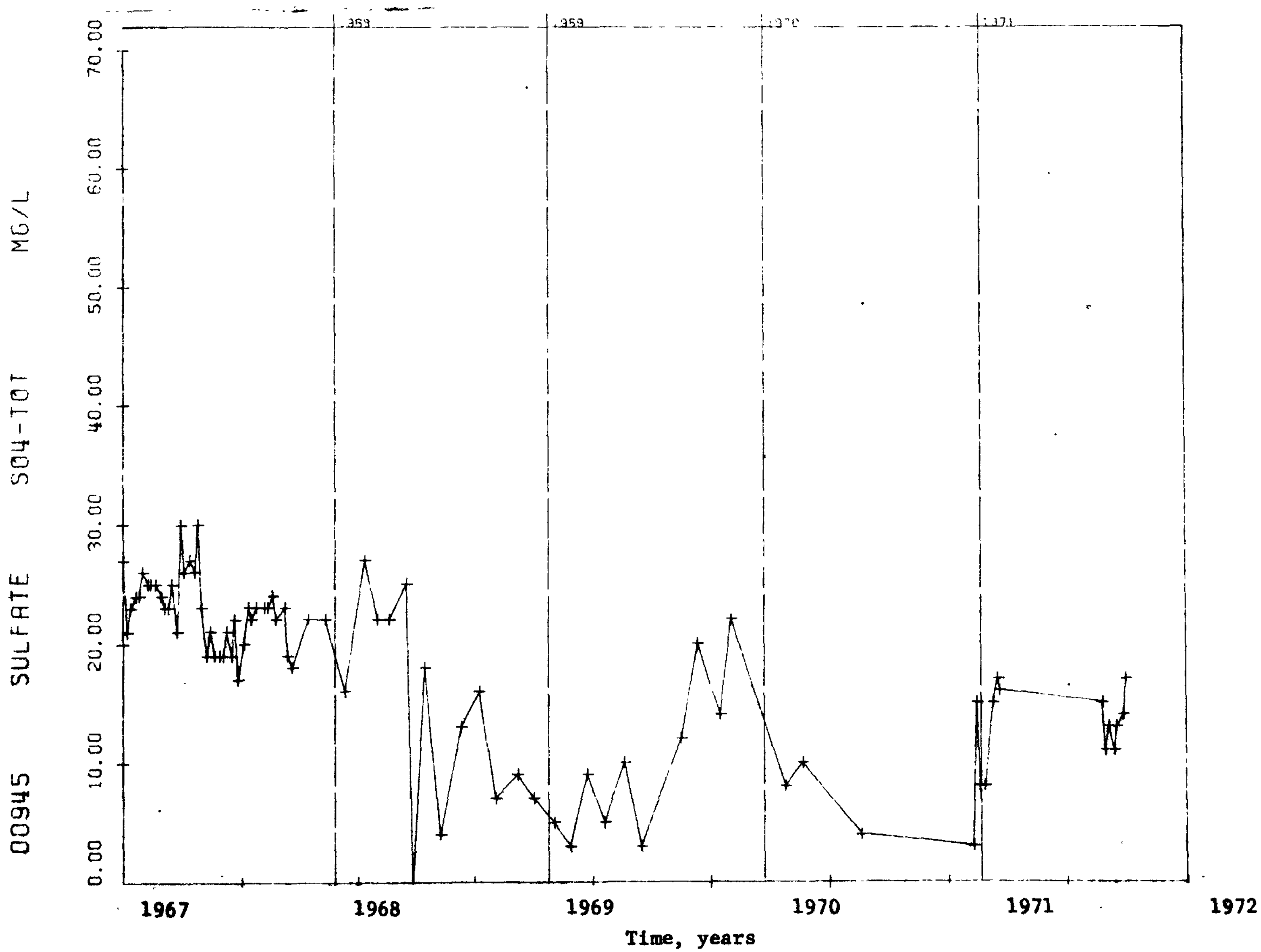

Figure 18.25

STORET WATER QUALITY PLOT

CAL13
Calumet Harbor
EPA data

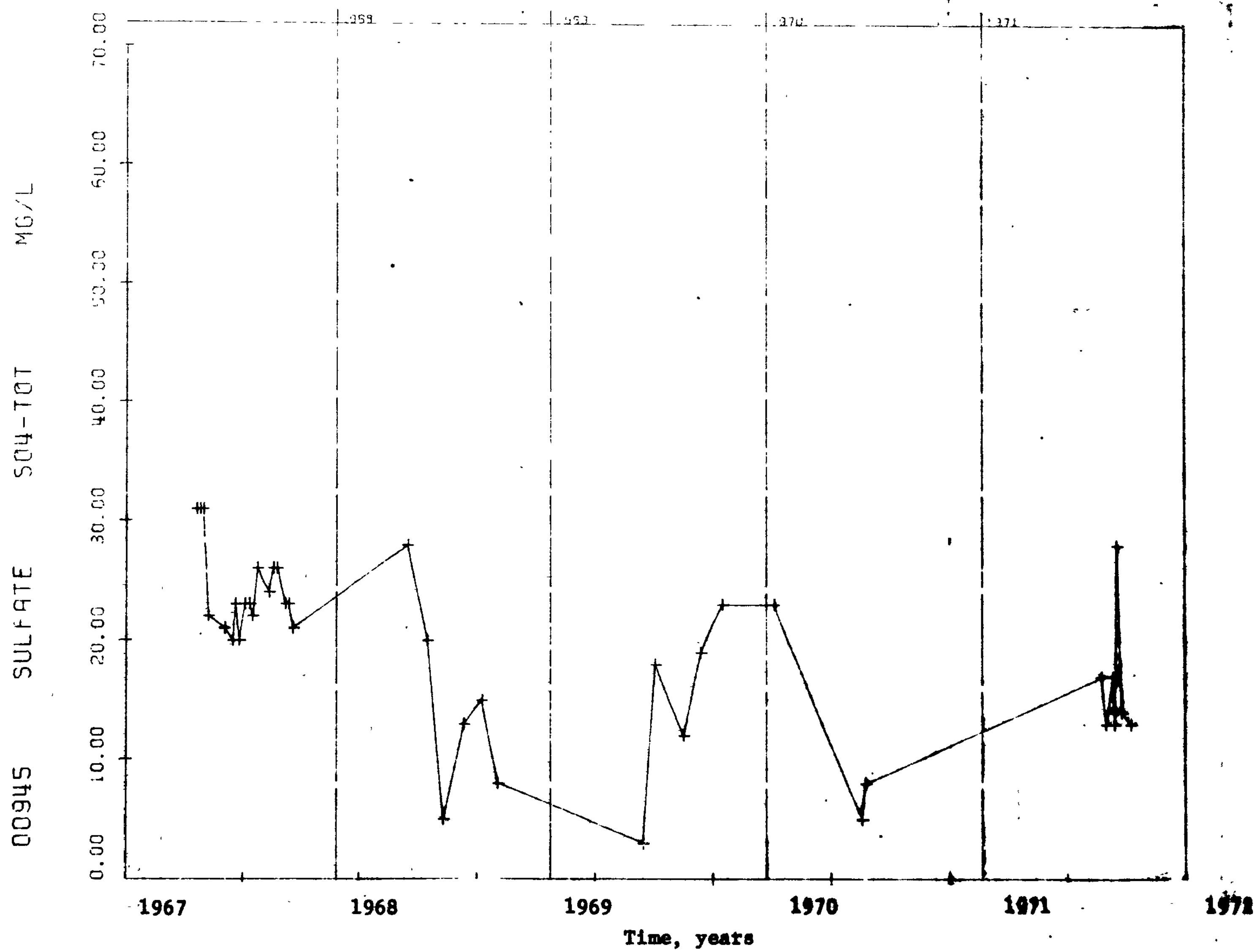

Figure 18.26

STORET WATER QUALITY PLOT

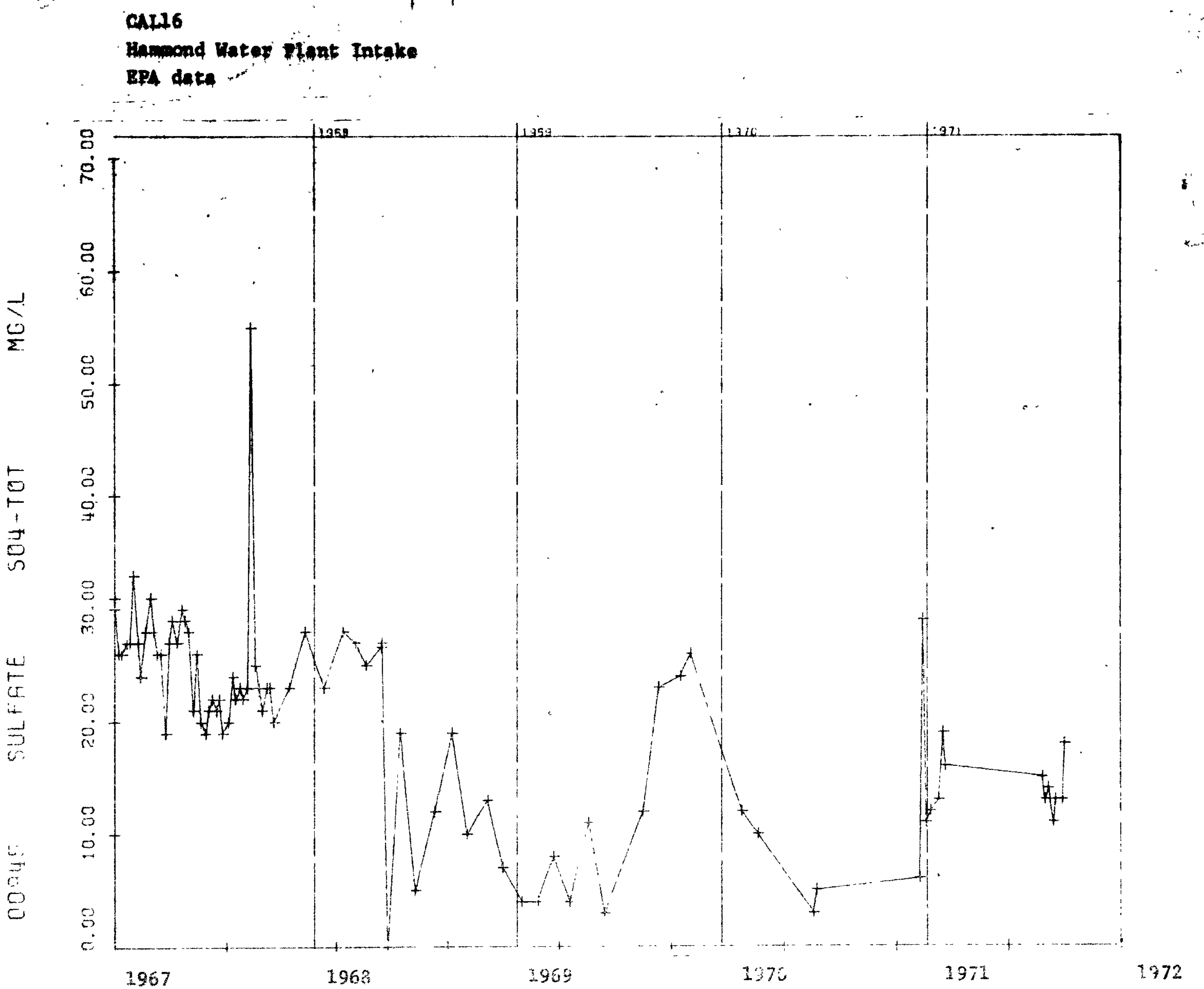

Figure 18.27

STORET WATER QUALITY PLOT

CAL15
East Chicago Water Plant Intake
EPA data

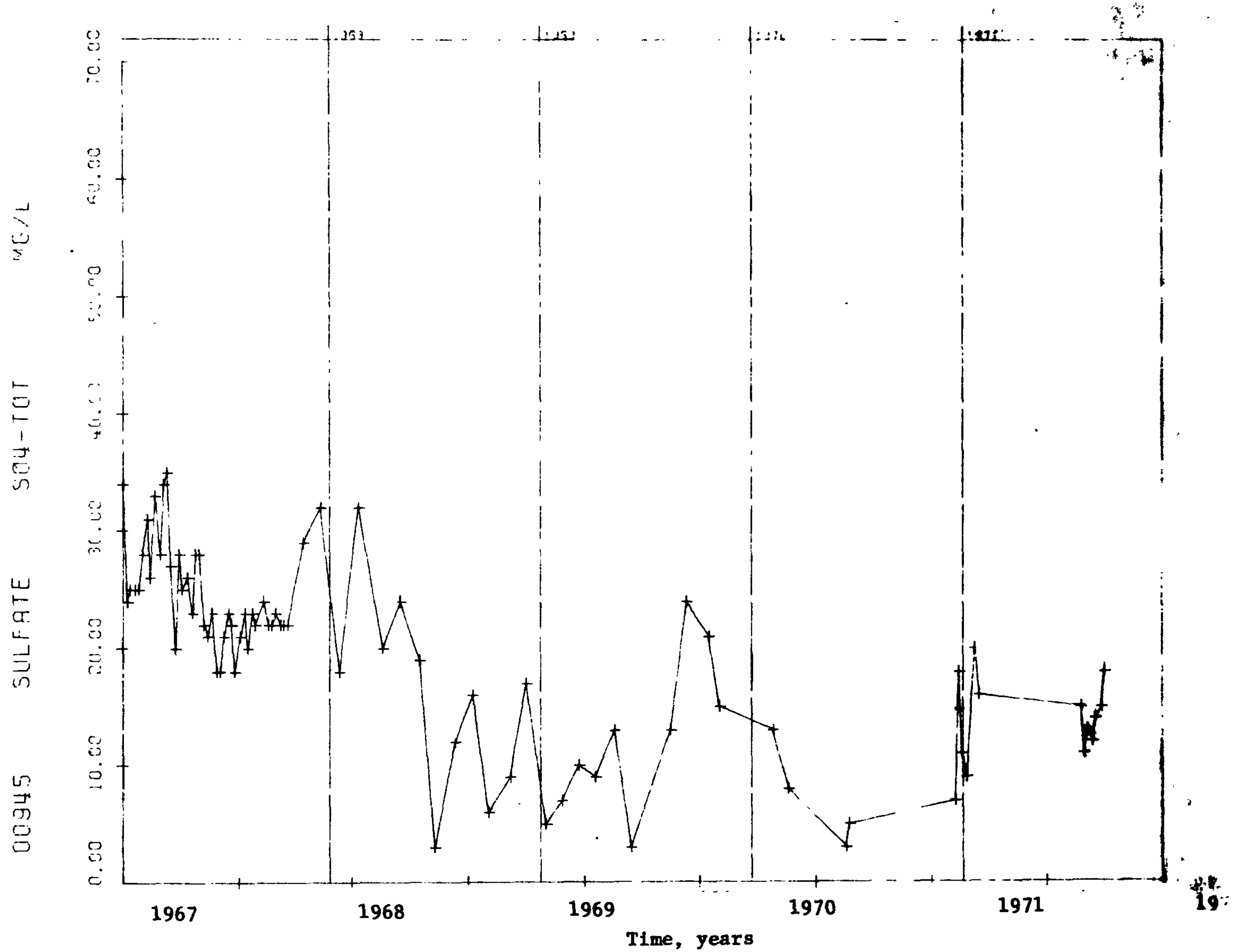

Figure 18.28

STORET WATER QUALITY PLOT

CAL14
Gary Water Plant Intake
EPA data

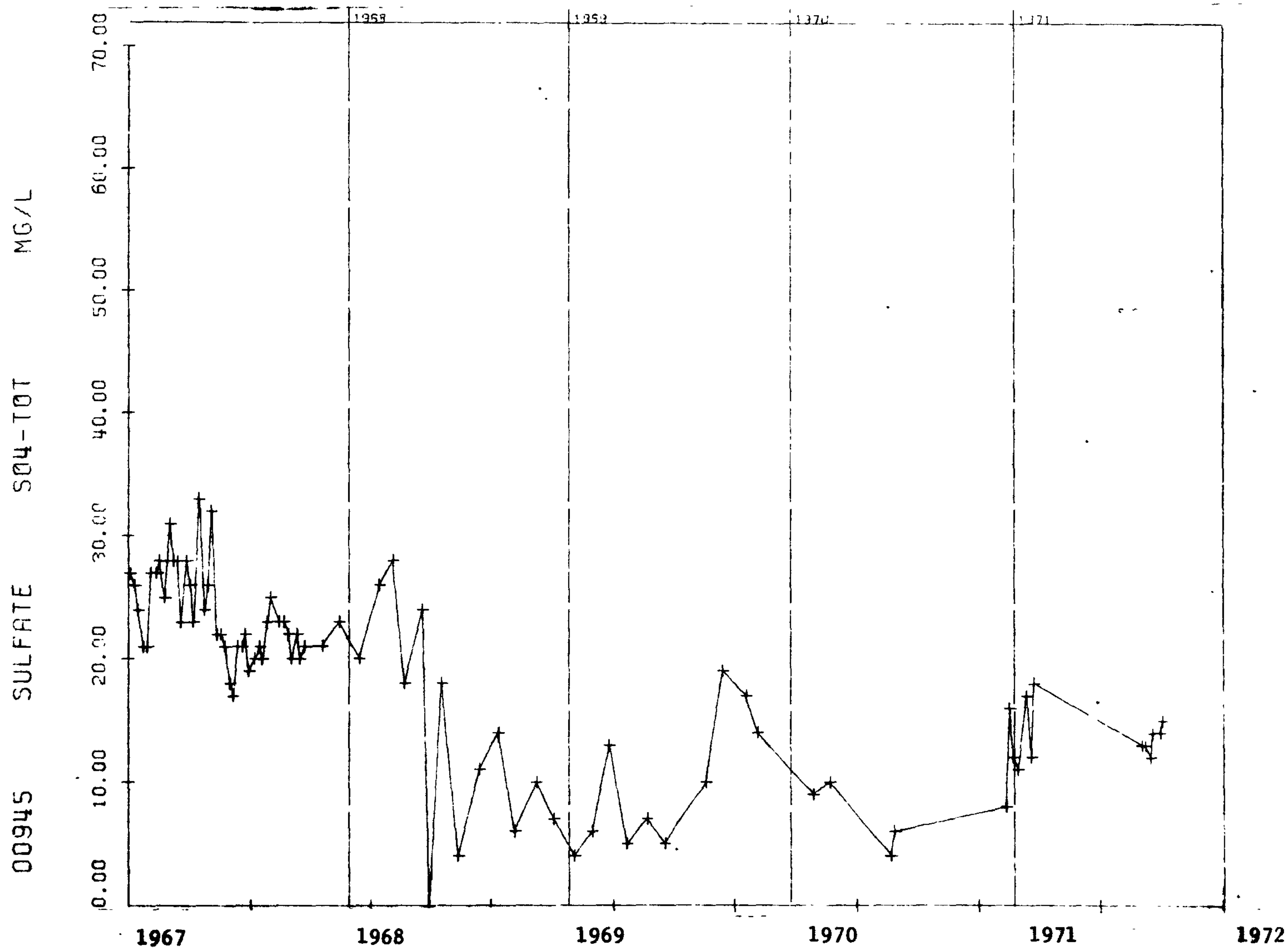

Figure 18.29

STORET WATER QUALITY PLOT

REFERENCES

Abbot, M. B., 1961

On the spreading of one fluid over another, LaHouille Blanche 16 (6) 827-846.

Atomic Energy Commission, 1973

Environmental Statement related to construction of Bailly Generating Station Nuclear-1, U.S. Atomic Energy Commission, Directorate of Licensing, Docket No. 50-367.

Alley, W. P. and Powers, C. F., 1970

Dry weight of the macrobenthos as an indicator of eutrophication of the Great Lakes, Proc. 13th Conf. on Great Lakes Res., Part II.

Asbury, J. G. and Frigo, A. A., 1971

A phenomenological relationship for predicting the surface areas of thermal plumes in lakes, Argonne National Laboratory, ANL/ES-5.

Ayers, J. C., 1959

The currents of Lakes Michigan and Huron, Great Lakes Research Institute, University of Michigan, Ann Arbor.

Ayers, J. C., Chandler, D. C., Lauff, G. H., Powers, C. F., and Henson, E. B., 1958

Currents and water masses of Lake Michigan, Great Lakes Research Institute Publication No. 3, University of Michigan, Ann Arbor, 169 pp.

Beeton, A. M., 1965

Eutrophication of the St. Lawrence Great Lakes, Limnology and Oceanography 10, 240-254.

Beeton, A. M., 1969

Changes in the environment and biota of the Great Lakes, in Eutrophication: Causes, consequences, corrections, National Academy of Sciences, Washington, D.C.

Beeton, A. M., 1974

Personal communication, Center for Great Lakes Studies, Univ. of Wisconsin-Milwaukee.

Beeton, A. M. and Edmondson, 1972

The eutrophication problem, J. Fisheries Res. Bd. of Canada, June.

Bellaire, F. R., 1963

Relation of winds, water levels and water temperatures to currents in lower Lake Michigan, Proc. 6th Great Lakes Research Conf., 219-230.

Bellaire, F. R., 1964

A comparison of methods of current determinations, Publ. No. 11, Great Lakes Research Div., University of Michigan, Proc. 7th Great Lakes Research Conf., 171-8.

Birchfield, G. E., 1967

A case study of coastal currents in Lake Michigan, Proc. 10th Great Lakes Research Conf., 264-273.

Bowden, Robert, 1974

Personal communication, U.S. EPA, Region V, Chicago

Businessmen for the Public Interest, 1972

Lake Michigan major industrial polluter inventory, prepared for Lake Michigan Enforcement Conference, September 1972, 14 pp.

Cederwall, Klas, 1970

Dispersion phenomena in coastal environments, J. Boston Soc. Civil Engrs. 57 (1) 34-70.

Chandler, D C., 1964

The St. Laurence Great Lakes, Great Lakes Research Div., University of Michigan, collected reprints, Vol. 1, 280-298.

City of Chicago, 1972

Report on Lake Michigan Water Quality Surveys, Division of Water Purification (1973).

Combinatorics, Inc., 1974

Load allocation study of the Grand Calumet River and Indiana Harbor Ship Canal, Report to State of Indiana, Stream Pollution Control Board.

Copeland, R. A. and Ayers, J. C., 1972

Trace element distributions in water, sediment, phytoplankton, and benthos of Lake Michigan, E. R. G., Inc., Ann Arbor, Michigan.

Corps of Engineers, 1968

Dredging water quality problems in the Great Lakes, Vol. 4, Appendix A 25, Preliminary report on effects of spoil disposal at Indiana Harbor, Indiana.

Corps of Engineers, 1969

Dredging and water quality problems in the Great Lakes, Summary report, U.S. Army, Buffalo District, Corps of Engineers.

Corps of Engineers, 1973

Environmental impact statement on proposed dredging of Indiana Harbor Ship Canal channel, U.S. Army Corps of Engineers, Chicago Engineer District.

Csanady, G. T., 1974

Personal communication, Woods Hole Oceanographic Inst., Woods Hole, Mass. 02543.

Environmental Protection Agency, 1974

Proposed effluent limitations guidelines and standards, Iron and steel point source category, Fed. Register 39 (34) 6487, Feb. 19, 1974.

Fish and Wildlife Service, U.S. Dept. of Interior, 1966

Fish and wildlife as related to water quality of the Lake Michigan Basin.

Frigo, A. A. and Frye, D. E., 1972

Physical measurements of thermal discharges into Lake Michigan in 1971, Argonne National Laboratory Report, ANL/ES-16.

Fruh, E. G., Armstrong, N. E. and Copeland, B. J., 1972

Water quality for estuarine ecological stability, in "Conflicts in water resources planning," E. F. Gloyna and W. S. Butcher, Eds., Center for Research in Water Resources.

Fuller, R. D., 1974

Personal communication, EPA Region V laboratory.

FWPCA, 1967

Lake currents, a technical report, 364 pp.

FWPCA, 1968a

Physical and chemical quality conditions, Lake Michigan Basin, 81 pp.

FWPCA, 1968b

Water pollution problems of Lake Michigan and tributaries.

FWPCA, 1968c

Water quality investigations, Lake Michigan Basin, Biology, 41 pp.

Great Lakes Basin Commission, 1971

Great Lakes Basin Framework Study, Appendix 18, Erosion and Sedimentation.

Harleman, D.R.G. and Stolzenbach, K. D., 1973

Fluid mechanics of heat disposal from power generation, Ann. Rev. of Fluid Mechanics 7, 7-32.

Harrington, M. W., 1895

Currents of the Great Lakes, U.S. Dept. of Agriculture, Weather Bureau Bull. B., 2nd Ed., 14 pp.

Harris, R. H. and Brecher, E. M., 1974

Is the water safe to drink, Consumer Reports 39 (6) 436-442.

Hiltunen, J. K., 1967

Some oligochaetes from Lake Michigan, Trans. Am. Microsc. Soc. 86, 433-454.

Hoglund, B. and Spigarelli, S. A., 1972

Studies of the sinking plume phenomenon, 15th Great Lakes Research Conf., 614-624.

Holland, R. E. and Beeton, A. M., 1972

Significance to eutrophication of spatial differences in nutrients and diatoms in Lake Michigan, Limnology and Oceanography, 17 (1) 88-96.

Howmiller, R. P. and Beeton, A. M., 1970

The oligochaete fauna of Green Bay, Lake Michigan, Proc. 13th Conf. Great Lakes Res., p. 15-46.

Howmiller, R. P., 1972

The oligochaete fauna of central Lake Michigan, p. 58-62 in R. P. Howmiller and A. M. Beeton, Report on a cruise of the R/V Neeskay in central Lake Michigan and Green Bay, 8-14 July 1971, Univ. Wisconsin-Milwaukee, Center for Great Lakes Studies, Special Report 13, 62+10 pp.

Howmiller, R. P., 1973

Review of biology and sediments of southern Lake Michigan, included as appendix to this final Report.

Illinois EPA, 1970

Lake Michigan open water and Lake bed survey, 87 pp.

Illinois EPA, 1971

Lake Michigan open water and Lake bed survey, 84 pp.

Illinois EPA, 1972

Lake Michigan shore and open water report, 107 pp.

Indiana Stream Pollution Control Board, 1970

Lake Michigan Enforcement Conf. Proc. 2 (May) 494.

Indiana Stream Pollution Control Board, 1973

Water quality standards, regulations SPC 4R (Lake Michigan and contiguous harbor areas) and regulation SPC 7R-2 (Grand Calumet River and Indiana Harbor Ship Canal), reaffirmed Sept. 11, 1973.

International Joint Commission, 1972

Great Lakes water quality, agreement between the U.S. and Canada, U.S. Govt. Printing Office, Washington, D.C. 20402.

Ippen, A. T., 1966

Estuary and coastline hydrodynamics, McGraw-Hill, New York.

Johnson, J. H., 1960

Surface currents in Lake Michigan, 1954 and 1955, U.S. Fish and Wildlife Service, Dept. of Interior, Special Scientific Report No. 338, 120 pp.

Keup, L. A., 1968

Phosphorus in flowing waters, Water Research 2, 373-386.

Knight, E. W., Schmeelk, W. G., and Lue-Hing, Cecil, 1972

Water quality trends in in-shore waters of southwestern Lake Michigan, manuscript of a talk, Metropolitan Sanitary District of Greater Chicago.

Lake Porter County Regional Transportation and Planning Commission, 1972

Water and waste water, a component of the regional plan, Dec.

LaVeille, W. C., 1972

Discussion before Phosphorus Committee, July 27, 1972.

Lee, G. F., 1972

Phosphorus, water quality and eutrophication of Lake Michigan, 31 pp., paper presented and included in transcripts of Lake Michigan Enforcement Conference, Sept. 1972. Proceedings of this conference have not been published, but are on file at U.S. EPA, Chicago, Illinois.

Merna, J. W., 1960

A benthological investigation of Lake Michigan, Unpublished M.S. Thesis, Michigan State University, 74 p.

Moore, S. L., 1974

Summary of waste load allocations GCR and IHC, memorandum of staff to Indiana SPCB, May 19, 1974.

Mortimer, C. H., 1968

Internal waves and associated currents observed in Lake Michigan during the summer of 1963, Special Report No. 1, Center for Great Lakes Studies, University of Wisconsin-Milwaukee.

Mortimer, C. H., 1970

A pictorial account of oscillatory responses to wind stresses in large lakes, with particular reference to long waves in Lake Michigan, manuscript, University of Wisconsin-Milwaukee.

Mortimer, C. H., 1971a

Chemical exchanges between sediments and water in the Great Lakes — speculations on probable regulatory mechanisms, Limnology and Oceanography 16 (2) 387-404.

Mortimer, C. H., 1971b

Large-scale oscillatory motions and seasonal temperature changes in Lake Michigan and Lake Ontario, Special Report No. 12, U.S. Army Engineers Contract No. DACW-35-68-C-0072, University of Wisconsin-Milwaukee, Parts I & II.

Mozley, S. C. and Garcia, L. C., 1972

Benthic macrofauna in the coastal zone of Lake Michigan, Proc. 15th Conf. Great Lakes Res., pp. 102-116.

Murphy, T. J., 1973

Phosphorus inputs from the atmosphere — their importance to oligotrophic lakes, 16th Great Lakes Research Conf.

National Academy of Sciences, 1969

Eutrophication: causes, consequences, correctives, Proc. of International Symposium on Eutrophication.

National Academy of Sciences, 1974

Water quality criteria, Report to U.S. EPA, to be published by U.S. Government Printing Office.

Noble, V. E., Huang, J. C. and Saylor, J. H., 1968

Vertical current structure in the Great Lakes, Special Report No. 37 of the Great Lakes Research Division, University of Michigan.

O'Connor, D. J. and Miller, J. A., 1970

A water quality model of chlorides in Great Lakes, J. Sanitary Engr. Div. ASCE, 96 (4) 955-975.

Palin, A. T., 1973

Chemistry and control of modern chlorination, LaMotte Chemical Products Co., Chestertown, Maryland 21620.

Palmer, M. D., 1974

Coastal region residence time estimates from concentration gradients, 17th Great Lakes Research Conference.

Parker, F. L., and Krenkel, P. A., 1969

Thermal pollution: status of the art, Report No. 3 prepared for FWPCA, Vanderbilt University, Nashville, Tenn.

Parsons, T. R. and Strickland, J.D.H., 1963

Discussion of spectrophotometric determination of marine-plant pigments with revised equations for ascertaining chlorophylls and carotenoids, J. Marine Research 21, 155-163.

People of the State of Illinois and the Metropolitan Sanitary District of Greater Chicago vs Inland Steel Co., 1974

Circuit court of Cook County, Illinois.

Phosphorus Technical Committee, 1972

Report to Lake Michigan Enforcement Conference, U.S. Environmental Protection Agency.

Powers, C. F. and Robertson, A., 1965

Some quantitative aspects of the macrobenthos of Lake Michigan, University of Michigan Great Lakes Research Division, Publication No. 13, 153-159.

Powers, C. F. and Ayers, J. C., 1967

Water quality and eutrophication trends in southern Lake Michigan in Studies on the environment and eutrophication of Lake Michigan, University of Michigan, Great Lakes Research Division, Special Report No. 30.

Pritchard, D. W., 1972

Testimony at Lake Michigan Enforcement Conference, Sept. 21, 1972, Vol. 3, Part 3, p. 789-883. (Unpublished, available from U.S. Environmental Protection Region V library.)

Reed, Philip and Pawlowski, C., 1974

Taste and odor incidents at 68th St. water intake, unpublished report, Chicago Water Dept.

Risley, Clifford and Fuller, R. D., 1965

Chemical characteristics of Lake Michigan, Proc. 8th Great Lakes Research Conf., 166-174.

Risley, Clifford and Fuller, R. D., 1966

Chemical findings from pollution studies in the Calumet area of Indiana and Illinois and the adjacent waters of Lake Michigan, Proc. 9th Great Lakes Research Conf., 423-9.

Robbins, J. A., Landstrom, Edward and Wahlgren, Morris, 1972

Tributary inputs of soluble trace metals to Lake Michigan, Proc. 15th Conf. Great Lakes Research, 270-290.

Robertson, A. R. and Alley, W. P., 1966

A comparative study of Lake Michigan macrobenthos, Limnology and Oceanography 11, 576-583.

Robertson, A. and Powers, C. F., 1965

Particulate organic matter in Lake Michigan, 8th Great Lakes Research Conf., 175-181.

Robertson, A. R., and Powers, C. F., 1967

Comparison of the distribution of organic matter in the five Great Lakes, in Studies on the environment and eutrophication of Lake Michigan, University of Michigan Great Lakes Research Div., Special Report No. 30.

Robertson, A., Powers, C. F. and Rose, Jeanne, 1971

Distribution of chlorophyll and its relation to particulate organic matter in the off-shore waters of Lake Michigan, 14th Great Lakes Research Conf., 90-101.

Rousar, D. C., 1973

Seasonal and spatial changes in primary production and nutrients in Lake Michigan, Water Air and Soil Pollution, 2, 497-514.

Sager, P. E. and Wiersma, J. H., 1972

Nutrient discharges to Green Bay, Lake Michigan from the lower Fox River, Proc. 15th Conf. on Great Lakes Research.

Santina, William and Bochantin, Bernard, 1974

Personal communication, U.S. Army Corps of Engineers, Chicago Engineer District.

Saylor, J. H., 1968

Lake Michigan harbor currents (Calumet area), Army Corps of Engineers, Subproject GLR-111.

Schelske, C. L. and Roth, J. C., 1973

Limnological survey of Lakes Michigan, Superior, Huron and Erie, Publ. No. 17, Great Lakes Research Div., University of Michigan, Ann Arbor, Michigan, p. 14.

Schelske, C. L. and Stoermer, E. F., 1971

Eutrophication, silica depletion and predicted changes in algal quality in Lake Michigan, Science 173, 434-4.

Schindler, D. W., 1974

Eutrophication and recovery in experimental lakes: implications for lake management, Science 184 (June 7), 897-9.

Schleicher, J. A. and Kuhn, J. K., 1970

Phosphorus content in unconsolidated sediments from southern Lake Michigan, Illinois State Geological Survey, Environmental Geology Note No. 39.

Sharp, J. J., 1969

Spread of buoyant jets at the free surface, J. Hydraulics Div. ASCE 95 (HY3) 811-825.

Shimp, et al., 1970a

Distribution of arsenic in unconsolidated sediments from souther Lake Michigan, Illinois Geological Survey, Environmental Geology Note Series, EGN 37.

Shimp, et al., 1970b

Distribution of major, minor, and trace constituents in unconsolidated sediments from southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 32.

Shimp, et al., 1970c

Phosphorus content in unconsolidated sediments from southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 39.

Shimp, et al., 1970d

Preliminary stratigraphy of unconsolidated sediments from the southwestern part of Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 30.

Shimp, et al., 1970e

Stratigraphy of unconsolidated sediments in the southern part of Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 35.

Shimp, et al., 1971a

Distribution of mercury in unconsolidated sediments from southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 44.

Shimp, et al., 1971b

High-resolution seismic profiles and gravity cores of sediments in southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 47.

Shimp, et al., 1971c

Trace elements and organic carbon accumulation in the most recent sediments of southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 41.

Shimp, et al., 1972a

Dep. patterns and trace element accumulation in the southern end of Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 58.

Shimp, et al., 1972b

Geologic cross-sections derived from seismic profiles and sediment cores from southern Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 54.

Shimp, et al., 1973

Major, minor, and trace elements in sediments of Lake Michigan, Illinois Geological Survey, Environmental Geology Notes Series, EGN 60.

Somers, L. H. and Josephson, P. D., 1968

Bottom sediments of southwestern Lake Michigan, Proc. Great Lakes Research Conf., 245-252.

Sonsogni, W. and Lee, G. F., 1972

Recovery of the Madison Lakes after nutrient diversion, AIChE meeting, Minneapolis, Minnesota, August 1972.

Stoermer, E. F., 1969

Plankton diatom assemblages in Lake Michigan, FWQA Report, Program No. 18050 DKC.

Sweeney, Dan, 1973

Citizens for a Better Environment as subcontractor to IITRI, Information obtained by site visits and interviews with personnel of East Chicago Sanitary District, September to December 1973.

Technical Committee on Water Quality, 1970

Water quality in the Calumet area, Conf. on Pollution of Lower Lake Michigan and Calumet Area, Issued separately by U.S. Environmental Protection Agency, Region V, Chicago, 131 pp.

Thomas, N. A., Hartwell, K. and Miller, W., 1972

Technical working report No. 3, Grosse Ile laboratory, U.S. Environmental Protection Agency.

U.S. Bureau of Outdoor Recreation, 1965

Water-oriented outdoor recreation in Lake Michigan basin, report to FWPCA.

U.S. Environmental Protection Agency, 1973a

Comparison of NTAC, NAS and Proposed EPA Numerical criteria for water quality.

U.S. Environmental Protection Agency, 1973b

Pretreatment of pollutants introduced into publicly owned treatment works, Office of water program operations, Washington, D.C.

U.S. Public Health Service, Dept. of HEW, 1963a

Currents at fixed stations near Chicago, Special Report No. 11, Great Lakes-Illinois River Basins Project.

U.S. Public Health Service, Dept. of HEW, 1963b

Currents in the southern basin, Special Report No. LM 12, Great Lakes-Illinois River Basin Project.

U.S. Public Health Service, Dept. of HEW, 1963c

Lake currents at a single station, Special Report No. LM 9, Great Lakes-Illinois River Basins Project.

U.S. Public Health Service, Dept. of HEW, 1963d.

Drogue surveys of Lake currents near Chicago, Special Report No. 10, Great Lakes-Illinois River Basins Project.

Van Oosten, John, 1963.

Surface currents of Lake Michigan, 1931 and 1932, U.S. Fish & Wildlife Service, Dept. of Interior, Special Scientific Report No. 413, 51 pp.

Vaughn, J. C., 1969

A current report on effect of water quality deterioration on the operation of Chicago's south water filtration plant, Presented at FWPCA Conference, City of Chicago, Dept. of Water and Sewers.

Vaughn, J. C. and Reed, P. A., 1972

Progress report on water quality of Lake Michigan near Chicago, Presented at four-state pollution conference at Chicago, Illinois, City of Chicago, Dept. of Water & Sewers Report.

Verber, J. L., 1964

The detection of rotary currents and internal waves in Lake Michigan, Proc. 9th Great Lakes Research Conf., 299-306.

Vollenweider, R. A., 1968

Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Report to the Organization for Economic Co-operation and Development, Directorate for Scientific Affairs.

Wilding, R. E. and Schmidt, R. L., 1973

Phosphorus release from Lake sediments, Report EPA-R3-73-024, U.S. Environmental Protection Agency, Corvallis, Oregon.

Winters, J. L., 1973
Personal communication, Indiana State Board of Health.

Winters, J. L., 1974
Ammonia loading to Lake Michigan from IHC, unpublished office memorandum, Indiana State Board of Health, May 9, 1974.

Wnek, W. J. and Fochtman, E. G., 1972
Mathematical model for fate of pollutants in near-shore waters, Environ. Sci. & Tech. 6 (4) 331-7.