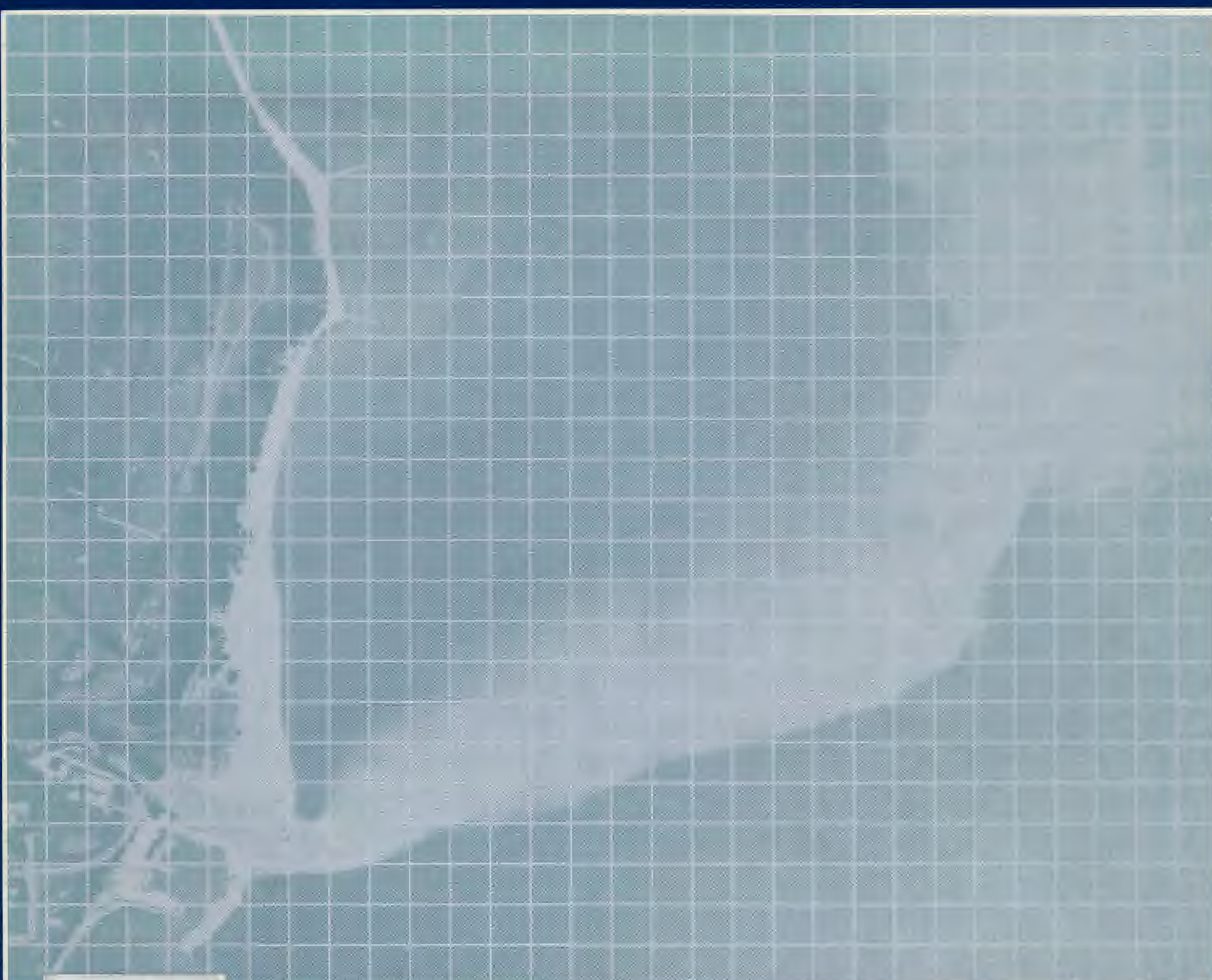
The Lake Michigan Pollution Case

A Review and Commentary on the Limnological and Other Issues



By Clifford H. Mortimer

Center for Great Lakes Studies
University of Wisconsin-Milwaukee

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Glossary

Frequently mentioned individuals, organizations, corporate bodies and technical terms have been abbreviated to save space. The acronyms are listed here for easy reference. Also, for clarity, certain key terms are defined below in the sense they are used in the text.

ABBREVIATIONS

BOD — Biological Oxygen Demand: A pollution index derived by incubating a sample (usually for five days: BOD_5) under standard conditions at a constant temperature. The oxygen uptake is a measure of the decomposable organic matter present.

cfs — cubic feet per second: A measure of flow.

CSO — Combined Sewer Overflow: Wastewater from combined sewers is a mixture of raw sanitary sewage and storm water. It is released into rivers and Lake Michigan when pipe capacity can no longer contain the flow. Combined sewers serve 27 square miles of Milwaukee and Shorewood.

DNR — Department of Natural Resources: State of Wisconsin.

DE — Defendant's Exhibit(s).

EPA — Environmental Protection Agency: United States.

FCC — Fecal Coliform Count: An estimate, determined by a simple standard procedure, of the most probable number of fecal coliform bacteria in a sample. Though not pathogenic themselves, fecal coliforms are indicative of pollution from the feces of warm-blooded animals (including birds) and therefore are a measure of the risk of infection from other, disease-causing organisms in fecal matter.

IJC — International Joint Commission: A U.S.-Canadian government commission with jurisdiction over the Great Lakes.

JISTP — Jones Island Sewage Treatment Plant: A Milwaukee plant that discharges its effluent directly into Milwaukee Harbor.

JVK — Joseph V. Karaganis: Chief counsel for the plaintiffs.

mg/L — milligrams per liter: Sometimes expressed in parts per million.

MIS — Metropolitan Interceptor Sewer: A system of large sanitary sewers carrying sewage from local systems to Milwaukee treatment plants.

MMSD	Milwaukee Metropolitan Sewerage District: Created by state authority in 1921 to plan and construct sewers in a 230-square-mile area to connect 18 Milwaukee County communities (not including the City of South Milwaukee) with the MIS and other Milwaukee sewage collection systems. The MMSD Commission includes five members from the City of Milwaukee Sewerage Commission and three from the rest of the district.
PE	Plaintiff's Exhibit(s).
ppm	parts per million.
SSSTP	South Shore Sewage Treatment Plant: A Milwaukee treatment plant that discharges its effluents directly into Lake Michigan.
tr. p.	transcript page: Page numbers of the official court transcripts of Illinois v. Milwaukee.

KEY TERMS

Activated Sludge — A biologically active suspension of microorganisms which, in the presence of oxygen, decompose the organic materials in sewage into simpler compounds that escape as gases or can, after further treatment (removal of solids, followed by chlorination), be safely discharged into surface waters.

Bypass — A flow relief device by which sanitary sewers or intercepting sewers can discharge a portion or all of their flow directly into a receiving body of surface water to alleviate sewer overloading.

Clear Water — Water entering a sanitary sewer system through infiltration or inflows is called "clear water." Clear water reduces a sewer system's capacity to carry sanitary sewage.

Combined Sewers — A sewer system that carries both sanitary sewage and storm water.

Eutrophication — Progressive enrichment of lakes and natural waterways with nutritient materials otherwise in short supply (notably phosphate and nitrate from treated and untreated human and agricultural wastes) with a consequent increase in biological productivity. When this leads to massive growth of algae (particularly blue-green algae) and other water plants, or to the proliferation of less desirable fish, eutrophication is perceived to be a nuisance -- but it is not a health hazard itself.

Inflow	With infiltration, the total quantity of water entering a sewer system. Infiltration means water entering through defective or improperly connected pipes and pipe joints, manhole walls, foundation drains and downspouts.
Peak Flow	The maximum volume of effluent expected to enter a treatment system in any given period of time.
Sanitary Wastewater	Wastewater entering a collector sewer and containing contaminants from a variety of human activities, but primarily those generated by bodily functions.
Separated Sewers	A system in which domestic and industrial wastes are carried in sanitary sewers that are separate and have no interconnections with sewers carrying storm runoff.
Sewer Service Area	This is a 420-square-mile area in which the MMSD could ultimately provide sewerage service. At present, 205 square miles are served by the MMSD, including all of Milwaukee County and all or part of eight communities in adjacent counties, which contract with MMSD for sewer service.
Virus	Submicroscopic infective agents of a proteinaceous nature that survive in many natural environments but can only propagate (and cause disease) after entering a living cell of a plant or animal host.

About the Author

Dr. Clifford H. Mortimer, distinguished professor of zoology, is a senior scientist and past director of the University of Wisconsin-Milwaukee Center for Great Lakes Studies. A native of Britain, he has been intensely interested in Lake Michigan since his first visit to Wisconsin in 1953. Over the past 25 years, Dr. Mortimer has conducted numerous limnological studies of Lake Michigan and other Great Lakes.

He served as director for the Center for Great Lakes Studies from 1966 until 1979. Dr. Mortimer is a past president of both the American Society of Limnology and Oceanography, and the International Association for Great Lakes Research. He is also a member of the International Association of Limnology and a fellow of the Royal Society of London. Before coming to the U.S., Dr. Mortimer was director of the Scottish Marine Biological Association's Marine Station at Millport, Scotland.

Dr. Mortimer received his Ph.D. from the University of Berlin, Germany, and a Doctorate of Science from the University of Manchester, England.

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I am most grateful to Mr. Ewald Moerke, co-chief counsel for the defendants, for his loan of trial documents and exhibits, to the University of Wisconsin Sea Grant Institute for its support and publication assistance, and the U.W.-Milwaukee Center for Great Lakes Studies for its support. I am indebted to R. R. Ristic and Joan Flores for their help in illustration and manuscript preparation, respectively. I am also grateful to the Wisconsin Department of Natural Resources and Dr. Roger Bannerman for use of the aerial photographs reproduced in figures 7-9. I am particularly grateful to Dr. George Bunn of the U.W.-Madison Law School, for his substantial comments on an earlier draft of this review.

Foreword

The judgement order resulting from the 1977 Illinois v. Milwaukee pollution case will, unless reversed in a pending appeal, impose a severe financial burden on the Milwaukee metropolitan community. That burden can be measured. Much less easy to measure will be the benefits accruing to the citizens of Illinois and to the Lake Michigan ecosystem. Because of the landmark stature and wide implications of this case, and because of my longstanding interest in Lake Michigan, I have attempted in this review to follow the lines of evidence and argument that guided Judge Grady to his findings and to speculate (as a legal novice, but with this case in mind) on how legal processes and judicial actions might evolve toward optimum use of experts, thus bringing scientific knowledge and uncertainty more effectively to bear on far-reaching decisions in environmental management and risk regulation.

This is in part a report on the limnological evidence, testimony and argument introduced during the trial, and in part a commentary leading to my personal conclusions, which were sometimes based on material (some more recent) that was not presented at the trial. As far as possible, I have attempted to separate reportage and commentary and to let the court record speak for itself. My own conclusions and commentary are specifically labeled as "comments" in Sections 2-6. Section 7 consists almost entirely of quotations from the closing statements of counsel and from Judge Grady's findings, though they have been rearranged to highlight the principal questions debated. Section 8 contains my speculations on procedure. Where appropriate, and because of their interest, illustrations have been taken from the court exhibits, though in some cases the quality of reproduction is not good. These figures are identified as defendants' or plaintiffs' exhibits (DE or PE). Figures not so marked or otherwise designated are original to this review. References are listed in the order of their appearance at the end of text.

The Illinois v. Milwaukee case raises many interesting points, and I trust that this review will serve as a guide to some of them. I also hope that it will contribute to an understanding of the Lake Michigan ecosystem and its response to human activities.

Section 1:

Introduction

1.1 Origins of the Complaint

In May 1972 the attorney general of the State of Illinois (William J. Scott) filed a complaint (Ref. 1) in U.S. District Court in Chicago on behalf of the "People of the State of Illinois" (plaintiffs) alleging that the defendants* were authorizing or allowing the discharge of "untreated raw sewage or improperly or inadequately treated sewage," thereby causing "serious and substantial deterioration in the quality of Lake Michigan waters within the territorial boundaries of the State of Illinois." The complaint further alleged that this discharge constituted "a severe danger to the health, safety, and welfare of the citizens and inhabitants of the State of Illinois."

In an answer to the complaint (Ref. 2) filed with the same U.S. District Court in December 1972, two of the defendants (the City of Milwaukee and the Sewerage Commission of the City of Milwaukee) countered as follows:

(1) the respondants are using approved methods to operate an "efficient sewage treatment system" and (admitting that the system could be improved) are "taking steps to comply with orders of the Department of Natural Resources of the State of Wisconsin prescribing action to be completed by 1977, with the object of substantially improving water quality."

(2) the defendants cannot be held responsible for pollutants that enter rivers outside the district served and pass through Milwaukee to Lake Michigan.

(3) "if any pollution exists in Lake Michigan adjacent to the City of Milwaukee, such pollution is rendered innocuous and insignificant within a short distance from Milwaukee" because of the diluting and "self-cleansing" properties of the lake and therefore "does not cause serious or substantial deterioration or damage in the quality" of water in Illinois.

(4) if polluting materials are found in Illinois waters, the principal sources are to be sought in that state.

(5) as a "trustee" of the Wisconsin waters of Lake Michigan, on behalf of its citizens and inhabitants, the State of Wisconsin promulgates laws, rules and orders, with all of which the defendants are taking steps to comply. The regulating authority and the authority to restrict the taxing and borrowing powers of the defendants are vested in the State of Wisconsin, which should therefore be included as "a necessary and indispensable party to this action," but against which the plaintiff has not sought relief.

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*Defendants (all in Wisconsin and incorporated under the laws of that state): City of Milwaukee, City of Kenosha, City of Racine, City of South Milwaukee, the Sewerage Commission of the City of Milwaukee and the Metropolitan Sewerage Commission of the County of Milwaukee.

However, that answer to the complaint and subsequent negotiations did not settle the question, and four years later Case No. 72 C 1253 was brought to court, with the results and consequences described below. To follow the course of the long proceedings, some historical background will be helpful. To save space, the text includes a number of abbreviations, which will be introduced when they arise as capital letters in parentheses. Many of the illustrations in this report are taken from exhibits introduced during the trial.

Seventy years ago, waterborne disease was much more common in our cities than is the case today. In 1910, the Milwaukee Health Department reported 1,605 cases of and 171 deaths from typhoid fever (Fig. 1). At that time, combined sanitary and storm sewers carried all wastes to the rivers and hence to Lake Michigan. Emergency chlorination was then instituted, and a 1911 study -- which called the Milwaukee River "unspeakably foul and offensive" -- resulted in the construction of intercepting sewers to convey domestic waters to a modern treatment plant, which began operation in 1925 on Jones Island. Later, additional Lake Michigan water intakes and filtration plants were built (Linwood Ave., 1939; Howard Ave., 1963). These measures contributed to a dramatic fall in waterborne diseases: reported typhoid fever cases were rare after 1940, and only 4 deaths from typhoid were reported in the period 1940-75 (Fig. 1).

But the problem of river and Lake Michigan pollution from combined sewer overflow (CSO; defined in the glossary) did not disappear; indeed, it became more severe with the increasing loads from Milwaukee's expanding suburbs. Although the Jones Island Sewage Treatment Plant (JISTP) was technically advanced for its time and incorporated sound principles of waste recovery (dried sludge sold as "Milorganite" fertilizer), the growing need for an expanded sewer network and for more treatment capacity became evident. In addition to the Sewerage Commission of the City of Milwaukee -- which is responsible for operation of sewers and treatment within the city, including the operation of the Milwaukee Interceptor Sewer (MIS) -- a Milwaukee Metropolitan Sewerage District (MMSD, with a commission) was created by state authority as a county entity in 1921 with the task of sewer construction in Milwaukee County and of connecting those sewers into the Milwaukee system, including the MIS.

Suburban communities and growing areas in outlying districts were progressively added to the district, and the need for expanded treatment facilities were met by the construction in 1968 of the South Shore Sewage Treatment Plant (SSSTP), which discharged its effluent directly into the lake. Some flexibility was provided by control devices that regulated the proportions of wastewater going to JISTP and SSSTP, but overflows to rivers, the harbor or the lake still occur -- as described below and under site-specific permits from the Wisconsin Department of Natural Resources (DNR) -- during episodes of heavy runoff, when the combined sewers, the interceptor sewers and the treatment plants become overloaded with storm water. These overflows and bypasses (at present, more than 100 sites) carry varying amounts of untreated sewage to receiving waters and eventually to Lake Michigan. In such an aging sewer system, the problem is compounded by infiltration of "clear water" from surface drainage entering damaged sewers from a variety of sources (illustrated in Fig. 2) or from connections (now illegal) of house and yard drains and sump pumps.

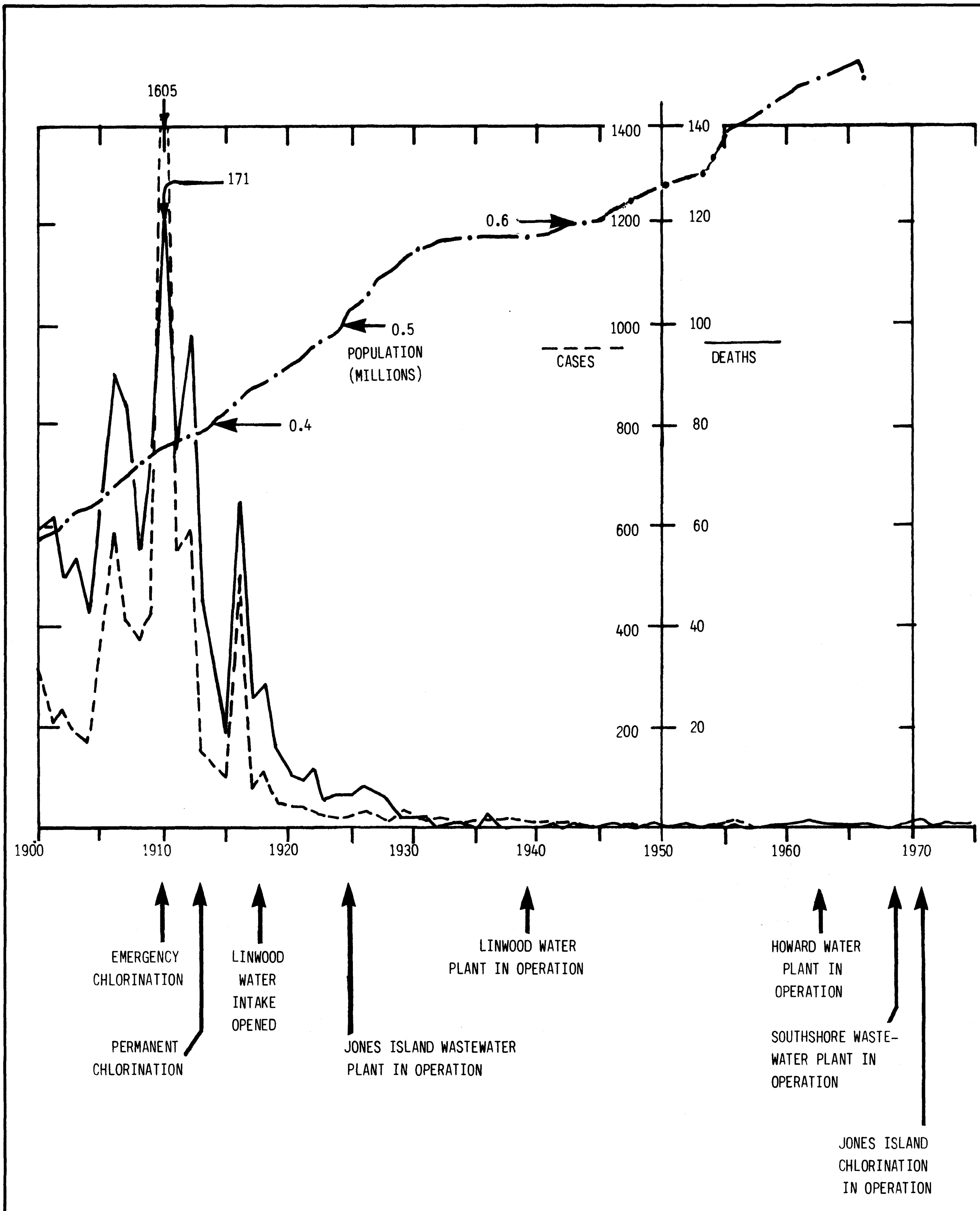


Figure 1. Incidence of Typhoid Fever in the City of Milwaukee (source: City Health Dept., Envirex Letter, Sept. 17, 1976). Redrawn from DE 494.
NOTE: Four deaths were reported in the period 1940-75.

Various studies, culminating in the recent studies set in motion by MMSD, have examined the technical feasibility and the cost of various schemes for preventing overflow and bypassing in all but very exceptional storms. As described later, consideration of these remedial measures and of their very large costs has been intensified and accelerated by the Illinois suit and the resulting judgement. Even if the suit had not been brought, a DNR stipulation concerning CSO and treated effluent quality still has to be met to bring Milwaukee into conformity with federal standards.

In recent decades, the problems of sewage treatment have been further complicated by the growth of industry and the disposal of a wide range of chemical wastes into the municipal sewer. This has caused interference with the delicate biological balance of the activated sludge process and has rendered sludge disposal more difficult. For example, the heavy metal content of Milorganite has prevented its use as fertilizer on land used to produce food crops; as a result, production will be discontinued in the future.

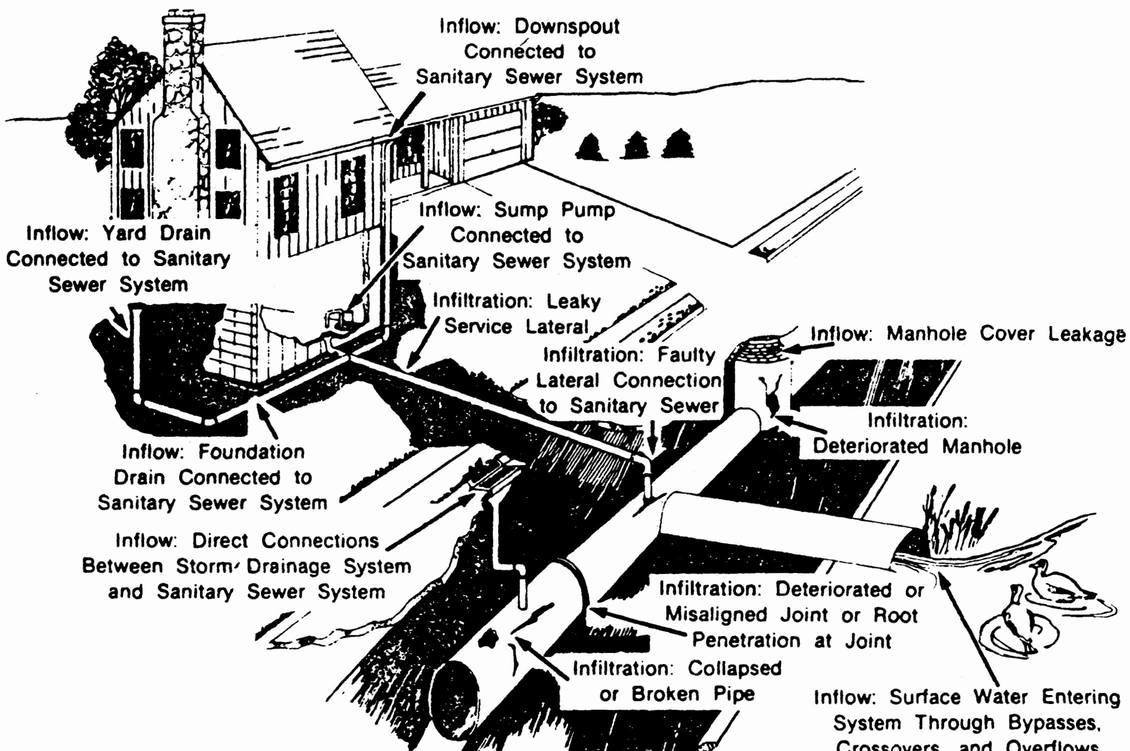


Figure 2. Sources of infiltration of clear water into the sanitary sewer (Ref. 4).

As pointed out earlier, one component -- perhaps the main component -- of the Illinois complaint rested on grounds of public health. The other components arose from perceived deterioration of water quality in Lake Michigan arising from a progressive over-enrichment known as eutrophication, which in extreme form becomes visible in the production of undesirable algae and in undesirable changes in fish stocks.

The Illinois Attorney General's office, which had been active and successful in suing industrial polluters of Lake Michigan near Chicago, persisted in the case against the City of Milwaukee and its codefendants in spite of the steps they were taking to comply with DNR and federal water quality regulations. Proceedings began in the U.S. District Court in Chicago on January 11, 1977, and ended 6 1/2 months later on July 29. Initially, the defendants included the City of Milwaukee, the Sewerage Commission of the City of Milwaukee, the Milwaukee Metropolitan Sewerage District Commission and the City of South Milwaukee. The cities of Kenosha and Racine, Wis., originally cited as codefendants in the 1972 complaint, had previously settled to abide by the court's findings. At the outset of the case, the City of South Milwaukee, Wis., also announced an out-of-court agreement to meet effluent standards approved by the plaintiff. The State of Wisconsin was not added to the list of defendants and did not take part in the proceedings. Joining the State of Illinois as plaintiff was the State of Michigan. However, its representatives took little part in the proceedings, being mainly concerned with eutrophication effects and citing evidence of actinomycete growths that are associated with organic pollution and producing objectionable water tastes in Green Bay. That evidence had little bearing on the Milwaukee-Illinois dispute and will not be considered further in this review.

The presiding judge was John F. Grady. Chief counsel for the plaintiff was Joseph V. Karaganis (JVK). Chief counsels for the City of Milwaukee, the Sewerage Commissions of the City of Milwaukee and the Metropolitan Sewerage District were Michael J. McCabe and Ewald Moerke (see Appendix II).

1.2 The Principal Limnological Issues

Because the original complaint cited water -- and not air or exchanges of people, animals, plants or goods -- as the carrier of harmful or potentially harmful agents and materials, the hydrodynamics and hydrobiology of Lake Michigan dominated the proceedings. Indeed, one might say the lake was presented as a co-plaintiff by the prosecution's counselor. A review of the court proceedings (14,257 pages of transcript) and the exhibits of the plaintiffs (275 in number) and defendants (1,406) reveals the following main limnological issues (public health issues, which weighed heavily in the judge's final decisions, will be considered briefly later):

(1) the nature, quantities and timing of pollutants, or perceived pollutants, discharged into Milwaukee Harbor and/or into Lake Michigan (a) by the sewage treatment plants (JISTP and SSSTP), (b) by CSO and (c) by the confluence of rivers entering at Milwaukee.

(2) possible mechanisms and probable frequencies of transport "pollutants" from Milwaukee to Illinois waters.

(3) survival of potentially pathogenic organisms, including viruses, in Lake Michigan waters and sediments. (The technology of removing these pathogens during the sewage treatment process and during the purification of drinking water from lake intakes was an important issue, but it receives no more than passing mention here.)
(4) the effects of Milwaukee's effluents (treated and untreated) -- particularly the algal nutrient elements, nitrogen and phosphorus -- on eutrophication changes in Lake Michigan.

Eutrophication is a progressive biological enrichment process characterized by over-nourishment, which occurs when organic materials (particularly human wastes) and their breakdown products are added to lakes in the form of untreated or treated sewage, and agricultural wastes. Such materials also enter lakes from more diffuse sources of drainage. It is evident that all rivers with agricultural drainage entering Lake Michigan and all municipalities discharging untreated or treated wastes to the lake have contributed to the eutrophication process. In fact, it can be argued that treated wastes are the most effective promoters of eutrophication because they are partially or wholly broken down into the nutrient-elements that the lake microflora (algae, phytoplankton) can immediately use for growth. Within limits, such nutrient enrichment enhances the biological productivity, including the fish-carrying capacity, of a lake. It is when the enrichment is in excess that problems appear.

The deleterious effects of eutrophication on fish stocks, poor water quality and in the production of undesirable algal growth first became apparent in certain parts of the Great Lakes region, such as Lake Erie, Green Bay and the southern extremity of Lake Michigan. In other parts of the region, the effects have been less apparent so far but are nevertheless a cause for concern -- although, as the court proceedings disclosed, experts differ on the causes and future scenarios for eutrophication in Lake Michigan. Eutrophication is a direct consequence of population growth. Since phosphorus is the limiting nutrient, measures to control the release of that element to the Great Lakes have been set in motion and have begun to show results (Ref. 3).

1.3 Summary of the Judgement Order of November 15, 1977, and Its Impact on the Greater Milwaukee Community

Though an understanding of its arguments will evolve during the course of this review, it may be helpful at this point to summarize the principal findings and consequences of the final judgement order. The order is reproduced in full in Appendix VI.

The order requires the defendants to do the following:
(1) eliminate all sewer overflows and bypasses to the rivers, harbor or to Lake Michigan by 1986.
(2) collect and convey all human fecal waste entering the sewers in the combined sewer area and by 1989 provide temporary storage sufficient to accommodate the most severe rainstorm of the 1940-77 period of record.

(3) install advanced sewage treatment facilities to produce an effluent containing (on a consecutive 30-day average basis) not more than 5 mg/L of suspended solids and possessing a 5-day biochemical oxygen demand (BOD_5) of not more than 5 mg/L (later referred to as the "5/5 standard"). That effluent is to be chlorinated to a specified level, and any one grab sample shall not contain more than 40 fecal coliform bacteria per 100 ml, and the monthly average phosphorus concentration shall not be more than 1 mg/L.

(4) permit the plaintiffs to monitor the progress of improvements under the above headings in conformity with the timetable summarized in Figure 3.

Much of the remedial work required to meet the stipulations of the judgement had already been programmed under DNR orders, based on U.S. Environmental Protection Agency (EPA) regulations. The principal differences lay in the severity of the effluent standard (as defined above, six times more stringent than current EPA standards) and in the accelerated timetable (Fig. 3). For example, the judgement order requires a solution to the CSO problem to be in place four years in advance of the DNR compliance date. In a subsequent appeal in federal court, the requirement for a 5/5 standard was removed, but the other stipulations and the timetable will remain unless removed as a result of a current appeal to the U.S. Supreme Court.

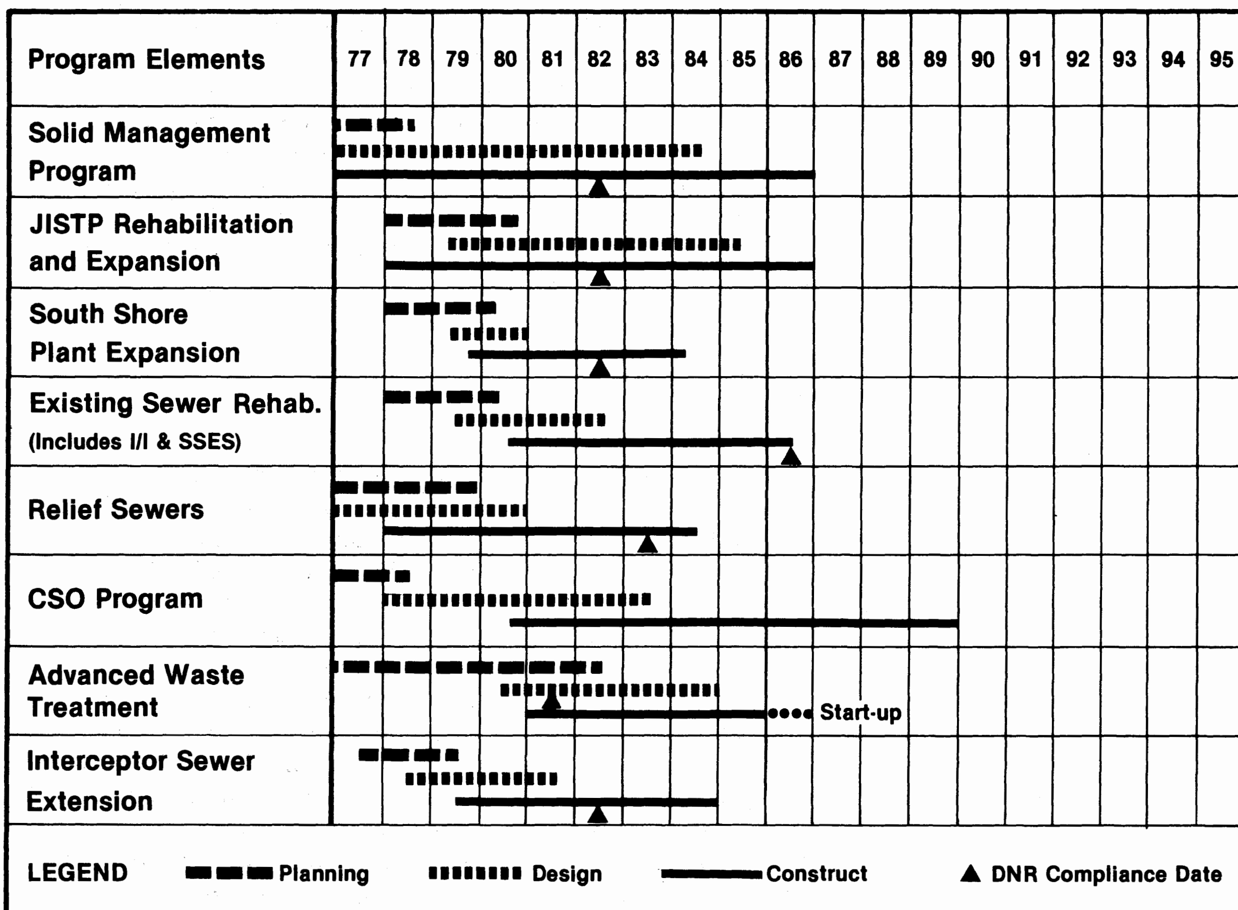


Figure 3. Schedule of compliance with the Illinois federal court order (Ref. 4).

The total capital cost of the Water Pollution Abatement Program has been estimated to be $1.658 billion in 1980 dollars (Ref. 5). In 1979, homeowners in Milwaukee were paying 65 cents per annum per $1,000 of "equalized assessment valuation" of their homes for sewer service. Based on anticipated receipts of federal and state funding assistance, it is estimated (Ref. 5) that the average annual sewer service charge will increase by a factor of six in the interval 1980-2005 and by a factor of eight in the peak years 1989-90, representing a peak-year charge of $403 on an $80,000 home. An additional, major one-time expense may be incurred by homeowners in certain areas, and some local communities may levy construction and operational charges.

Not surprisingly, methods of financing and distributing the burden are being and will continue to be intensely debated. The extent of a federal contribution to the cost is in doubt because, under the somewhat complex procedures set out in the Clean Water Act, the maximum federal contribution (75%) applies only to the most cost-effective solutions that fit clear and consistent project criteria set by the state. Court judgements do not, apparently, increase the project ranking. An accelerated timetable also means that the cost cannot be (less expensively) spread over a longer period. As discussed in Section 8.5, the impact of the order is more than financial. It represents an application of the federal common law of nuisance (granting anticipatory relief without proof of actual harm) in an interstate pollution conflict, which other communities in a similar situation to Milwaukee's must be viewing with trepidation. Even communities already in compliance with federal pollution standards are presumably no longer immune. And the fact that Milwaukee is required by the order to upgrade its collection and treatment system to a level and under a timetable that go beyond present federal and state requirements weakens local control and may be inconsistent with optimal, cost-effective management of water quality on a regional basis.

1.4 Present Status of Appeals (December 1980)

Predictably, the defendants have appealed the stipulations of the judgement. However, the appeal is based not on technical grounds -- the limnological arguments reviewed here have not been reopened -- but on grounds of law and equity. As already noted, the 7th U.S. Circuit Court of Appeals in Chicago overturned (in 1979) the requirement for advanced treatment facilities to achieve an effluent standard six times purer than that presently required by federal and state regulations, but it upheld Judge Grady's ruling that combined sewer problems be eliminated by 1989, thereby setting a standard "well in excess of those set by Illinois for its own cities, including Chicago" (Ref. 5). In March 1980, the U.S. Supreme Court agreed to review the legal aspects of the case and the judgement. If the Supreme Court ultimately rules in favor of the defendants, "it could reduce the expected project costs by at least $100 million and perhaps up to $300 million or more," and local control of the project would be restored; "the exact savings would depend on whatever sewage overflow are subsequently set" by the DNR (Ref. 5). It should be pointed out, however, that setting those standards will reintroduce technical and limnological considerations in which costs will be balanced against perceived benefits in protection of public health and the quality of Lake Michigan waters.

1.5 Reasons for Undertaking This Review

This Lake Michigan (or Milwaukee) pollution case ranks with the Reserve Mining case -- which halted the disposal of ore tailings in Lake Superior -- as a landmark in aquatic environmental law. Both cases represent local but potentially far-reaching applications of federal common law of nuisance to a pollution conflict in the Great Lakes, and in both cases the plaintiff, defendants and judge relied on the testimony of an unusually large number of experts covering various areas of hydrodynamics, hydrobiology, waste treatment technology and public health.

The proceedings had stretches of tedium, but also moments of drama. Of interest to the author of this report is (1) the manner in which the adversarial proceedings brought various aspects of the Lake Michigan ecosystem into focus (or not), and (2) the weight given by the judge to particular testimony in arriving at his final judgement. As we have seen, one man's judgement on a case brought about by an agency in one state imposed substantial burdens on a community in another state (and, indeed, on a single generation of that community) greater than that imposed by local jurisdiction. As the interaction between Milwaukee and Lake Michigan is not unique, it is worthwhile to explore (1) how the decision was arrived at, (2) how the various factors were weighed, (3) how the environmental and public health benefits were perceived and whether an attempt was made to balance them against the cost, and (4) whether a better *modus operandi* -- for example, a judicial combination of legal, technical and scientific expertise -- can be devised to resolve environmental disputes of this magnitude and public significance (see Section 8).

POSTSCRIPT: The Supreme Court Decision

On April 28, 1981, as this report went to press, the U.S. Supreme Court ruled by a 6-3 vote that federal courts could not use the federal common law of nuisance to establish water quality standards stricter than those imposed by Congress through regulatory agencies. Judge Grady's 1977 order in the *Illinois v. Milwaukee* case was thereby overturned, and the case was sent back to the lower courts for new decisions.

Writing for the majority and referring to the passage by Congress of the Clean Water Act amendments in 1972, Justice William Rehnquist said that "Congress has not left the formulation of appropriate federal standards to the courts through application of often vague and indeterminate nuisance concepts." In a dissenting opinion, however, Justice Harry F. Blackmun, Jr., stated his belief that Congress did not intend to eliminate the federal common law remedy in such cases.

Section 2:

The Nature and Frequency of the Discharge

2.1 Sewer Overflows and Bypasses

Though Milwaukee's treated sewage effluent "compares favorably" in quality (DE 69) with that of comparable large cities with plants discharging into southern Lake Michigan, the combined sewer overflow and other bypasses to rivers or to the lake constitute a substantial source of untreated sewage during periods of high runoff. In extensive testimony (tr. pp. 133-405), Donald Wieland (director of engineering, Sewerage Commission, City of Milwaukee) indicated 110 CSO points (by DNR permit) in the system, nine of them operated by monitored pumps, the remainder by gravity (Fig. 4). Milwaukee City Engineer Edwin Laszewski indicated, in addition to the CSO points, 78 "crossovers" in those newer parts of the district that have separate sanitary and storm sewers. The crossovers (less than half of which operated during 1976) relieve those sanitary sewers that are overloaded (by clear water infiltration) and prevent back-flooding into basements. When rainfall exceeds a half inch, the MIS can become overloaded and CSO discharges occur. Bypass also occurs at JISTP (and DNR authority has been requested for a bypass at SSSTP) when the inflow exceeds capacity. The combined volumes treated at JISTP and SSSTP (dry weather flow, plus some limited wet weather flow) are illustrated in Figure 5, which shows only limited capacity to treat excess flow. During severe rainstorms or snowmelts, bypassing occurs at the plant in addition to CSO at other points in the system. At such times, large volumes of floodwater from the three rivers pass into the harbor and almost directly into the lake (see Fig. 6). The question before the court was: how much untreated sewage passes into the rivers and thence to the lake during such occasional overflows?

2.2 Flood Events

Figure 6, not introduced in court, implies that during floods (when CSO is most likely to be operating) significant quantities of untreated sewage may be discharged not only to Milwaukee Harbor, but also the the lake. This figure is a black-and-white copy of a picture taken on September 22, 1972, from a height of 60,000 feet by NASA with color infrared film, with the visible green band added. It must therefore be interpreted with care.

For example, the optically lighter band of water along the shore in the upper part of the picture (around the Lindwood Avenue Water Filtration Plant) is produced by sediment resuspended by wave action resulting from strong north-to-northeast winds on preceding days; the lighter water mass at bottom-right (near the black cloud shadows) has probably been warmed by cooling water discharges from the Lakeside Power Plant. During the six days preceding the photograph, a total of 3.81 inches of rain fell at Milwaukee (Mitchell Field), of which the highest daily total was 1.75

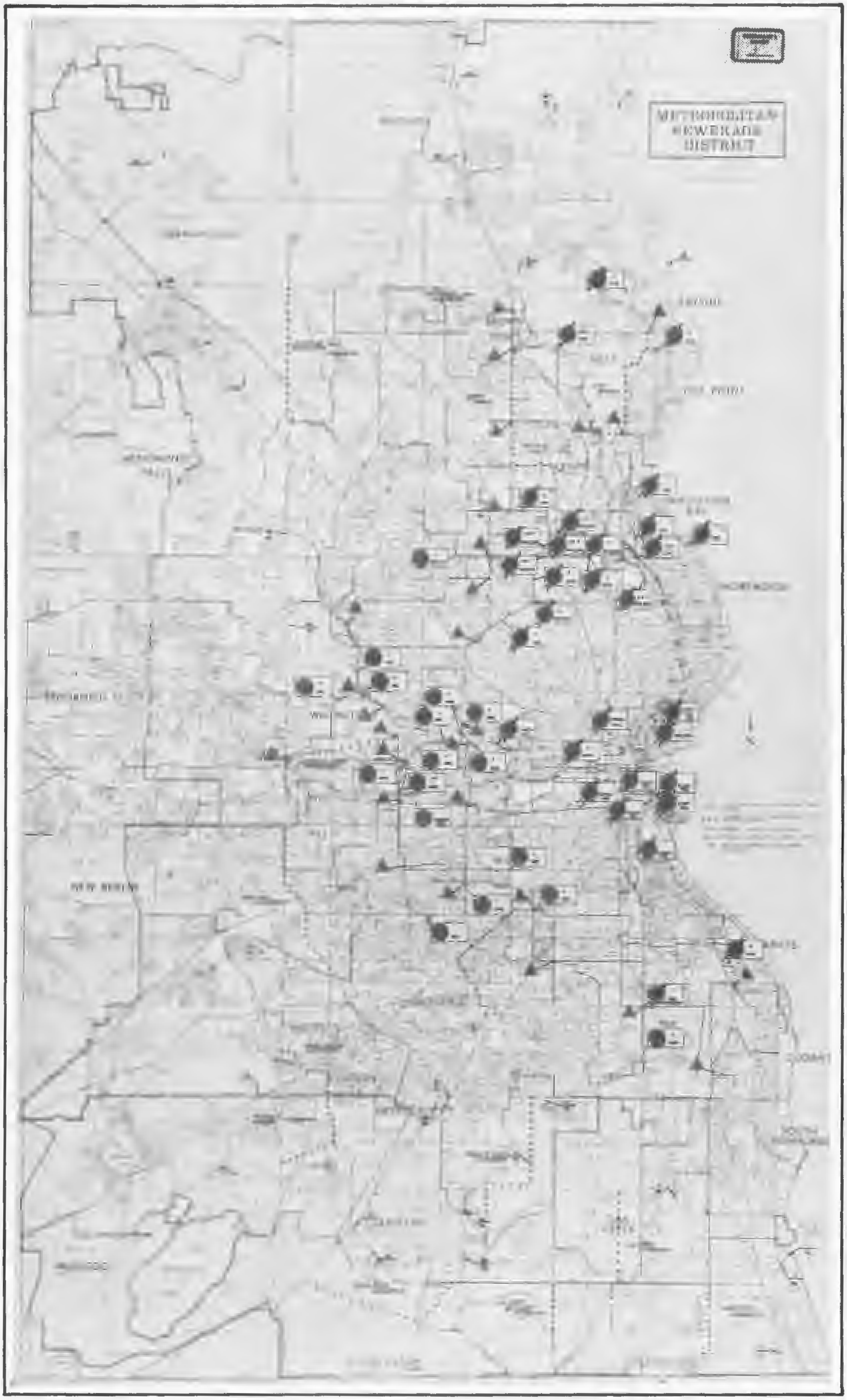


Figure 4.

Map (DE 3) of diversion points (triangles), overflow points (dots) and overflow reliefs (dots with lines through them) in the MMSD system.

inches on September 18. The lighter color of the water mass, which fills most of the outer harbor and is driftng southward outside in the lake, could have been partly the result of a temperature difference (lighter means warmer), but the main factor was turbidity produced by material resuspended in the rivers during flooding after the rain. River sediments

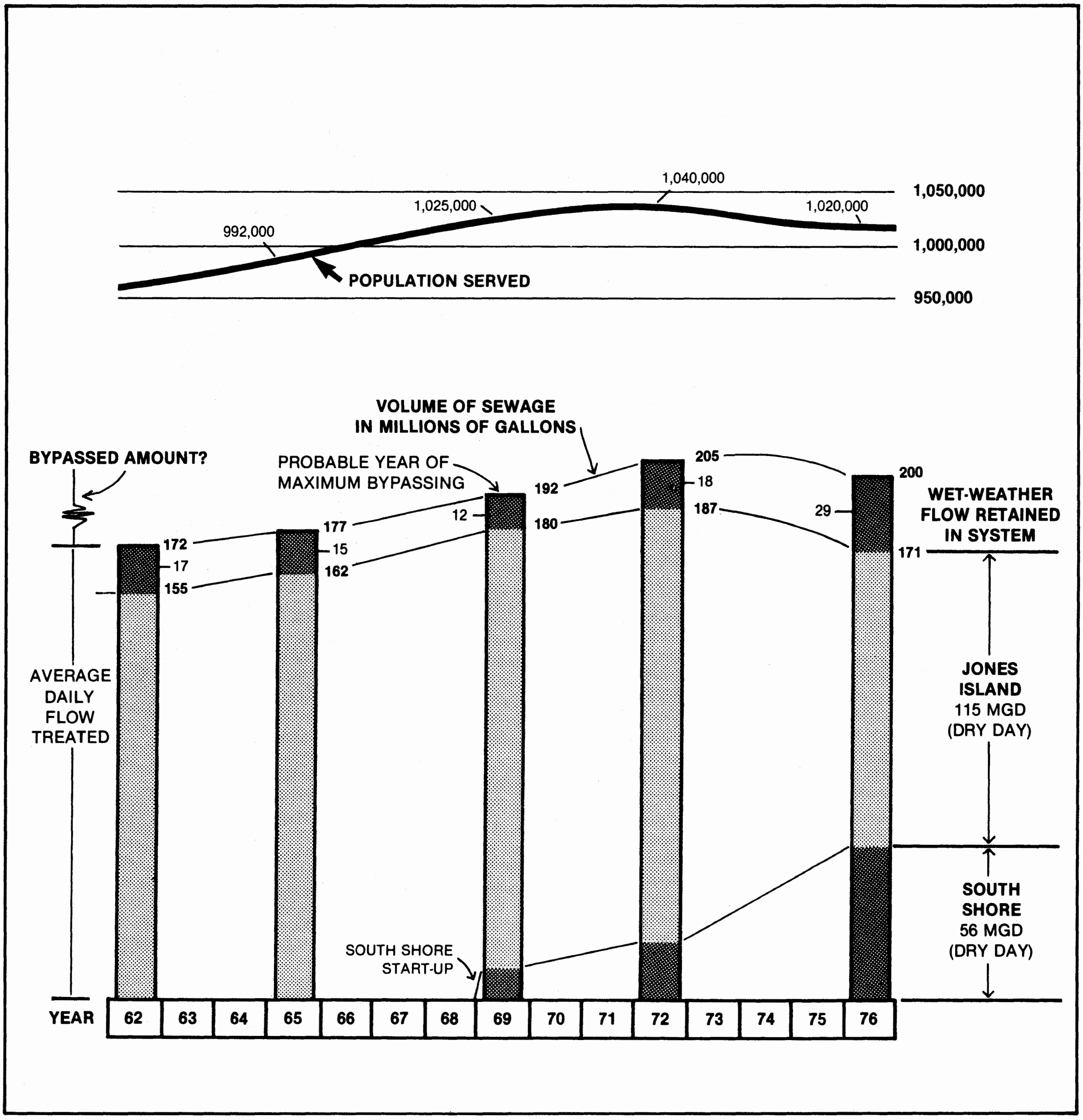


Figure 5. Volumes of sewage and wet weather inflow treated by the Sewerage Commission of the City of Milwaukee, 1962-76. (DE 1310, rearranged).

were thereby flushed into the harbor and lake. This is confirmed by a greenish tinge of the harbor plume in the original color photograph. The plume from JISTP can also be seen (Figs. 6 and 7) as a clearer intrusion into the turbid plume a little south of the point where the inner harbor opens into the outer basin.

Figure 6. Milwaukee Harbor and Lake Michigan: enlarged portion of a 9-inch square transparency (color infrared, plus green band) taken from a height of 60,000 feet on Sept. 22, 1972, after 3.81 inches of rainfall during the preceding 6 days. A turbid plume is leaving the harbor and travelling southward. (Copy of NASA photograph in Engineering Library, UW-Madison.)

Figure 7. Milwaukee Harbor, July 18, 1977: copy of color photos taken from 500 feet by Wisconsin DNR (courtesy of Dr. R. Bannerman; see Ref. 10).
JISTP: Jones Island Sewage Treatment Plant.

A closer view of JISTP and of the flood plume after heavy rainfall is presented in Figure 7, which is a black-and-white copy of a normal-color aerial photograph provided by Dr. Roger Bannerman of the DNR and taken from 500 feet on July 18, 1977 (while the court was still in session). Daily rainfall at West Allis in Milwaukee County, (a representative weather station) on July 17 and 18 was 1.75 and 2.18 inches, respectively, and (judging by the shadow of the JISTP stack) Figure 7 was photographed during the evening of the 18th, soon after the storm ended. Figure 8, photographed at the same time, shows the turbid plume beginning to enter Lake Michigan at the main harbor entrance (lower picture) and also at the north entrance (top picture). Both plumes were then veering to the north. On the next day (July 19) pictures were taken from 1,000 feet (Fig. 9). They show a more extensive plume from the harbor out into the lake (upper picture) and a narrower, northward-deflected plume from Oak Creek, 12 km to the south.

Figures 6-9 capsulize several of the conclusions brought out in the trial and not disputed, except in quantitative terms. Heavy rainfall is quickly followed by large-volume flow into the harbor. That flow is turbid and contains resuspended river sediments (i.e., probably much of the sediment that settled and accumulated during the previous dry weather period). During floods, particularly at peak flows, much of the flowage passes directly from the inner harbor entrance (bottom of Fig. 7) to the outer entrance and thus into Lake Michigan. Initially, the flood water forms a distinct bolus, or "slug," in the lake, the shape of which is subsequently distorted by lake currents that can carry the plume either northward, as in figures 8 and 9, or southward, as in Figure 6. The up-current edge of the plume tends to be sharply defined, while the down-current edge is distorted by turbulent eddies, which promote mixing of the plume into ambient lake water (Fig. 8, bottom portion).

2.3 Conditions During Low-Precipitation Periods

During low-flow periods, the harbor-lake exchange is much reduced, though it is probable that some oscillatory exchange is driven by Lake Michigan seiches (see below), particularly the transverse seiche of 2.2 hour-period, which sometimes persists for many days (Ref. 6). But during dry periods, the harbor retains much of the material -- pollutants and nonpollutants -- delivered to it, and the much more active currents outside the harbor rapidly dilute the small amounts of materials (i.e., small compared to floods) that pass through the harbor mouth during dry weather. Consequently, pollution indices differ at points lying inside and just outside the harbor mouth by several orders of magnitude. For example, the fecal coliform counts (FCC) run in the hundreds and thousands per 100 ml inside the harbor, while the numbers found 0.2 miles or more outside the three harbor entrances were very much lower, often less than 1 per 100 ml (Figure 10; DE 501; Refs. 7 and 9). Similar conclusions can be drawn from the evidence in Figure 11 (Ref. 8; not presented in court), which displays the distribution of a flourescent byproduct of organic decomposition in the rivers and harbor. The concentration pattern in Lake Michigan close to all three harbor entrances demonstrates how rapidly it and other materials carried in harbor water are diluted upon entering the lake.

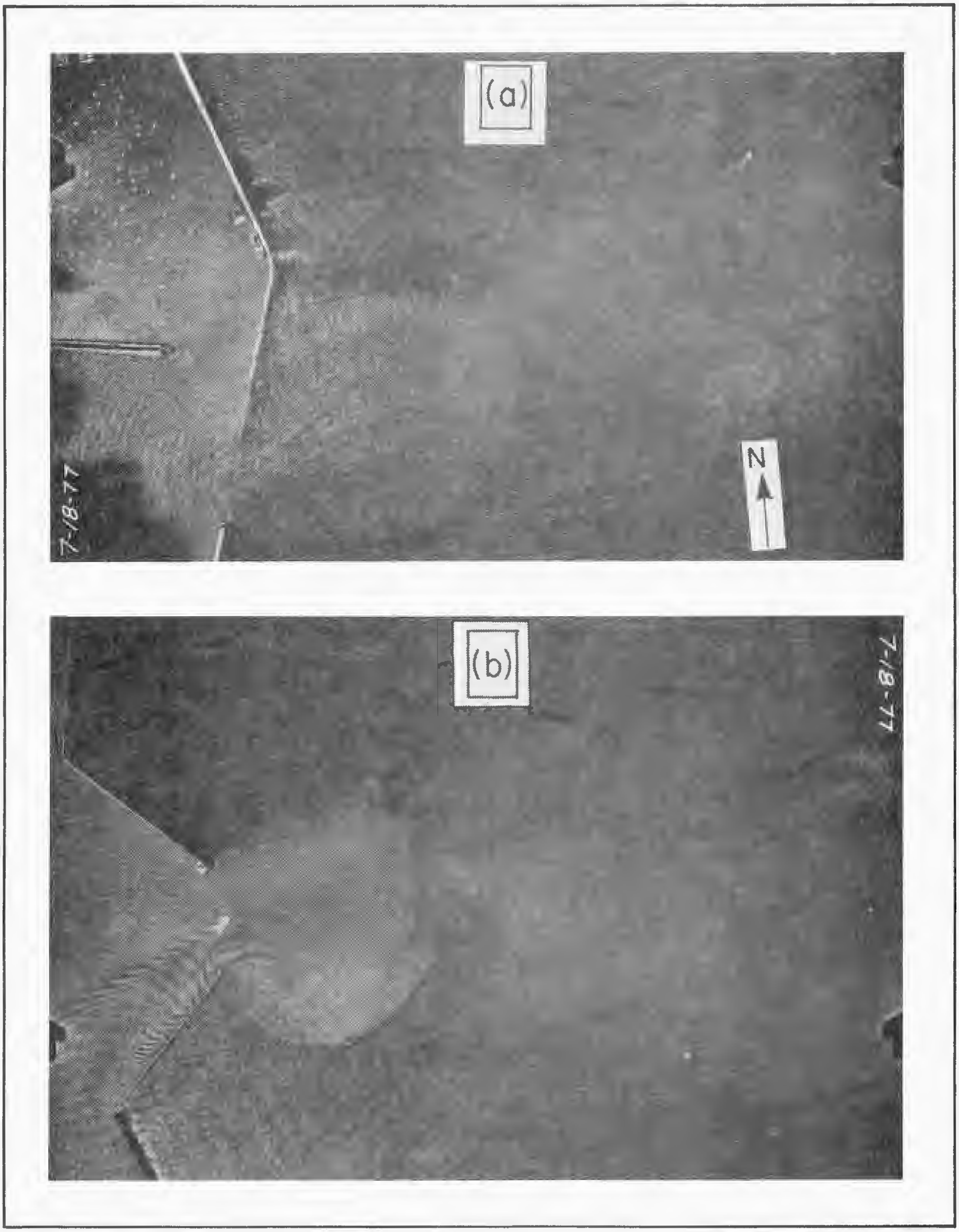


Figure 8. Legend as for Fig. 7: (a) north harbor entrance; (b) main harbor entrance.

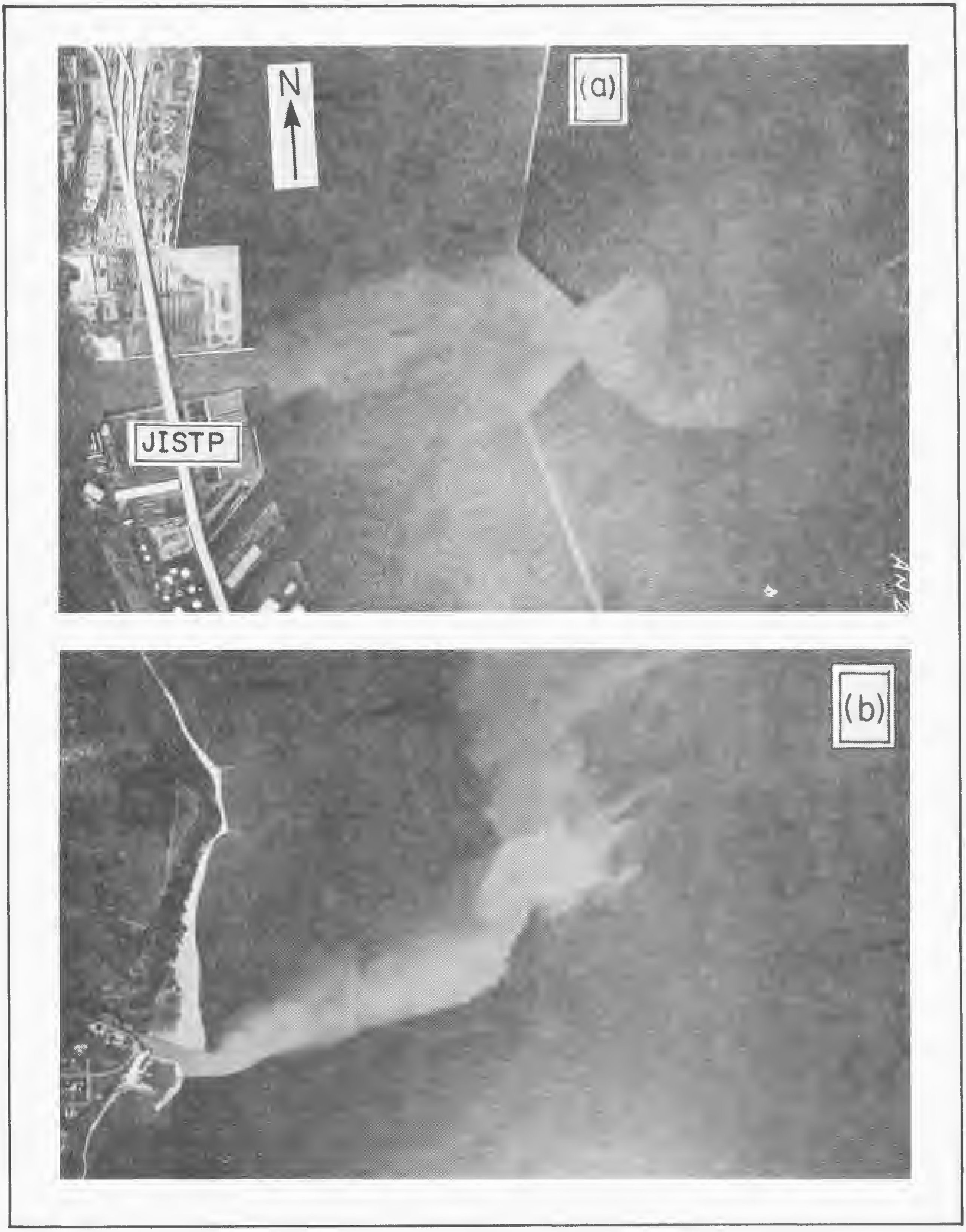


Figure 9. Legend as for Fig. 7, but with date changed to July 19, 1977, and height to 1,000 feet: (a) main harbor; (b) Oak Creek plume.

During nonflood intervals, the treatment plant effluents continue unabated (JISTP into the harbor, and SSSTP directly into Lake Michigan), and the question of quality maintenance was argued at length in the court. DNR regulations require that monthly effluent averages not exceed 30 ppm for suspended solids, 30 ppm O_2 for biological oxygen demand and 1 ppm for soluble phosphate as P. Those standards were not being met every month at the two plants, and remedies for this were being sought and implemented to meet a DNR stipulation by 1982.* Total solids in the effluent occasionally rose sharply when sludge settlement during the treatment process was disturbed and "spewing" of sludge occurred. The activated sludge process is also vulnerable to variations in the composition of industrial wastes, so strict control of the quantity and quality of the ever-increasing variety of industrial wastes is essential to reliable municipal waste treatment.

Barring accidents, such as sludge upsets and floods, treatment plant effluent is low in suspended solids and the micro-organisms in it have been reduced to safe levels by chlorination. However, the effluent carries, in solution and in relatively concentrated form, the end-products of the oxidative and breakdown processes performed by the activated sludge in the waste purification sequence. Those end-products include the building bricks that went into the original synthesis of the organic waste; they include plant growth-promoting substances and nutrients like phosphate and combined forms of nitrogen (ammonia, nitrate), which stimulate production of planktonic algae in the lake and of bottom-attached algae along its shorelines. As we shall see, the latter algae (e.g., *Cladophora*, the green slime alga) provide convenient indicators of nutrient enrichment.

2.4 Harbor-Lake Exhanges

Lake Michigan receives, through the harbor and from SSSTP effluent, materials from a variety of sources -- treatment plant effluents ("steady input"), river drainage from point and nonpoint sources at a low rate during dry weather and at a high rate during floods, and CSO during episodes of high rainfall. During such episodes, G. T. Csanady (appearing for the plaintiffs, tr. p. 1,980) estimated a harbor-to-lake flow rate of 6,000 cubic feet per second (cfs), or approximately 2 billion gallons per day "for a number of hours, not necessarily a full day." He estimated that the runoff from the most severe storm anticipated during any five-year period would be 20,000 cfs (tr. p. 1,981; PE 24-30). Generally, the month with the highest average flow rate is April (1,300 cfs; tr. p. 1,984). Csanady further assumed (from DE 86, Ref. 9) that an FCC of about 100,000 per 100 ml would be found "at the river mouth, following rainstorms" (tr. p. 1,980). For average conditions, the residence times of materials in the inner and outer harbor have been estimated at five and six days, respectively, (Ref. 10, not entered in the court proceedings), probably less during floods. Of the materials delivered to the harbor by the rivers each year, an estimated 45% of the suspended solids, 61% of the total phosphorus and 35% of the soluble phosphorus enter the inshore zone of Lake Michigan.

*The CSO remedial program must be completed to DNR stipulations with substantial elimination of overflows by 1993. Judge Grady stipulated that all overflows must be eliminated by 1989 (see Fig. 3).

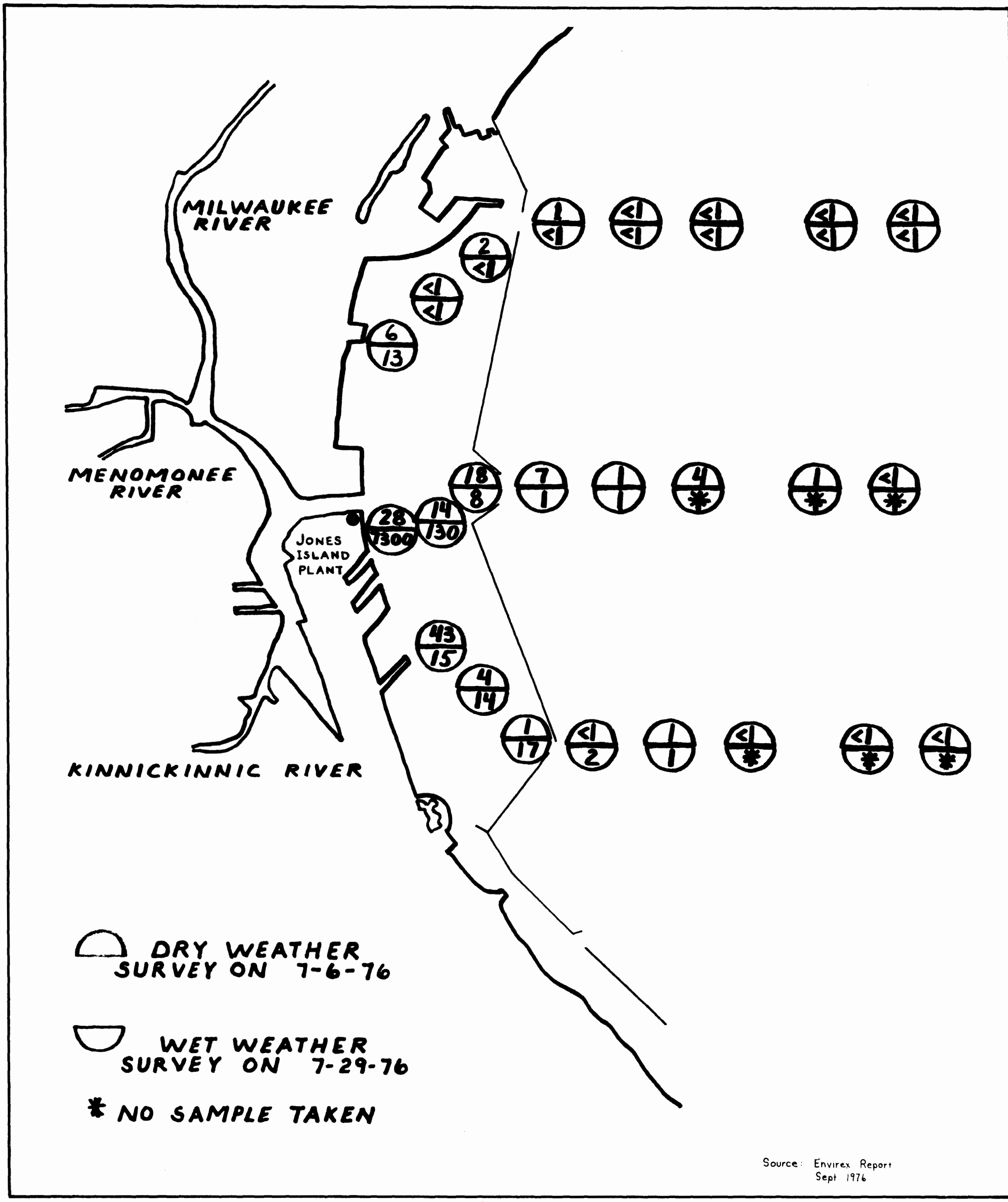


Figure 10. Fecal coliform counts (per 100 ml) in Milwaukee Harbor and adjacent Lake Michigan. Numbers in the upper and lower semicircles were obtained during surveys after dry and wet weather, respectively, on the dates indicated. (Source: Envirex Report, 1976; DE 73, 86; copy of colored diagram, DE 501).

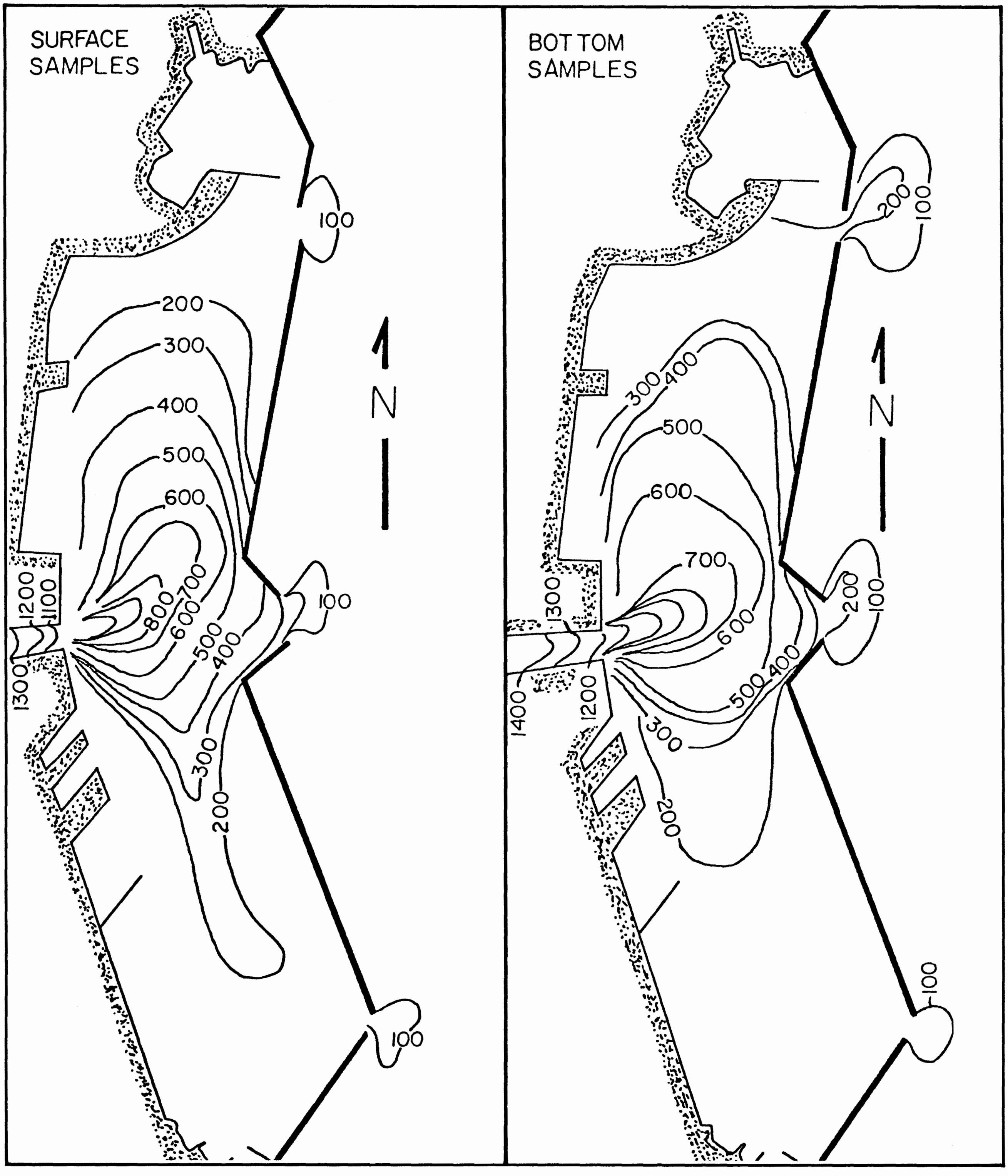


Figure 11. Milwaukee Harbor: isopleths of residual flourescence at the surface and near the bottom, November 27, 1973 (Ref. 8).

"Although the percentages were only gross estimates, they demonstrated that a significant portion of the annual loading from the river and [JISTP] were retained in the harbor. Although the portion of the event pollutants retained in the harbor was not known, it was estimated that 70% of the suspended solids discharged from the Menomonee River during events was retained in the inner harbor each year. The amount of suspended solids in the plume for the July 18 event [see Figs. 7 and 8] was estimated to be 5% of the total suspended solids entering the inshore zone each year. The pollutants associated with the particulate matter were obviously settling out during their residence time in the harbor." (Ref. 10; brackets indicate inserts by author.)

Thus the harbor acts as an effective sediment trap and tertiary waste treatment "pond" (tr. pp. 7,288-92) very beneficial to Lake Michigan. The SSSTP, on the other hand, discharges directly into the lake, a less desirable state of affairs.

The detailed hydrodynamics of harbor-lake exhanges were not discussed in court, but measurements (Ref. 10) indicate this transport to be controlled more by the action of the lake and harbor seiches than by the combined flow from the rivers. The seiche has been observed to cause the direction of flow, for different strata or for the entire water column, to reverse itself during runoff events at the harbor mouth and at the central breakwater opening. This oscillation of flow between regions results in a pulsing of event-related pollutants from the more polluted region to the less polluted region across these two boundaries. The pulsing phenomenon was also supported by the water quality at those two openings, which alternated between that of the inshore zone and the harbor. The size of the slug of pollutants is largely dependent on the characteristics of the seiche for any period. This apparent pulsing occurs during times of both event and nonevent flows. An exception to this pulsing, seiche-controlled pattern probably occurs during times of exceptionally large event flow, when a relatively consistent flow of water could be expected to move outward into the inshore zone with very little residence time in the harbor. On July 18, 1977 (see Figs. 7 and 8), the flow at the surface was not observed to reverse direction during the period of measurement.

2.5 Comments on Inputs to Lake Michigan

From the evidence presented, it became clear that untreated and partially treated sewage was occasionally introduced into the lake, particularly during flood events. Those inputs were, however, not well quantified in relation to organic and toxic waste inputs from other sources -- waste from outside the MMSD area and from industries. Such wastes, at present outside the control of the defendants, accumulate in the river and harbor system and are then flushed out into the lake during flood events. A realistic estimate of the magnitude of the episodic transport, occurring largely as sediment transport, is needed before the cost-effectiveness of remedial measures within the MMSD system can be assessed.

The next section examines the arguments concerning the transport and fate of the suspended and dissolved materials once they have entered Lake Michigan, by whatever mechanism or route.

Section 3:

Transport and Dispersion in Lake Michigan

3.1 Lake Michigan Hydrodynamics Outlined by Season

Once a water mass with its suspended and dissolved load has moved into the lake through one or more of the harbor entrances or through the SSSTP outfall, it enters the field of lake motion and becomes subject to advective transport by currents and dispersal by turbulence. Because the currents and the intensity of turbulence are much stronger outside than inside the harbor, considerable dispersal and dilution occurs, as discussed earlier, immediately at the harbor entrances. Where and how fast the introduced materials go from there depends on the speed and direction of the currents, on the layering (stratification) of the water masses and on the intensities and scales of turbulent motions (i.e., upon the structure of the eddy spectrum). To answer or to comment upon one of the big questions before the court -- whether materials introduced at Milwaukee arrive in significant concentrations in Illinois waters -- requires a basic account of Lake Michigan's hydrodynamics that is too lengthy for the purposes of this report (for more information, see Ref. 11). However, the following five principal seasonal regimes should be recognized:

(1) winter mixing, in which the main basin remains free (in most years) of all but drifting or shore ice and in which the temperature of the wind-stirred water mass falls to below $4^{o}C$, the temperature of maximum water density.

(2) the spring warming trend, first seen (about April) in the shallowest nearshore waters, where the water stratifies with warmer layers floating on top of colder layers.

(3) a progressive spread of stratification out from shore to cover the whole basin (late June).

(4) persistent summer stratification (July to September) with a well-mixed upper layer (epilimnion at 15^{o}-$20^{o}C$ or higher) of 20 m (60-70 feet) mean thickness separated from a colder, denser bottom layer (hypolimnion, $5^{o}C$) by a relatively thin layer (the thermocline) in which the temperature drops rapidly with increasing depth (see Fig. 12).

(5) an autumnal cooling regime, starting when the net heat input to the basin becomes negative in August and the upper layer cools, thereby progressively reducing the density difference between top and bottom so that the depth of the upper, wind-stirred layer increases at the expense of the bottom layer. The thermocline accordingly descends until the whole water column is fully mixed again in December, and the winter regime returns.

3.2 Current patterns

Currents in the winter mixing regime (1) are almost entirely wind-driven but are also (as are all currents in large lakes) subject to the rightward deflecting influence of the earth's rotation and the constraints of shorelines. In general, therefore, nearshore currents tend to run shore-parallel, one way or the other along the shore, in response to the wind. Except when under ice, the nearshore water is well mixed from top to bottom, and there is relatively free exchange with water masses further offshore, which by the end of winter have cooled to 2°C or so. During the spring warming regime (2), stratification starts nearshore. The surface water, warmed above the temperature of maximum density, mixes at its offshore edge with winter water below the temperature of maximum density. The mixed water thus is denser than either of the parent water masses and sinks, forming a shore-parallel line of convergence called the thermal bar. As warming continues, this "barrier" moves progressively offshore until stratification is established over the whole lake in late June. From the point of view of the transport question raised in court, however, the most important feature of the thermal bar is the combined

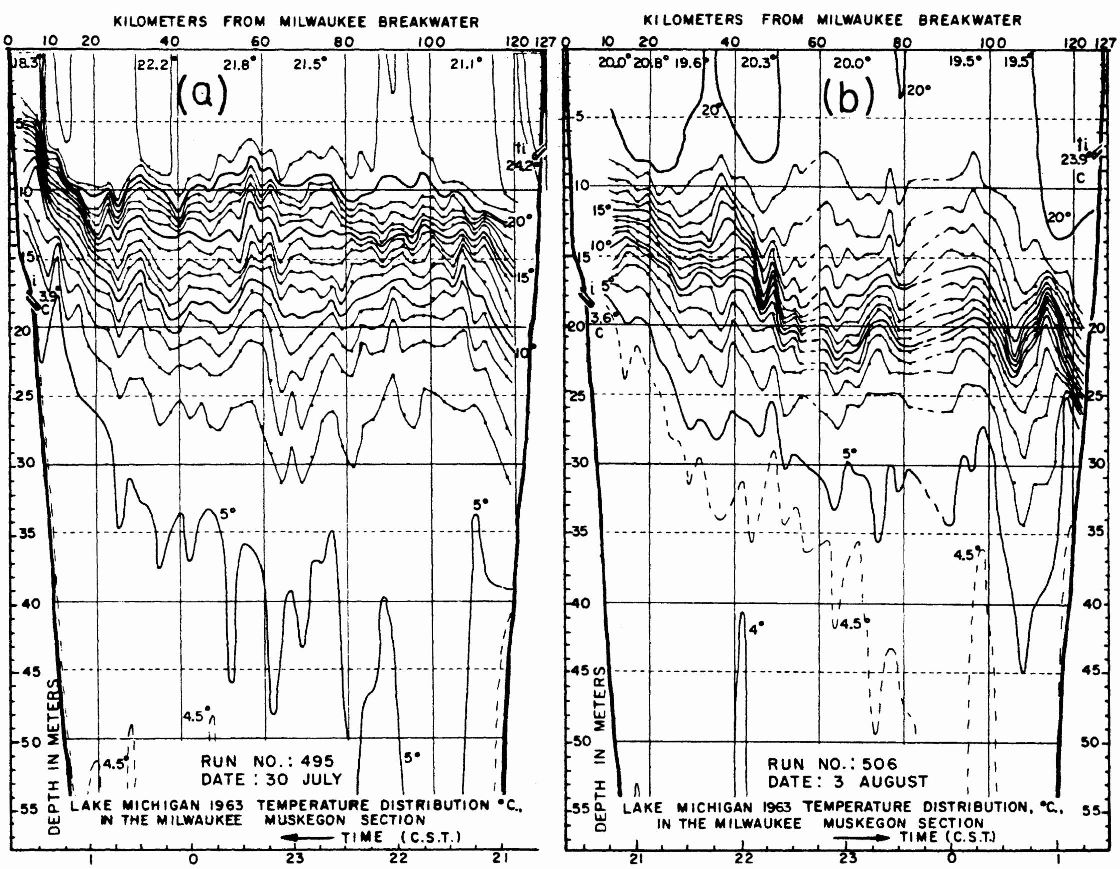


Figure 12. Lake Michigan, 1963. Temperature structure in the cross-section Milwaukee, Wis., to Muskegon, Mich., observed during a six-hour crossing by a railroad ferry (Ref. 12): (a) July 30, after predominantly southerly wind on July 27-28; (b) August 3, after a strong southeasterly wind on August 2. Continued with (c) and (d) on a following page. Close spacing of isotherms denotes the thermocline layer.

result of nearshore heating and the earth's rotation, namely a heat-driven current that progresses around the basin periphery, inside the thermal bar, in a counterclockwise direction only (i.e., southward along the western shore of Lake Michigan). Unpublished measurements with drifting buoys, compiled by the author in collaboration with Dr. Verner Suomi of the Space Science and Engineering Center at the University of Wisconsin-Madison, have shown that when it is fully developed, this coastal current attains speeds in excess of 20 cm s^{-1}, or 17 km day^{-1}. The distance from the Milwaukee Harbor entrance to the Illinois-Wisconsin state line (60 km) could therefore be covered in four days. Although it has not yet been thoroughly explored, this current may persist for more than a week, and

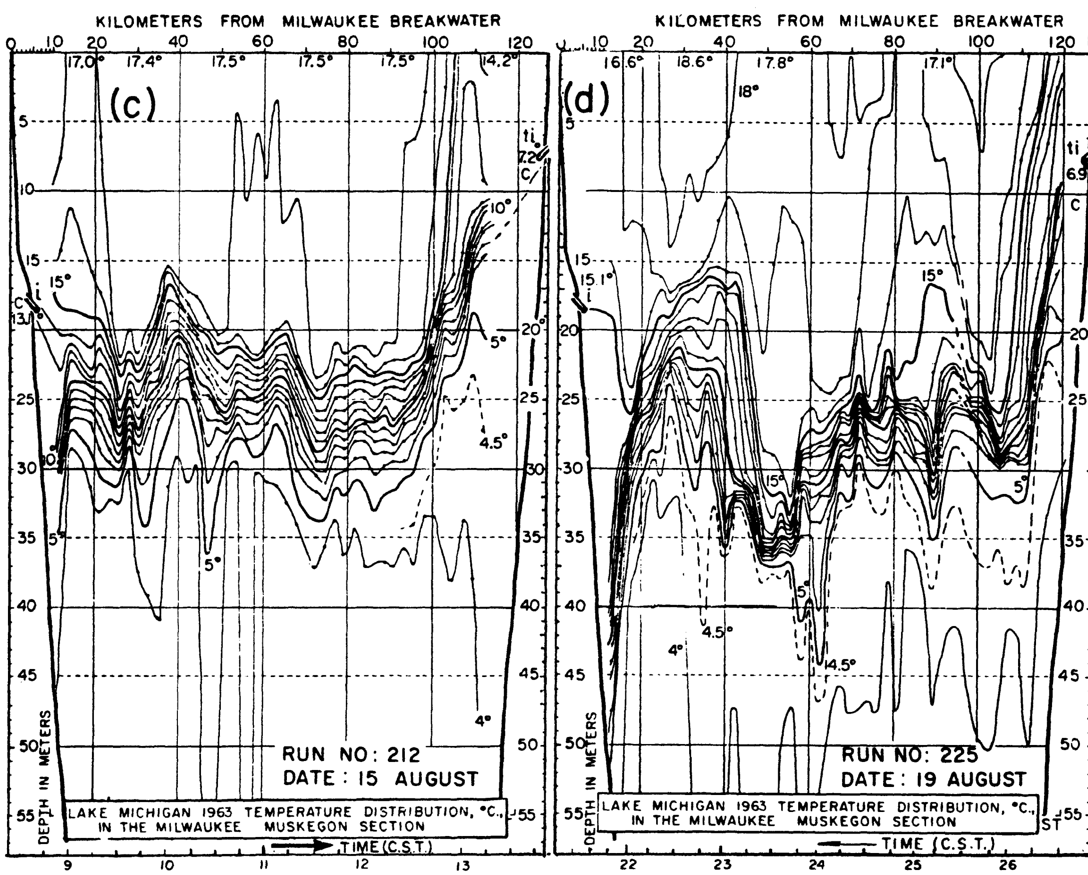


Figure 12 continued (for legend, see previous page): (c) and (d) after strong northerly winds on August 11 and 17, respectively.

while it may be modified or even destroyed by wind, it is itself not wind-powered. This particular seasonal contribution to the southward nearshore transport from Milwaukee Harbor was not discussed in the court proceedings.

When stratification has become established over the whole basin by early July (regime 4; Fig. 12), the presence of the thermocline profoundly influences the dynamics. A simplified, but valid, picture presents Lake Michigan as two layers separated and virtually isolated from each other by a relatively slippery interface, the thermocline. Turbulence, and therefore internal friction, is suppressed by the vertical density gradient in that interface, and the upper and lower layers can slide over each other with relative ease. Wind impulses, acting on the lake surface and combined with effects of the earth's spin, impose a mobility on this two-layered structure that is evident in the changing patterns of cross-lake temperature distribution illustrated in Figure 12. For example, in Figure 12a, the thermocline that occupied the depth range 10-20 m between Milwaukee and Muskegon on August 30 was tilted upwards nearshore at its western edge and downwards at its eastern edge, and there were wave-like features in between. This configuration -- upwelling of cold waters on the western shore, downwelling of warm water on the eastern shore -- was produced by the drag of previous southerly and southeasterly winds acting on the surface layer and setting it in motion. Once in motion, the upper layer was deflected to the right by earth-spin and moved eastward (nearly 90° to the right of the wind direction) away from the Milwaukee shore. To take its place, the lower layer was raised upward at Milwaukee. After a strong southeast wind pulse on August 2 (Fig. 12b), the western upwelling and eastern downwelling were intensified.

But after a very strong north wind on August 13, the picture was reversed (Fig. 12c), with downwelling at Milwaukee and upwelling at Muskegon, and further intensified (Fig. 12d; August 19) after a north-to-northeast wind pulse on August 17. Points to be noted in Figure 12 are (1) that the upwelling-downwelling motions, forced by wind and earth-spin, are confined within an area about 15 km from the shore, (2) that the wave-like features in mid-lake are increased in amplitude after episodes of wind-forcing, and (3) that each wind disturbance increases the depth of the upper layer by mixing.

It will come as no surprise that the motions illustrated in Figure 12 are accompanied by strong currents, generally shore-parallel in the nearshore regions of upwelling and downwelling. Elsewhere, rotation in direction is common. That rotation, an accompaniment of the mid-lake wave features noted above, is sometimes called inertial motion. It takes place with a periodicity of about 17 hours at the latitude of Milwaukee and is another consequence of the earth's rotation (Ref. 12). While it is clear (from Fig. 12) that whole-basin motions strongly influence nearshore currents, particularly during the season of stratification, the main focus of the arguments in court was on the nearshore strip from Milwaukee Harbor to the Illinois-Wisconsin state line, some 10 km in width and 60 km in length.

What are the speeds and directions of the currents, and are they sometimes sufficiently persistent to carry a "slug" of polluted water from Milwaukee to Illinois? How much is the slug diluted on the way? Those were the questions that the principal expert witnesses -- G. T. Csanady for the plaintiffs and D. W. Pritchard for the defendants -- attempted to answer.

Csanady based his conclusions on his own observations of coastal currents in Lake Ontario (summarized in Ref. 13) and on Reference 14 (PE 38), which represents the most detailed survey to date of coastal currents in Lake Michigan. That survey also happens to have been made in an area lying directly in the path of any Milwaukee-to-Illinois pollution transport (i.e., an area 20 km south of Milwaukee and 40 km north of the state line). It is appropriate, therefore, to illustrate the character of the currents by some examples from that survey, made with 10 current meters in a box about 10 x 10 km (see inset map at bottom right of Fig. 13). Figure 13 compares current speed and direction at the station (T_2) nearest Wind Point during the month of November with wind speed and direction at the Milwaukee (Mitchell Field) airport 22 km to the north-northwest. While wind over land cannot accurately represent wind over water, the correspondence between wind and current direction (both shown as "direction towards") is very close during November at Station T_2, and the correlation between current speed and the square of the wind speed (proportional to wind stress on the water) is also high. The current is clearly responsive to local wind and is constrained to run toward the south-southeast or toward the north most of the time. Although the picture is more complex during the summer stratification, currents at the stations nearest shore (T_1, T_2) were predominantly shore-parallel, either north-going or south-going, and flipping from one direction to the other within a few hours.

When a thermocline is present, currents further offshore are much less directly responsive to local winds. In August at Station 5 (Fig. 14), for example, the most conspicuous feature was a relatively regular rotation in current direction, characteristic of an "inertial oscillation," with a mean period of nearly 17 hours. There was no correlation between Mitchell Field wind speed and the current speed, which exhibited a slowly varying mean value modulated by the inertial oscillation. The progressive vector diagram (Fig. 15) shows a predominantly circling motion during August and a north-northwest drift with circling superimposed during September.

Based on analyses of Reference 14 and from examination of an earlier set of current records made at stations covering the whole basin (Ref. 15), Csanady concluded that the currents at Oak Creek headed south more often than they headed north and that the southerly flow sometimes persisted long enough to carry material from Milwaukee Harbor to Illinois waters. In his opinion, this could happen several times during the course of a year. Also appearing for the plaintiffs was J. L. Verber, the author of Reference 15, who referred to results from stations 7, 12 and 17, all within 10 km of the shore between Port Washington, Wis., and Waukegan, Ill. He concluded that 76%-80% of "flow along the shore is moving either to the north or south," and in one case a south-going current persisted for 19 days at a speed corresponding to a distance traveled of 108 miles (tr. p. 2,383).

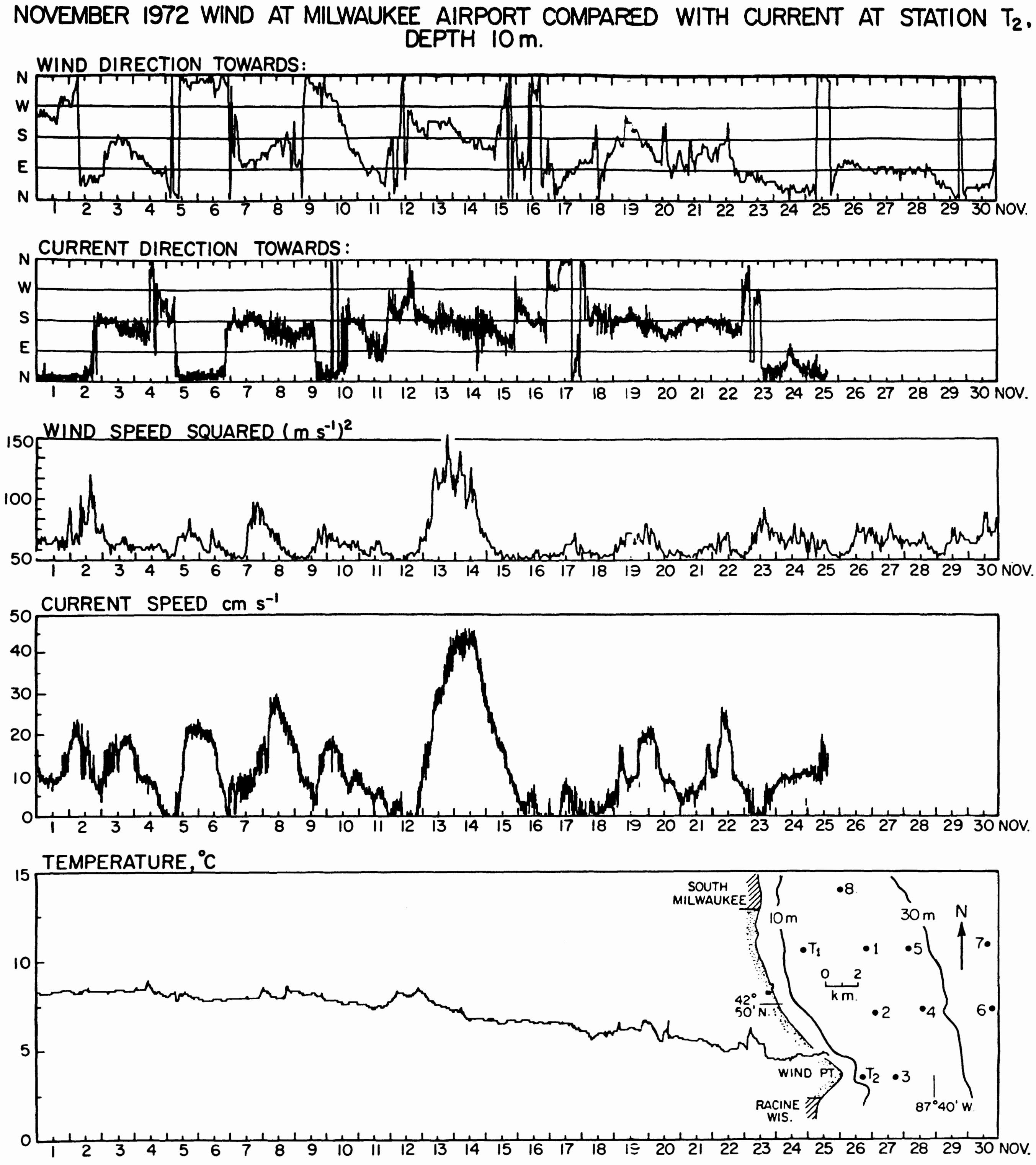


Figure 13. Lake Michigan: current speed and direction and water temperature at 10 m depth during November 1972 at a station 1.5 km from shore (Station T_2 near Wind Point, Racine, Wis.; see insert map) compared with wind speed and direction at a nearby airport (redrawn from Ref. 14).
NOTE: Wind and current directions are both shown as "direction toward."

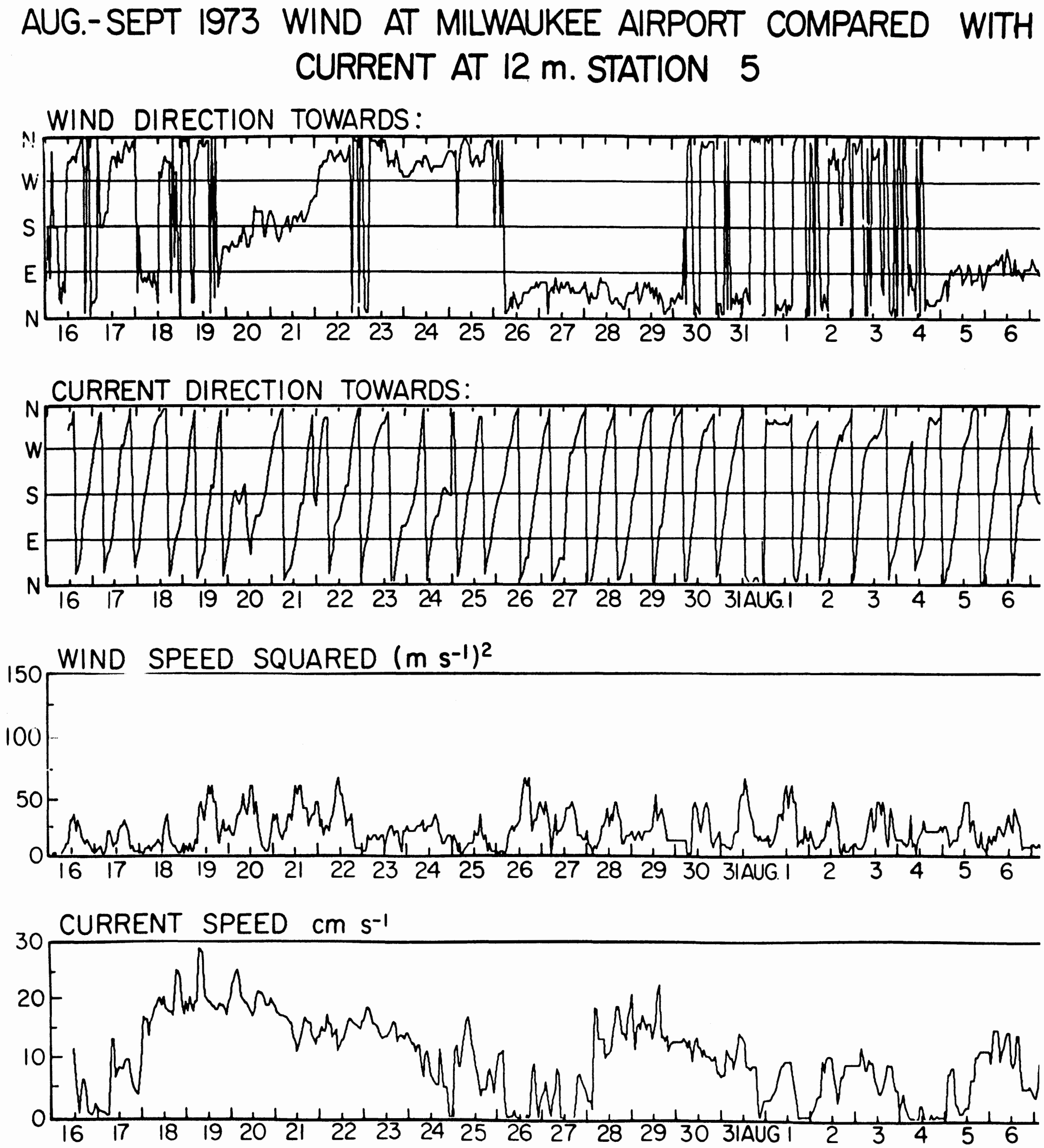


Figure 14. Lake Michigan: current speed and direction at 12 m depth, August-September 1973, at a station 9 km from shore (Station 5, near Oak Creek, Wis.; see insert map in Fig. 13) compared with wind speed and direction at a nearby airport (redrawn from Ref. 14).
NOTE: Wind and current directions are both shown as "direction toward."

For the defendants, Pritchard drew attention to possible inadequacies of measurements made in Reference 14 (tr. pp. 6,312-17) and Reference 15 (tr. pp. 6,286-90) for estimating currents close enough to the shore and close enough to the surface to reliably determine pollution transport rates. Also, he suggested, errors may have arisen from wave action in those measurements because the instrument rotors were of the Savonius type (tr. pp. 6,331-33). Pritchard based his own conclusions regarding the statistics of nearshore currents on results from two current meters (Endeco propellor type, which reduced possible errors arising from wave action) that were placed much nearer to shore (0.25 and 0.8 km) and nearer the surface (shallowest at 2 m; tr. p. 6,377) at Zion, Ill., just south of the Wisconsin-Illinois state line. During one year of continuous records (Ref. 16, DE 282), there were about 200 days during which the currents persisted to the south or to the north for periods of 30 minutes or more. Analysis of 4,708 hours of hourly averaged currents (Fig. 16) shows northward and southward flow for 50% and 41% of the time, respectively, at a mean speed of a little over 10 cm s^{-1}.

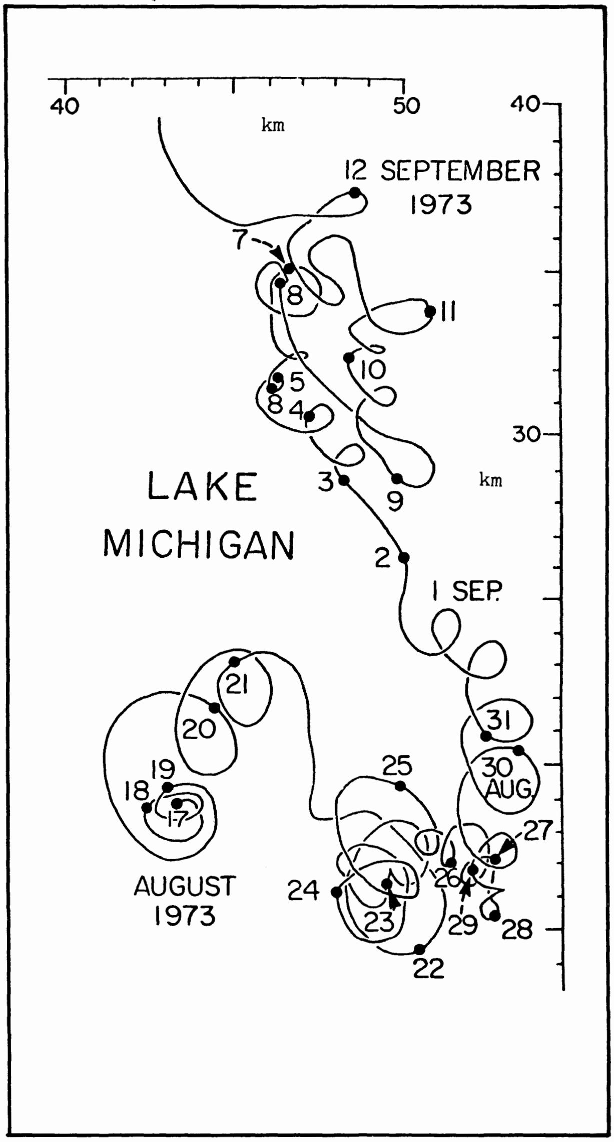


Figure 15. Approximate current track at 12 m depth at Station 5, August-September 1973, constructed as a progressive vector diagram from the current data presented in Fig. 14. Dots indicate noon on the dates shown. North is vertically upward on the page.

Pritchard placed emphasis on the currents very near shore, because he assumed that a pollutant plume would generally follow the 8 m (27 feet) depth contour (tr. pp. 7,116-20) (i.e., the depth of the Milwaukee Harbor entrance) and would therefore not be influenced by faster and variably directed currents offshore. Csanady, on the other hand, stressed the occasional importance of "coastal jets," which develop about 5 km offshore during and as a response to downwelling episodes of the kind illustrated in Figure 12d and in Figure 17 (Csanady's figure from Ref. 13). One may visualize a "coastal zone" of about 8-10 km (5-6 miles) width -- the zone involved in upwelling-downwelling motions and the ensuing internal wave responses (Ref. 12) -- with the high-velocity core of the coastal jet at about 4-5 km offshore (tr. p. 1,949) with typical speeds of 40 km (25 miles) a day (tr. p. 1,952). This is an example of the influence of whole-basin motions on the nearshore current regime (i.e., local downwelling produced by wind stress applied to the whole lake surface, combined with earth-spin).

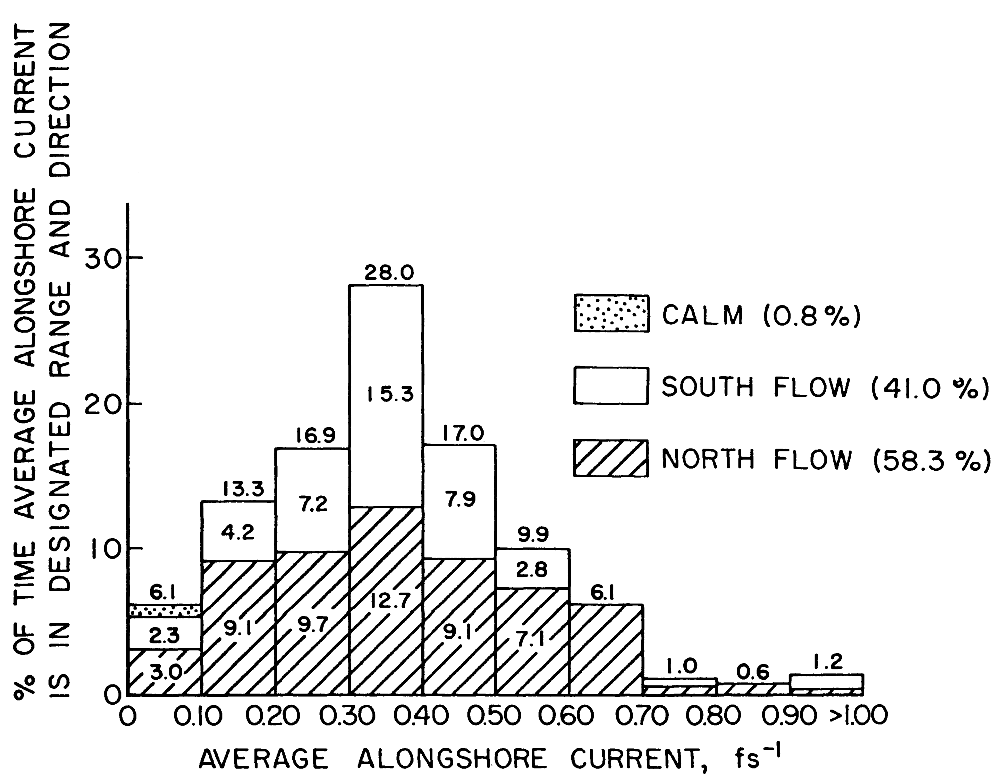


Figure 16. From Hydrocon, Inc., 1975: lake currents in the nearshore zone of Lake Michigan near the Zion Nuclear Generating Station. Research Report to Commonwealth Edison Co., Chicago, Ill., with 4,708 hourly averaged currents classified into speed ranges and direction (N or S) at Station C, 1.84 m depth, 0.8 km from shore, December 1972-January 1974 (Ref. 16; DE 282).

Another example mentioned (tr. p. 2,031), but not emphasized, by Csanady is the upwelling phenomenon (e.g., Fig. 12a), which is more common than downwelling on the Wisconsin shore and in which the upper part of the water column (and any pollutant load) is carried offshore. That process breaks up and disperses pre-existing pollution plumes, thereby flushing out the nearshore zone with upwelling bottom water.

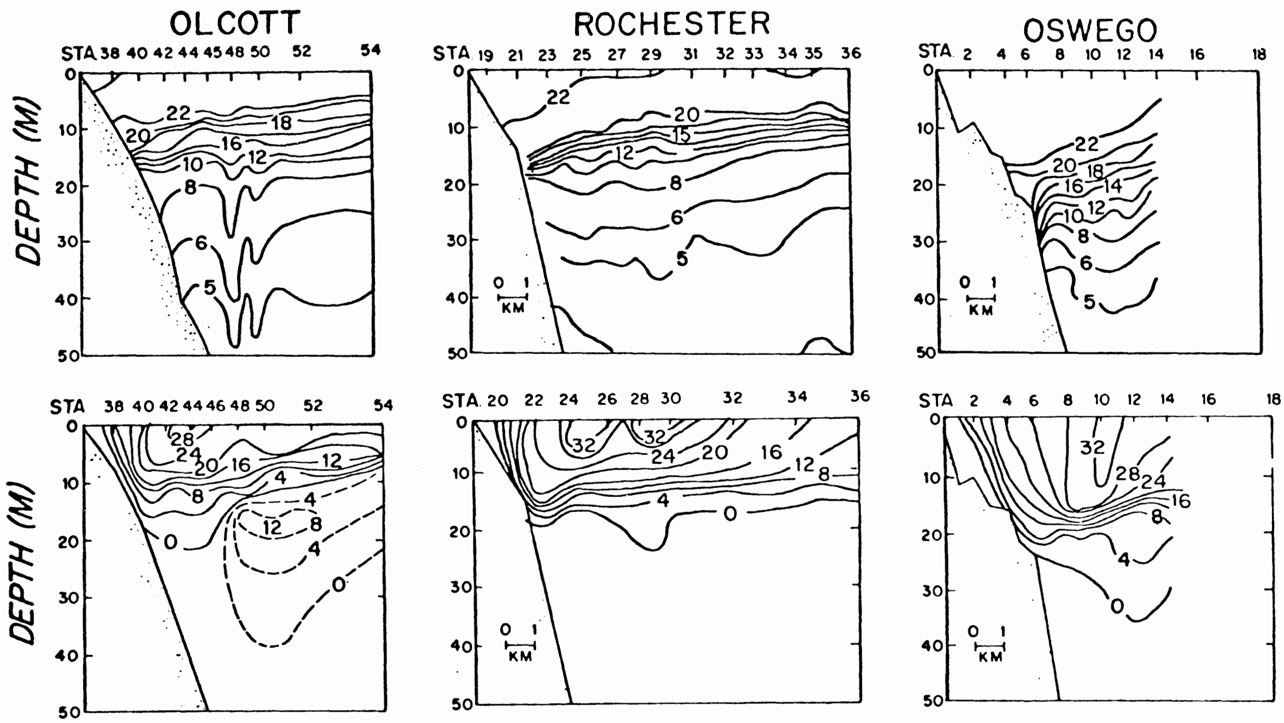


Figure 17. Coastal jet shown in three sections perpendicular to the south shore of Lake Ontario, July 23, 1972: isotherms (°C, upper row); along-shore velocity contours (cm s^{-1}, lower row, positive out of the page). (Source: Ref. 13.)

3.3 Rival Models of Dispersal and Diffusion

While hydrodynamicists on both sides finally agreed that transport routes from the Milwaukee outfalls to Illinois waters could be traversed by nearshore currents more than once a year, there was disagreement on how often this was likely to occur, and there was further, perhaps more important disagreement on what degree of dilution the materials would experience -- through dispersal and diffusion -- during the journey.

In his calculations, Csanady assumed that a "slug" of pollutant from the rivers during a flood, for example, would be diluted by a factor of 10 upon entering the lake and would then travel in coastal waters in an elongated "slug" or plume, or as a series of slugs if the original input had been intermittent. The length of the slug or plume depends principally on the lake current speed and the duration of efflux at the Milwaukee Harbor mouth (tr. p. 2,018). The plume may meander toward or away from the shore (tr. pp. 2,021, 2,025). The width of the plume depends principally on the rate of efflux from the harbor, on the value chosen for the coefficient of turbulent diffusity (K) and the rate at which K changes with time. The choice of that coefficient is critical. Csanady calculated the dimensions of a series of model slugs (Fig. 18; PE 134) with different, but constant, values of K (discussed more later). These models depict persistent narrow plumes ("narrower than smoke plumes," tr. p. 1,967) in which, if the plume is wide enough, the concentration at the center decreases only slowly with time, though rapid dilution is taking place at the edges.

Csanady, under direct examination by JVK for the plaintiffs (tr. p. 2,013):

> Q. "Based on the initial flow rate that you selected, the 6,000 cfs, could you state to the court what the size of this slug is likely to be as it leaves the Milwaukee area and then what its size is as it arrives in Illinois or in Illinois water?"
>
> A. "Yes. The calculations yielded figures ranging in size at the Milwaukee Harbor entrance from about 2,000 feet width to three times that, or 6,000 feet width -- that is to say, roughly a mile to a third of a mile in width -- after the initial dilution, after this entry into the lake through the river and harbor system. Then there was subsequent mixing at the edges, which pushes the edges out. But before that affects the center concentrations, some considerable time elapses in view of the large initial size of this slug. So further dilution is found generally to be quite slow, and in some conditions almost negligible. The center concentration only dropped by a few percent."
>
> Q. "When you say a few percent, you mean -- "
>
> A. "One or two under some conditions, and 15 percent under other conditions, and one can vary these figures. But by and large, the dilution subsequent to the initial dilution was very ineffective."

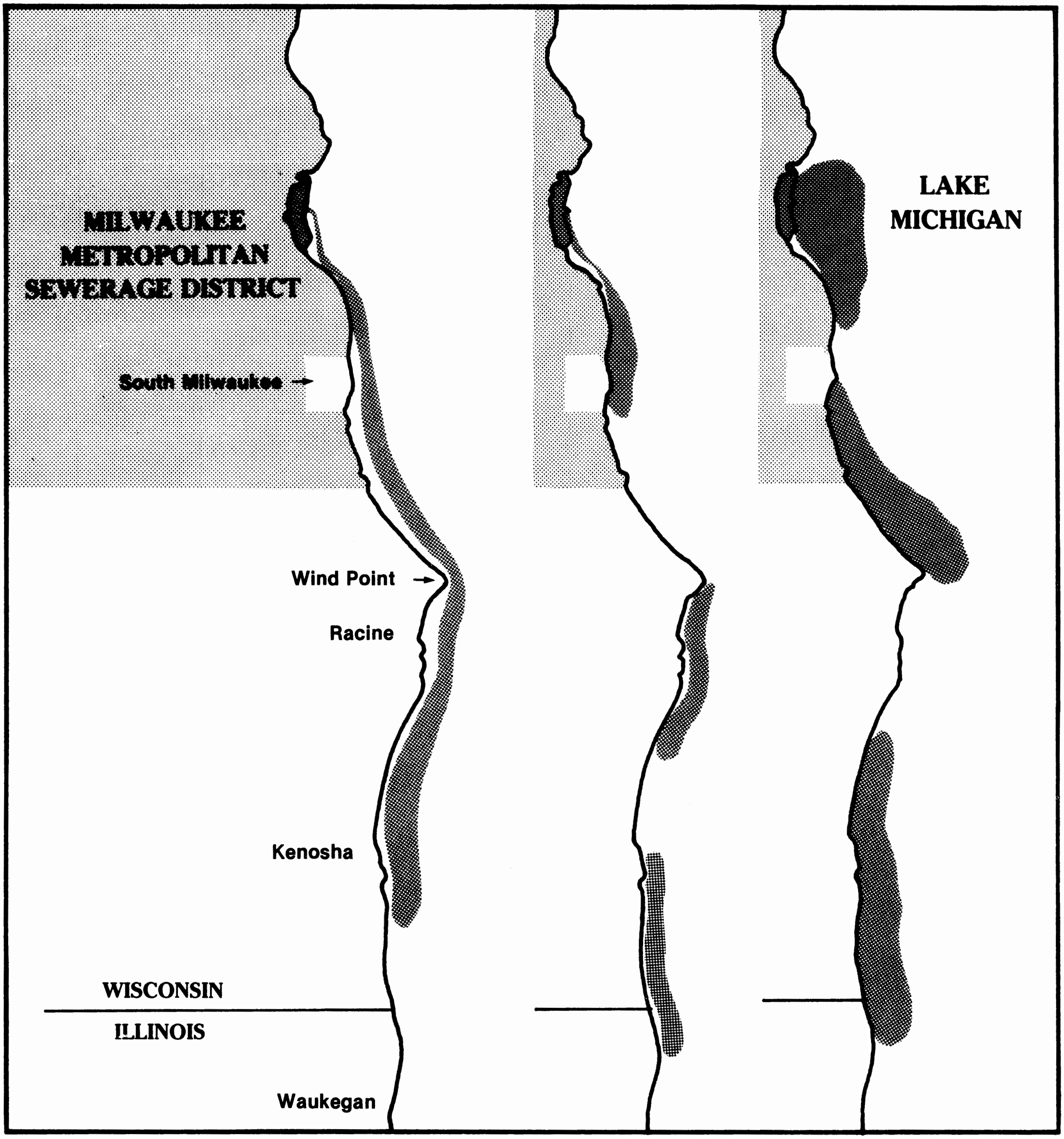


Figure 18. Model pollutant plumes and "slugs" computed by G. T. Csanady for various values of the coefficient of turbulent diffusivity (K) and for various rates of continuous and intermittent pollutant release from Milwaukee Harbor. In each case, K was maintained constant in time. This figure is assembled from a series of colored diagrams (PE 134) and illustrates the general features of Csanady's model, including the low rate of dispersal that it predicts, as described in the text.

Csanady here made the important point that in the smoke plume-type model, the concentration at the center of a large plume will slowly decline. The assumption of constant diffusity was based on observations of dye plumes in Lake Huron (Ref. 17). Csanady also made another telling point (tr. pp. 2,004-6, 2,669) that heavy rainstorms (with flooding and consequent CSO) in summer often occur as a low pressure system passes, "usually followed by brisk northerly winds" that induce relatively persistent south-going coastal currents. Persistence for 7 days is "reasonably frequent" (tr. p. 1,957).

Pritchard pinned his faith to another type of diffusion model -- the Pritchard-Okubo model -- fitted to observations of diffusing dye patches in a wide range of natural waters, lakes and oceans. In this model, the diffusivity is not constant but increases with the inreasing size of the patch, reflecting the presence in nature of a mixture or spectrum of turbulent eddies ranging in size from the dimensions of the basin in question down to the smaller eddies approaching the dimensions of molecular motion.

Pritchard, under direction examination by R. D. Moake for the defendants (tr. p. 6,468):

> Q. "Is this a general pattern, then, that the larger the area, the more eddies of varying sizes we will have acting upon it, and that those eddies act in a compounding manner upon this water?"
>
> A. "That is right. The general principle is that the energy available for diffusion or for mixing, for dispersion, however you want to call it, increases with the scale or the size of the body being dispersed, or the volume being dispersed."

In that quotation, Pritchard is presenting what might be called the classic view of dispersal of a plume of "pollutant" in a lake or ocean current, in which dispersion is brought about by turbulent eddies that cover a much greater size range in the horizontal than in the vertical. If, for simplicity, it is assumed that the pollutant source delivers at a constant rate into a lake current of steady velocity and spatial uniformity, and if the field of turbulence is more-or-less homogenous with a continuous eddy size range (continuous eddy spectrum), then the width of a pollutant plume will increase with time and, therefore, with distance from the source. In many well-known models (e.g., the Brooks model, Ref. 18), the diffusivity increases with the four-thirds power of the dimensions of the diffusing patch or plume. The rate of dispersal in the Pritchard-Okubo model is governed by a "diffusion velocity," which can be transformed into a diffusivity coefficient (as was laboriously done in court, tr. pp. 6,831-34). A constant diffusion velocity implies a diffusivity that is not constant but increases as the plume or patch dimensions grow.

In support of his diffusion velocity model -- and in opposition to Csanady's model of constant diffusivity -- Pritchard cited results from Reference 19 (DE 1156-A), in which the diffusion of a T-shaped patch of flourescent dye, laid out in surface water about 1.5 km from the eastern shore of Lake Michigan, was followed by aerial photography and boat surveys. The advection (motion with the lake current) and diffusive spread of the patch with time is derived from aerial photographs in Figure 19. Figure 20 displays the concentration distributions across the patch in north-south and east-west directions at 1:45 p.m., and at 24 minutes and 105 minutes later. The calculated diffusivities for these and for measurements continuing beyond 105 minutes are plotted against patch scale in Figure 21 and are there compared with other results from the Great Lakes and oceans (for detailed references, see Ref. 19). Under redirect examination by R. D. Moake for the defendants (tr. pp. 6,977-78), Pritchard answered that Figure 21:

> "...shows just in more detail that when data covering a very wide range of scales is plotted on this kind of diagram, it produces a line with at least as great a slope as that which is found in the ocean. It is not coincident with the line in the ocean, but that is not the important point in this case.
>
> "The important point is that it indicates that the scale of the size of the relationship between the eddy diffusivity and the scale of the size of the diffusing patch of material that fits the relationship Ky is proportional to the standard deviation to the 1.1 power, or if that same data had been plotted on the other kind of diagram, which shows the variance or the standard deviation as a function of time, it would essentially say the diffusivity increases slightly faster than the O-P solution...but further, the authors point out, that is, the authors of the text from which this data comes, point out that perhaps the Michigan data, at least in the lower and mid range, could be also adequately fitted by the four-thirds power law. That is this third assumption that the diffusivity is proportional to four-thirds of the standard spread; hence, the variance increases as time to the third power and the standard deviation increases as time to the 1.5 power.
>
> "So that essentially they are saying some of the Great Lakes data indicates that the rate of expansion of the cloud is at a faster rate than the O-P solution and more nearly like that of the neighborhood theory, four-thirds power."

Csanady, on the other hand, had earlier supported his constant diffusivity model with results from a number of nearshore drift bottle and dye plume experiments in Lakes Erie and Huron. He found (Ref. 17) that in the initial growth stages of plumes (as in Fig. 19), the diffusivity did increase with plume width; but at distances of a mile or more from the source, a "final" condition was approached in which diffusivity remained constant with time. Cross-examined for the defendants by R. D. Moake (tr. pp. 2,602-3), Csanady agreed that his model is the one that gives the least dilution of the plume with time (or distance from the source) but insisted that the observations

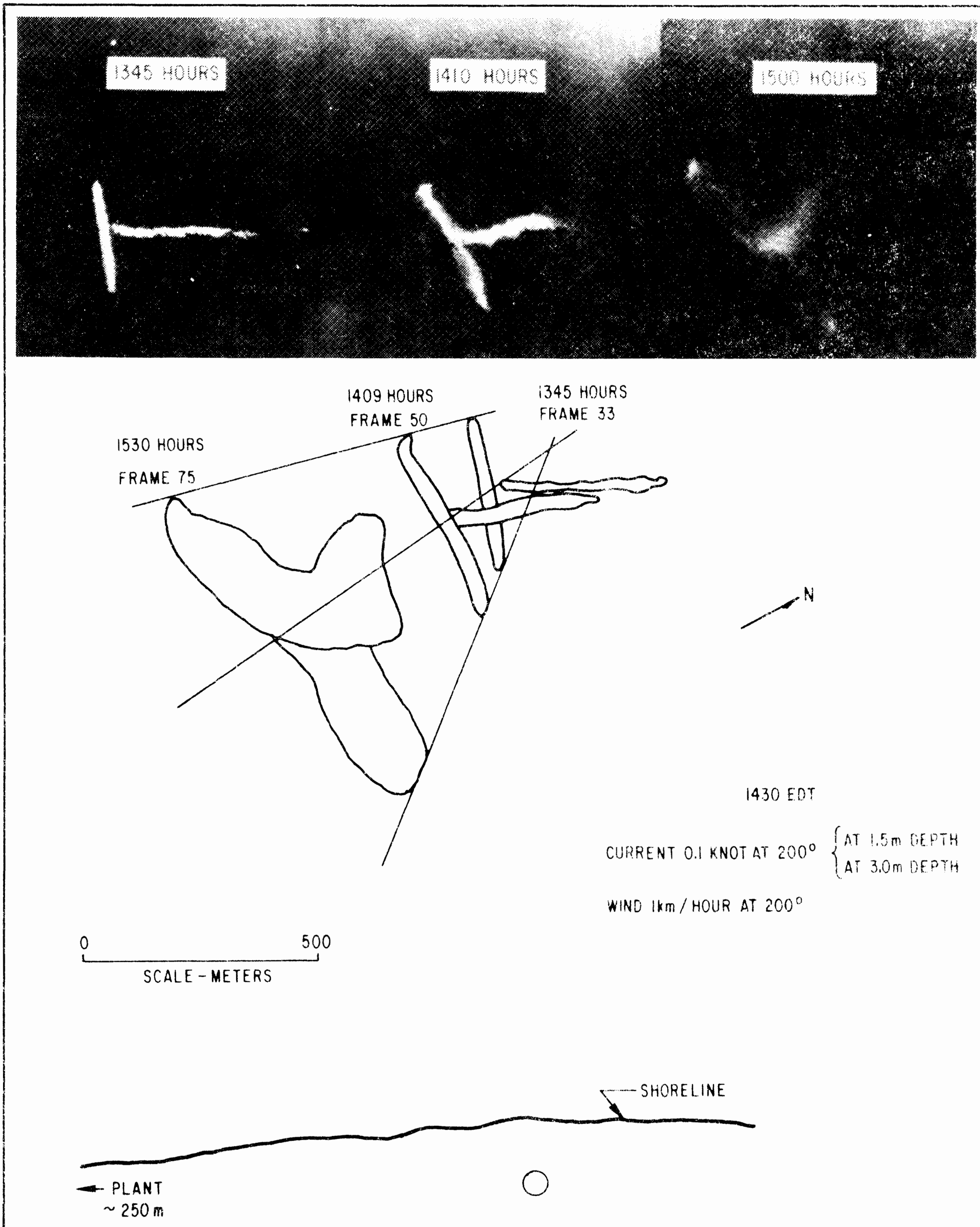


Figure 19. Drift and diffusion of T-shaped dye patch near the eastern shore of Lake Michigan (Donald C. Cook Nuclear Power Plant) October 23, 1973 (Ref. 19; DE 1156-A).

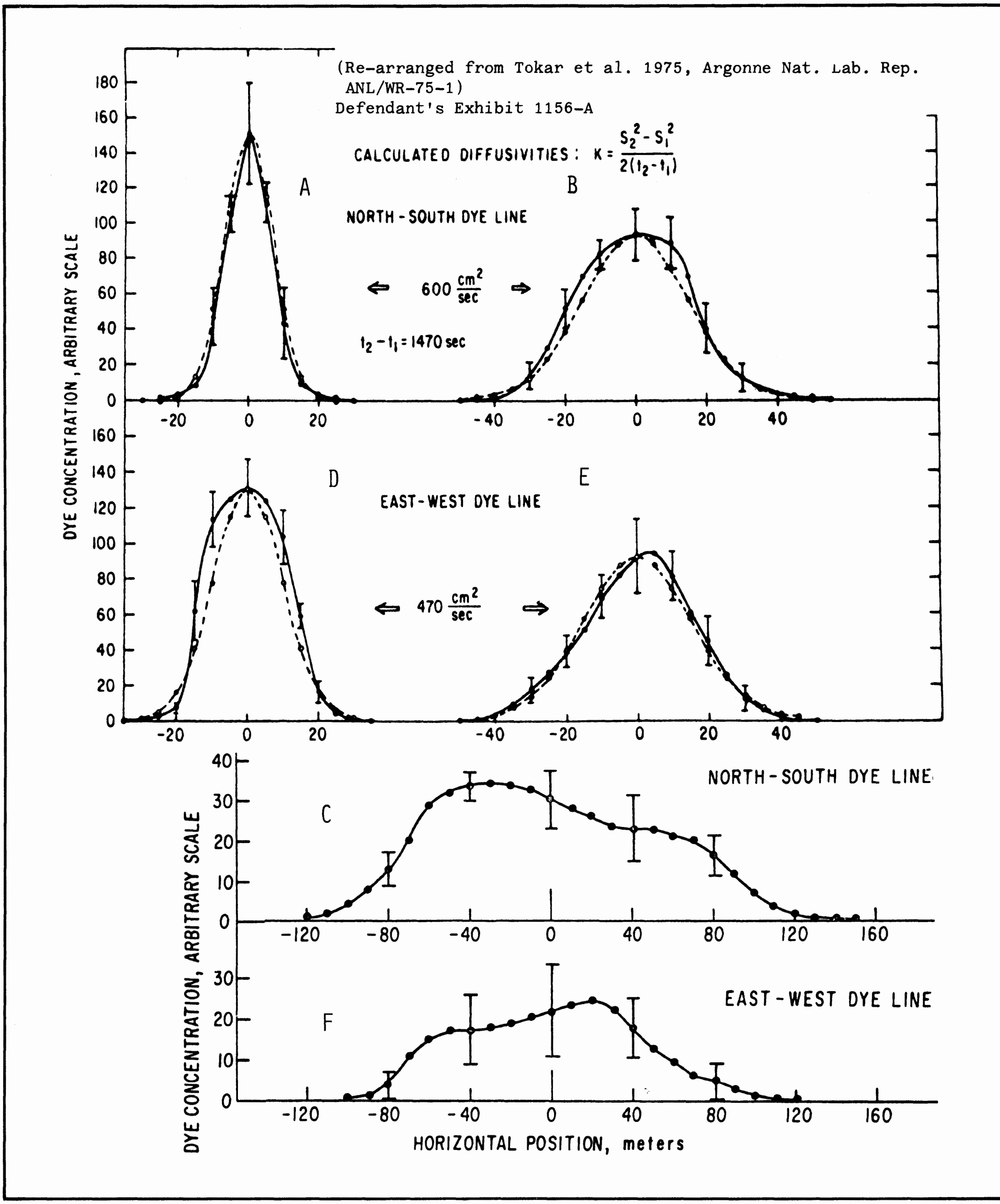


Figure 20. Relative horizontal distribution of dye showing the spread of the T-shaped patch illustrated in Fig. 19: these photodensimetric determinations, A, B, C, were made on a north-south line and D, E, F, on an east-west line, with approximately 1,500 seconds elapsing between each determination (from Ref. 19; DE 1156-A).

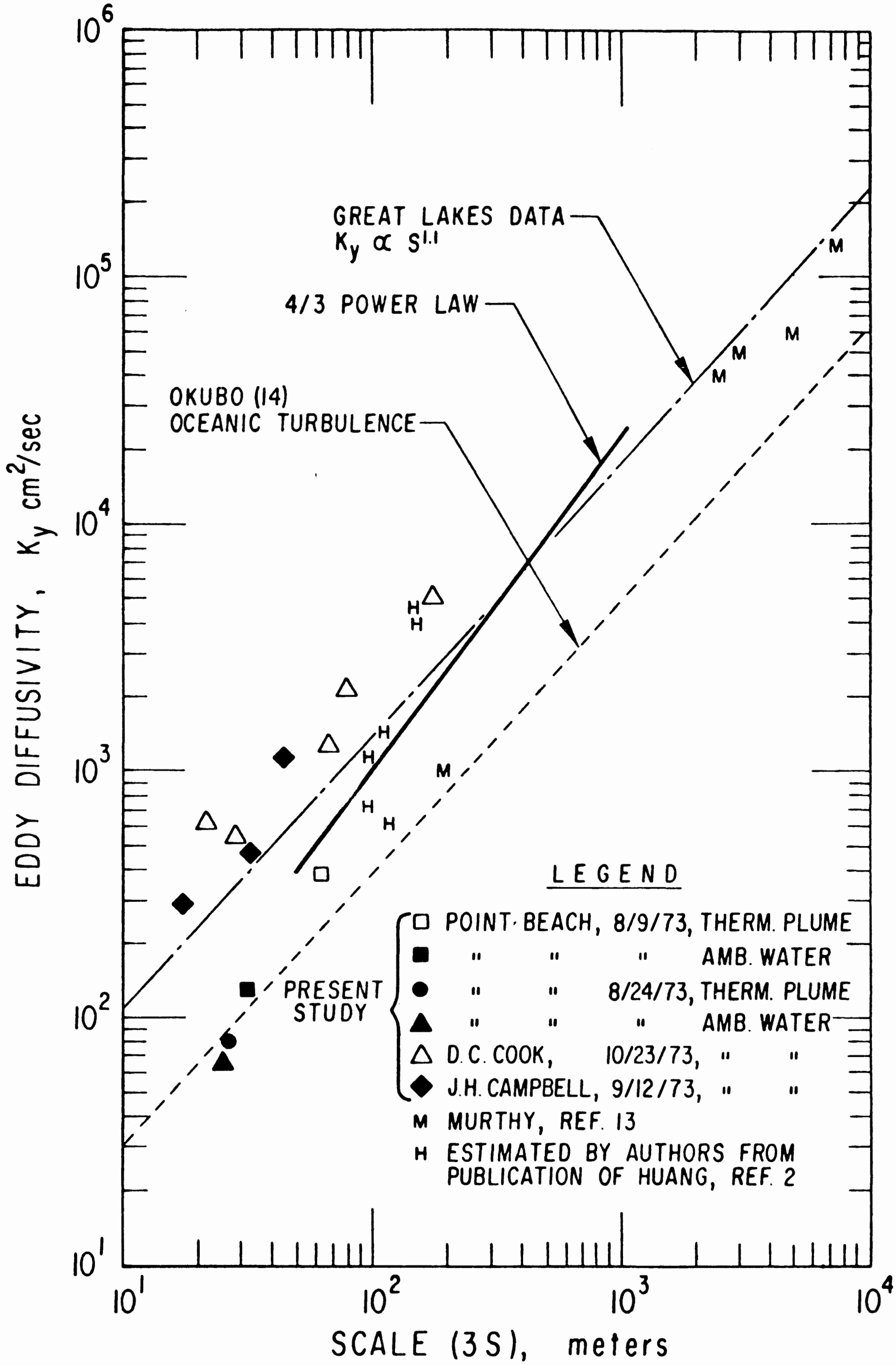


Figure 21. Coefficients (k_y) of horizontal eddy diffusivity calculated from the study reported in Ref. 19 (and illustrated in Figs. 19, 20) for various nearshore regions of Lake Michigan, compared with values from other Great Lakes and oceanic investigations (from Ref. 19; DE 1156-A).

do not fit models (e.g., the Brooks model) in which diffusivity increases with the four-thirds power of plume width or the Pritchard-Okubo model with constant diffusion velocity (example illustrated in Fig. 22; DE 1150):

Q. "That is correct, and the one of least dilution is the one which assumes a constant diffusivity?"
A. "Yes."
Q. "That is, at least to a significant extent, comparable to the formula that you have used in the Milwaukee situation, is it not?"
A. "Yes, I have used that formula in this context."
Q. "There is no question in your mind, is there, doctor, that these other two formulas are alternative formulas that one could use to determine or to compute a diffusion or a plume?"
A. "No, there is a great deal of question. See, when Brooks wrote his paper, he didn't know very much how many of these plumes would behave. There is a great deal of experimental evidence since that time and particularly in the Great Lakes as well as, by the way, in coastal regions in California, for example.

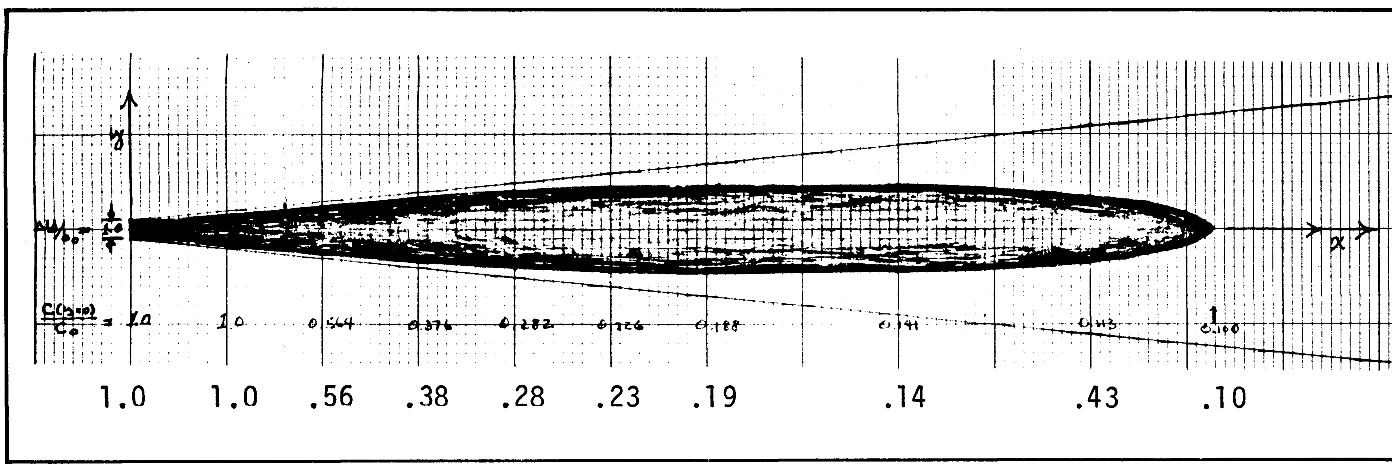


Figure 22. Steady-state plume (DE 1150) predicted by the Okubo-Pritchard model under the following assumptions (tr. pp. 6,481-83): (1) a steady discharge of pollutant at concentration C_o occurs at a line source of width b_o (left-hand edge of shaded portion); (2) discharge takes place into a steady, uniform current of velocity u moving in the x direction; (3) the pollutant is conservative (i.e., its concentration, C, at any point is solely determined by dispersal and diffusion; (4) the diffusion velocity, omega in the model, is set at u/10 (therefore, at any distance x along the plume, the standard deviation concentration corresponding to the lateral spread at that point is found at distance x/10 from the centerline, at the position indicated by the diverging lines the figure); (5) the plume is only visible (shaded portion) at concentrations great than $C_o/10$. The ratio of the centerline concentration to the source concentration, C_o, is shown on the bottom scale.

"What one generally finds for an individual plume is that the behavior of that plume is better described by a constant diffusivity than by, certainly, that extreme formula, the four-thirds power rule. That certainly is an extreme overestimation, at least, of plumes that travel long distances; but even the other one, the constant diffusion velocity, which implies that the plume increases in direct proportion with distance, as your previous picture shows, that plume increases linearly. It has straight outlines. It looks like a cone, a projection of a cone. It moves out in straight lines.

"Now, when you actually look at plumes that we have looked at in the Great Lakes, you will find that this is not so, that those outlines start curving in after some distance, whether you have that plume close to the shore or far from the shore."

(NOTE: Csanady is saying here that the diverging lines in Figure 22 would eventually curve in and become parallel.)

3.4 Comments on Dispersal and Diffusion

The fundamental differences between the rival models is that Csanady assumed (based on observations in Lake Huron) that the eddy diffusion coefficient (diffusivity) remains constant with time (i.e., with distance down the plume), whereas Pritchard's use of "diffusion velocity" in the Pritchard-Okubo model infers a diffusion coefficient that increases with time.

Pritchard reasoned that as plume dimensions increase, larger and larger eddies contribute energy to the diffusion process. This assumes that the system does not run out of energetic eddies of ever-increasing dimensions (up to the limits of the basin), or in other words, that there are no cut-offs or gaps in the eddy spectrum. Csanady's observations of very long dye plumes in Lake Huron suggest that, indeed, there may be such a gap between eddies of characteristic dimension 10 m and very large eddies of order 10 km, the influence of which is seen in the meandering of the narrow plumes at long distances from the source, moving them alternately toward and away from the shore (Ref. 17).

After extensive agrument and calculation, much of which served only to confuse the court,* there was agreement that both models could be made to yield similar results by appropriate choice of diffusion coefficients and initial conditions within reasonable limits (summary by JVK during re-cross examination of Pritchard, tr. pp. 7,162-66). There was also broad agreement on the extent of the coastal zone to which most of the transport affecting Illinois would be confined. Csanady, for example, under direct examination by JVK for the plaintiffs (tr. p. 1,949) states:

*Confronted with colored graphs predicting plume growth according to various models, Judge Grady became impatient at both sides for "overtrying the case" (as we shall see in later discussion, tr. pp. 6,992-93) -- "none of your mathematics is going to convince me which one of those patterns to select."

A. "The total width of the zone is approximately five-six miles, or that order of magnitude, within which one finds, again, perhaps some subregions. Very close to shore is a region where friction dominates the currents, where currents are relatively slow on account of the breaking effect of the bottom on the currents. Then in the summer, say, two or three miles from the shore, one finds very strong concentrated currents driven by the wind when the wind has just acted on that body of water. These are what I referred to before as coastal jets."

Q. "Apart from coastal jets, how far is the region from the shore into the point that currents increase, where the currents' speed increase, where you have indicated that the bottom exerts a friction effect to slow down the currents?"

A. "Perhaps three or four miles one finds a peak in the current speed. That is where the fastest currents are found, when one gets out from the influence of the shallow bottom, but before getting into the offshore region, where the currents are freer to move in all directions."

Furthermore, both sides agreed that potential existed for pollutants to travel from Milwaukee to Illinois several times in an average year (Csanady's estimate 12; Pritchard's, 3), and their estimates of the maximum concentration, which would persist into Illinois waters in such a (worst case) pollution event, differed only by a factor of three. But many court-days were consumed in arriving at that conclusion.

The predicted infrequency of Milwaukee-originating pollution events in Illinois is a consequence of complex interactions between dispersal mechanisms operating during the remainder of the year. That complexity was not thoroughly addressed in court. Indeed, it can be argued that the models (of both camps) are oversimplified and that both are applicable, but to different stages, in understanding the dispersal process. In addition, that process is influenced, not only by advection and turbulence, but also by changing current regimes responding to variable winds. Upwelling-downwelling motions are another influence, with large offshore-onshore components leading to plume break-up and "cleansing" of the coastal zone by current reversals that are often encountered when passing away from the shore or downward through the water column. And the dispersal process is further influenced by the relation between effluent density and the density structure of the receiving water column.

For example, if the effluent density is greater or less than any layer in the water column, the effluent will sink to the bottom or rise to the top, respectively (Fig. 23, a rising plume). At an intermediate density, the effluent will insert itself as a diffusing sheet in the water column at the appropriate density level. So effluent and water temperatures are important factors to consider with regard to Lake Michigan in winter and early spring. If a receiving body of water has a temperature less than 4°C (i.e., of density less than maximum), a warmer effluent will

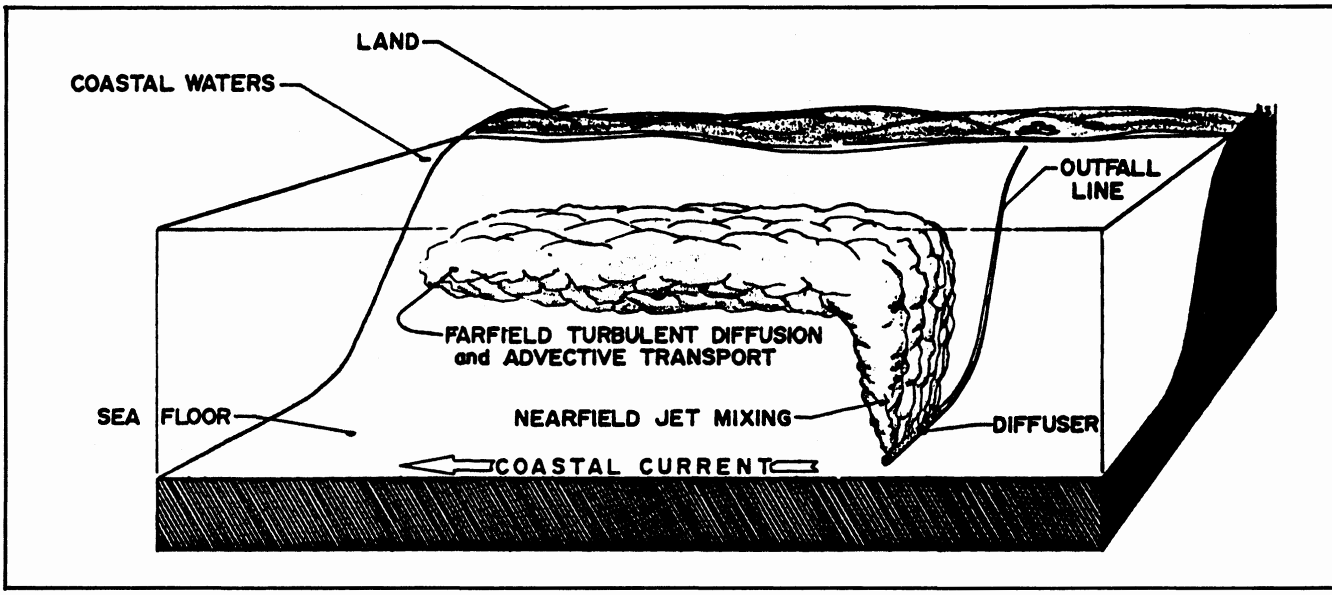


Figure 23. A rising plume (portion of a figure in Ref. 20).

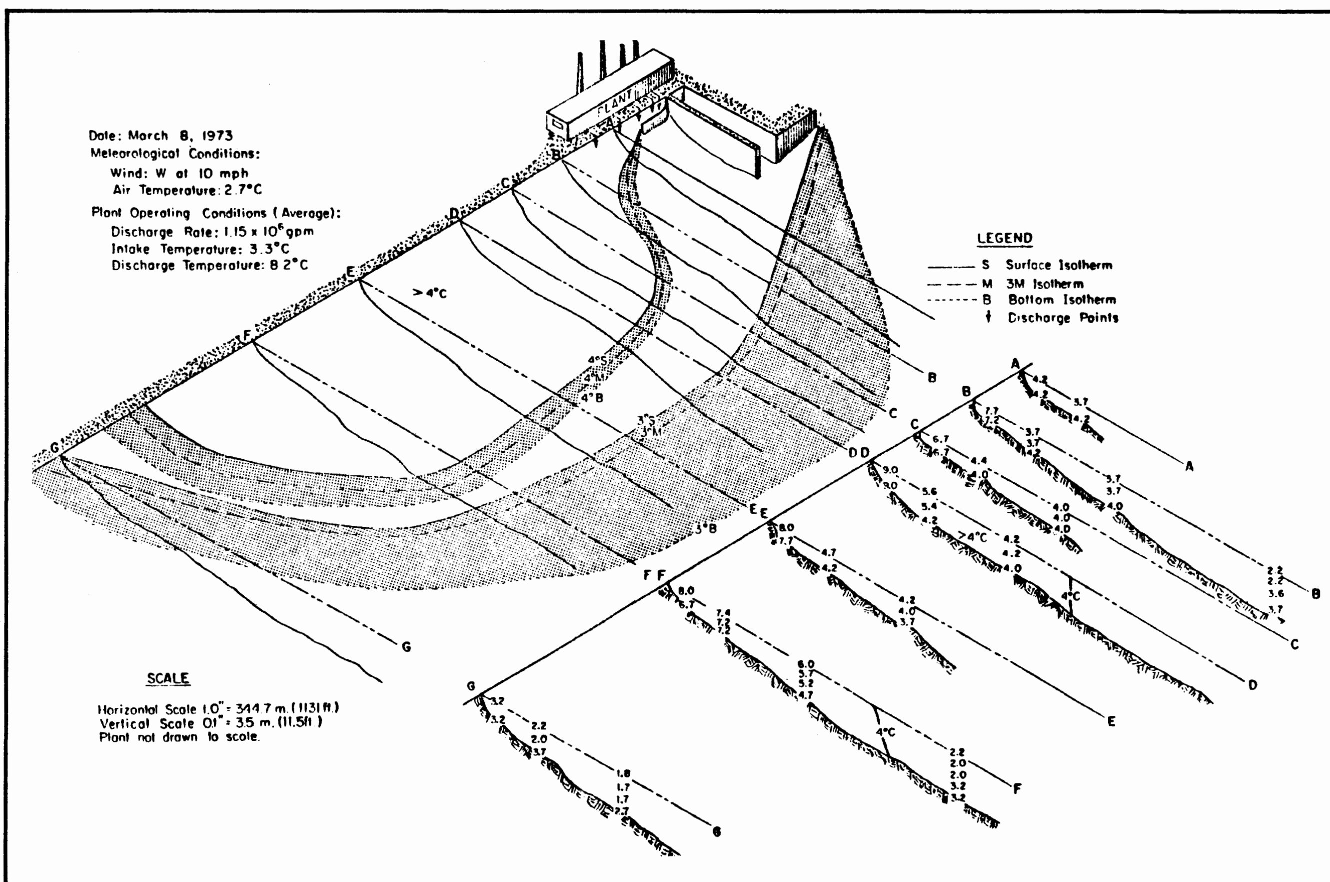


Figure 24. A three-dimensional view and sections showing temperature distribution through a plume sinking into Lake Michigan at a power plant at Oak Creek, Wis., March 8, 1973 (Ref. 14).

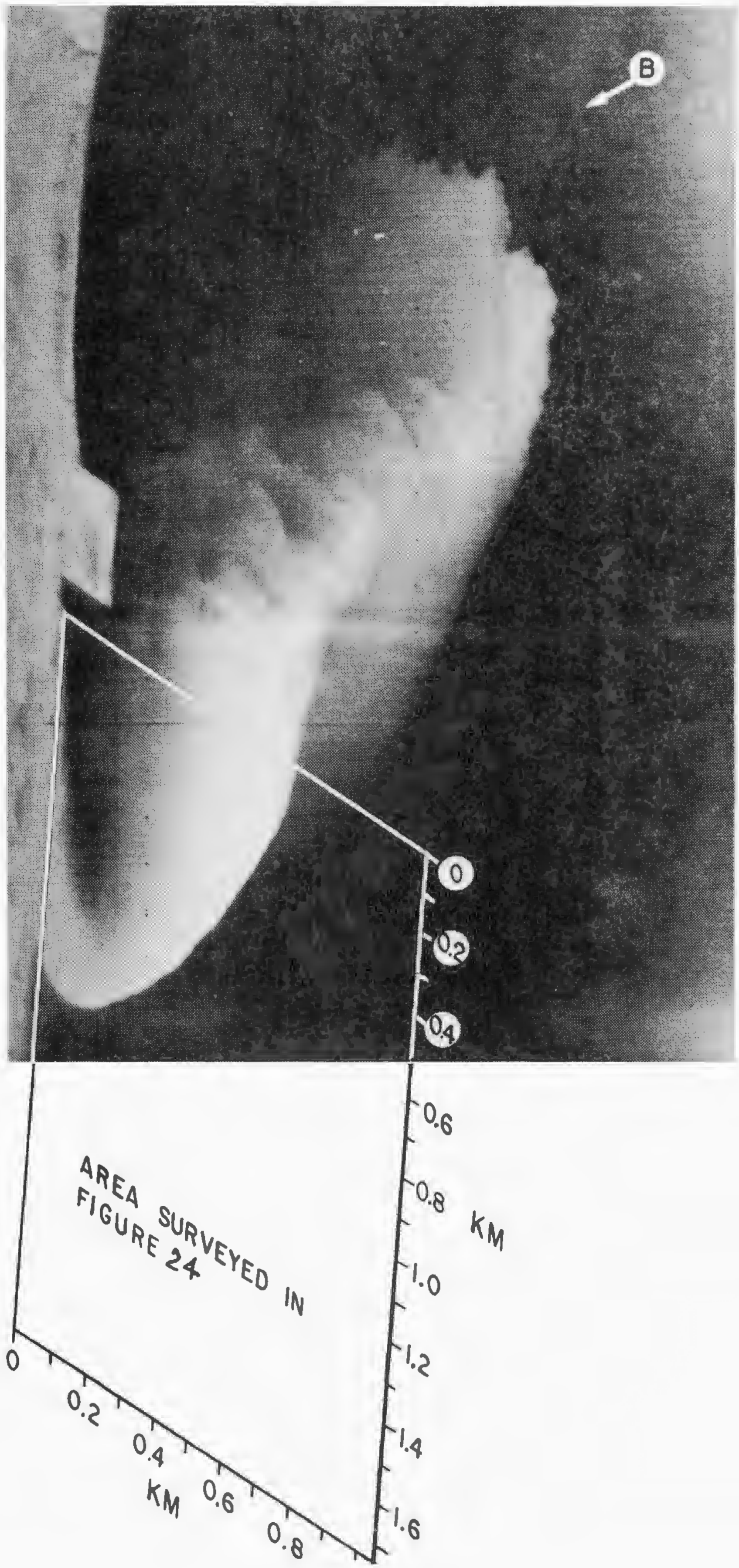
contribute to a mixed water mass of greater density (at/near 4°C). This denser mass, in turn, will sink and flow down along the bottom into deep water (i.e., out of the surface layers of the coastal zone). Examples of such a sinking plume (or localized thermal bar convergence) produced by the warm effluent from the Oak Creek, Wis., power plant (Ref. 14) are illustrated in Figures 24-25. In the latter example, lake currents turned the plume north; active sinking occurred at its outer edge.

Another vehicle for pollution transport along the Wisconsin-Illinois littoral was not considered by the court in detail (i.e., sediment transport resulting from intermittent resuspension of beach sediments by strong wave action). On average, the largest waves on that shoreline are produced by the winds with the longest fetch (i.e., winds from the north or northeast). Therefore, the net littoral sedimentary drift is southward, as is illustrated by the sand accumulation north of the breakwater at Oak Creek in Figure 9. Because these resuspension events occur with north-to-northeast winds -- which also generate south-going currents in the water -- there is a slow, net southward transport not only of beach sand, but also of finer particles. And since some pollutants (e.g., PCBs) are adsorbed on or otherwise associated with such particles, an intermittent, predominantly southward drift occurs. The finest particles formed by this intermittent reworking of the nearshore sediments settle the slowest and are carried by currents and dispersing eddies out into deep water. There they eventually settle or are ingested by filtering organisms whose fecal pellets also settle (more rapidly) and become part of the main basin sediment, which is the final repository, or sink, for much of the material that the lake receives.

Figure 25.

Thermal plume
at Oak Creek, Wis.,
April 2, 1968
(courtesy of Wisconsin
Electric Power Co.;
infrared imagery by
Texas Instruments).

The plume exits southward and, on this day, was deflected by Lake Michigan currents. It is inferred (because offshore lake temperatures were less than 4°C) that the plume is sinking at its outer edge. A natural thermal bar is perhaps indicated at B.



Section 4:

Signs and Gradients of Pollution in the Coastal Corridor

4.1 Plaintiff and Defendant Strategies

It was a relatively simple matter to establish the possibility of occasional Milwaukee-originating pollution (and eutrophication) of Illinois waters, but it was much more difficult to prove whether harmful pollution actually occurred. The plaintiff's strategy was not to engage in field studies along the presumed transport route,* but to rely on Illinois EPA and other agencies' records regarding water quality at Illinois beaches, water intakes and waste treatment plant outlets, and in Lake Michigan. Those records showed evidence of pollution and eutrophication (nutrient enrichment) persisting in the Illinois section of Lake Michigan (e.g., occasional taste and odor problems at the Glencoe, Ill., water filitration plant; R. Goodin's testimony, tr. pp. 13,517-38) despite substantial improvements in waste treatment by former local polluters (e.g., the North Shore Sanitary District). The defendants sought to show from records and from their own field studies that:

(1) evidence or effects of Milwaukee-derived pollution and nutrient enrichment remain local or are rapidly diluted and dispersed in Lake Michigan.
(2) "Milwaukee effects" do not extend into Illinois waters.
(3) the situation is not one in which a uniform pollution gradient extends from a Milwaukee source to the state line, but rather one in which a series of communities (including some in Illinois) act as local pollution sources.
(4) that sources much nearer to or within Illinois are responsible for the pollution signs observed on the beaches or at the water intakes for that state.

Thus, the defendants were faced with the heavier burden of proving they were not doing significant harm (i.e., proving a negative) or with establishing firm grounds for at least a Scottish verdict of "nonproven." Their principal defense rested on three studies: (1) a series of water quality surveys in the neighborhood of Milwaukee Harbor and southward along the shoreline to Waukegan, Ill. (Ref. 9), (2) an experiment to determine the rate of disappearance of fecal coliform bacteria in Lake Michigan (DE 73, later published as Ref. 7) and (3) surveys along the same shore of the growth of the alga *Cladophora* on rocks and jetties as an indicator of nutrient availability (described in Section 4.6).

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*Which prompted a question from Judge Grady (tr. p. 14,098) during JVK's closing statement:
Judge Grady: "What you are saying to me is that it is impossible to come up with any empirical data better than is in this record. Is that what you are telling me?"
Mr. Karaganis: "That is correct."
Judge Grady: "I do not believe that."

4.2 Fecal Coliform Surveys and the Coliform Disappearance Experiment

Coliform bacteria play an important role in water quality monitoring because their presence indicates pollution with fecal matter and, therefore, the possible presence of other organisms that are potentially harmful to health but more difficult to test for regularly. Tests for total coliform bacteria have been routinely carried out at waste treatment plants, water treatment plants and/or public bathing beaches for many years. In recent years, fecal coliform tests have become more specific. The fecal coliform count (FCC) is expressed in numbers per 100 milliliter (ml) of sample. As noted earlier, the FCC in the rivers flowing into Milwaukee Harbor is higher in wet weather. According to Reference 7:

> "During dry weather these organisms originate mainly from treatment plant effluents discharged into the Menomonee and Milwaukee rivers from communities north of the present service area. During wet weather, the organisms originate from urban and rural runoff and combined sewer overflows in addition to the upstream treatment plant effluents."

Six surveys covering 24 stations -- 15 of which were outside the harbor breakwater and up to 3.2 km (2 miles) out into Lake Michigan -- disclosed that from the river mouth outward, the FCC (Ref. 7):

> "...dropped significantly with distance out into the lake. Past the breakwater structure, the counts dropped to low levels in some cases, and to negligible levels in most cases. This reduction in count is the result of both natural die-off and environmental dilution. The beneficial aspect of the breakwater structure in terms of water quality in the open waters of the lake is apparent from the results."

In an attempt to distinguish between environmental dilution of coliforms in Lake Michigan and their disappearance due to other factors (e.g., natural mortality, sedimentation, ingestion by filter-feeding plankton), the investigators (Ref. 7) devised the following experiment. At SSSTP on July 10, 1974, chlorination of the effluent was interrupted and a known quantity of rhodamine WT dye was pumped into the effluent for 4.5 minutes, after which chlorination was resumed. During that 4.5 minutes, frequent samples of the dyed effluent were drawn for total coliform counts. Fifteen minutes later, the slug of dyed effluent arrived at the Lake Michigan outlet and, being warmer than the lake water, rose to the surface. It was followed by boat for the next 12 hours and sampled for dye content (by flourometer) and for total coliforms. Because the initial dye concentration and the coliform content of the slug were known, subsequent dilution of dye in the lake was a measure of physical dilution, and the subsequent disappearance of coliforms could therefore be separated into (a) that attributable to physical dilution and (b) loss arising from other causes. The progress of that loss, corrected for the physical dilution effect and for previously determined background counts of coliforms in the ambient lake water, is illustrated in Figure 26.

The estimated time for 90% reduction was 380 minutes, somewhat lower than results for similar experiments in seawater, but higher than many values reported in polluted rivers or in laboratory tests. The results of such experiments, the authors of Reference 7 believed, are not valid for conditions in a large lake. In dicusssing "die-off" (or better, "disappearance") studies that have considered more than one group of enteric bacteria, the authors concluded that the disappearance results for total coliforms in Lake Michigan "could not be appreciably different in the case of the fecal coliform group."

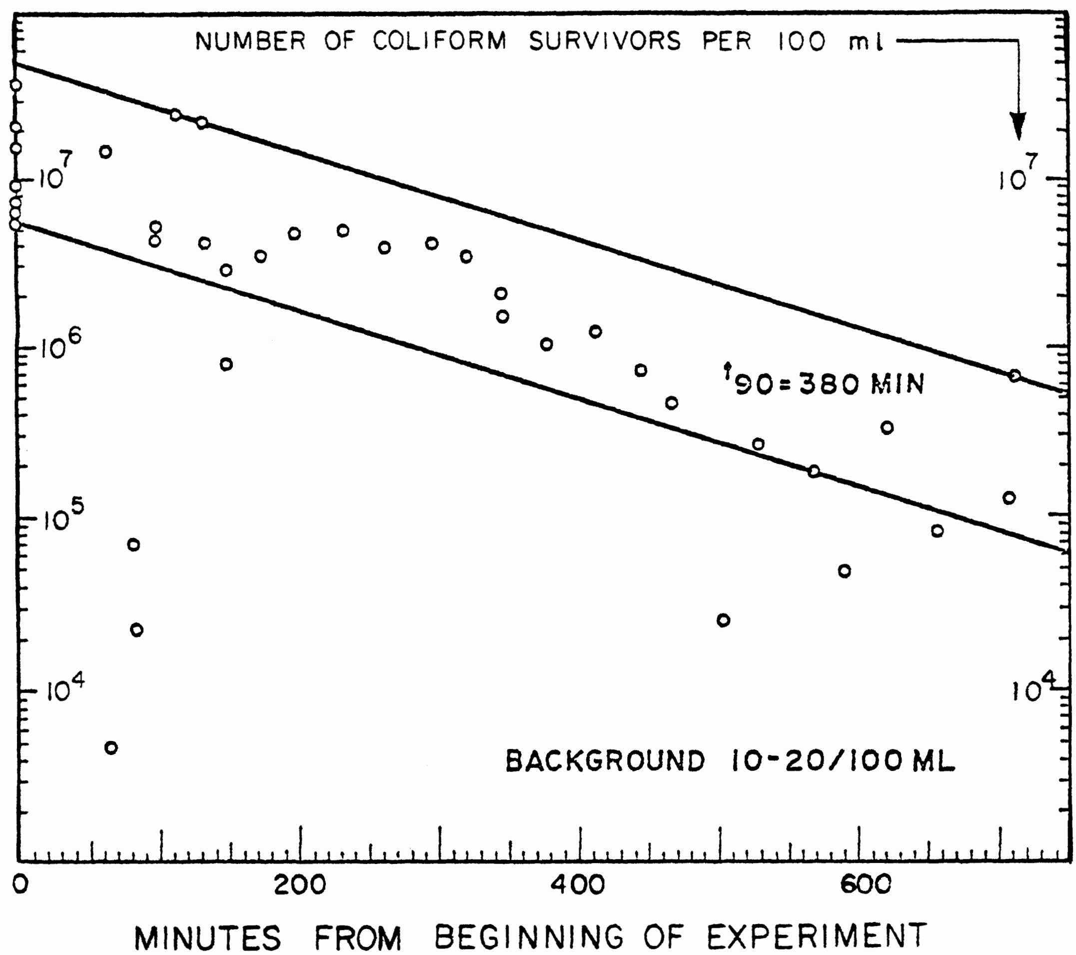

Figure 26. Change in total coliform numbers with time in a dye-labelled batch of unchlorinated sewage effluent release into Lake Michigan at the South Shore Sewage Treatment Plant outfall, July 10, 1974 (Ref. 7). The numbers, which are for surface water, are corrected for the effects of physical dispersion (measured by dye dilution) and therefore provide an estimate of the rate of disappearance due to all other causes. A reduction to 10% of the initial number occurred in 380 minutes.

The result of the coliform disappearance experiment is obviously of great significance in the context of this case, because if the observed logarithmic rate of decrease can be extrapolated unchanged beyond the interval covered by Figure 26, the large coliform population introduced in the unchlorinated slug would be reduced to the Lake Michigan background level (10-20/100 ml, observed at SSSTP) in less than two days by processes other than physical dilution by ambient turbulence. With physical dilution added, the rate of decrease in colifornn concentration would be even greater, and high coliform numbers observed elsewhere along the coastal corridor (including those found in Illinois) could not realistically be attributed to Milwaukee as a source. This conclusion would hold even if the real rate of decrease was only half that experimentally deduced. Not surprisingly, therefore, JVK (as counsel for the plaintiffs) sought to throw doubt on the result. Before examining the arguments, however, the findings of water quality surveys in the coastal corridor from Milwaukee to Waukegan, Ill. (Envirex report, DE 86; Ref. 9) will be reviewed.

Six coastal surveys (tr. pp. 4,083-88: four surveys in 1974, Ref. 9; two in 1976, not reported in Ref. 9) in which FCC and other evidence of "degraded" water quality were measured at 39 points (and at surface, middle and bottom depths) along the coastal corridor demonstrated (Ref. 9):

> "...that the quality of nearshore waters (as close as 500 feet from shore) during dry weather approached the quality expected for open waters of the lake. During wet weather, storm-generated discharges caused a deterioration in water quality for the entire 50-mile stretch of Lake Michigan shoreline examined. The greatest degree of deterioration occurred in the vicinity of metropolitan areas on both sides of the Wisconsin-Illinois state line.
>
> "Wind conditions on the day of sampling were found to have a very significant effect on the water quality results obtained. Westerly and southwesterly wind caused the evidence of water quality deterioration to extend further east from the shore and, to some extent, beyond the breakwater structures. During one lake survey, wind conditions were such that resuspension of bottom sediment caused a substantial increase in turbidity and specific conductance, and a decrease in secchi disk reading in the nearshore waters. These results would be termed 'pollution' by some observers."

The distribution of FCC along the 80 km (50-mile) shore during the "wet weather" surveys was "sawtoothed" (tr. p. 4,083), as illustrated by the example in Figure 27. Composite exhibits used in court (e.g., Fig. 28) contrasted the FCC distributions in "dry" and "wet" surveys.

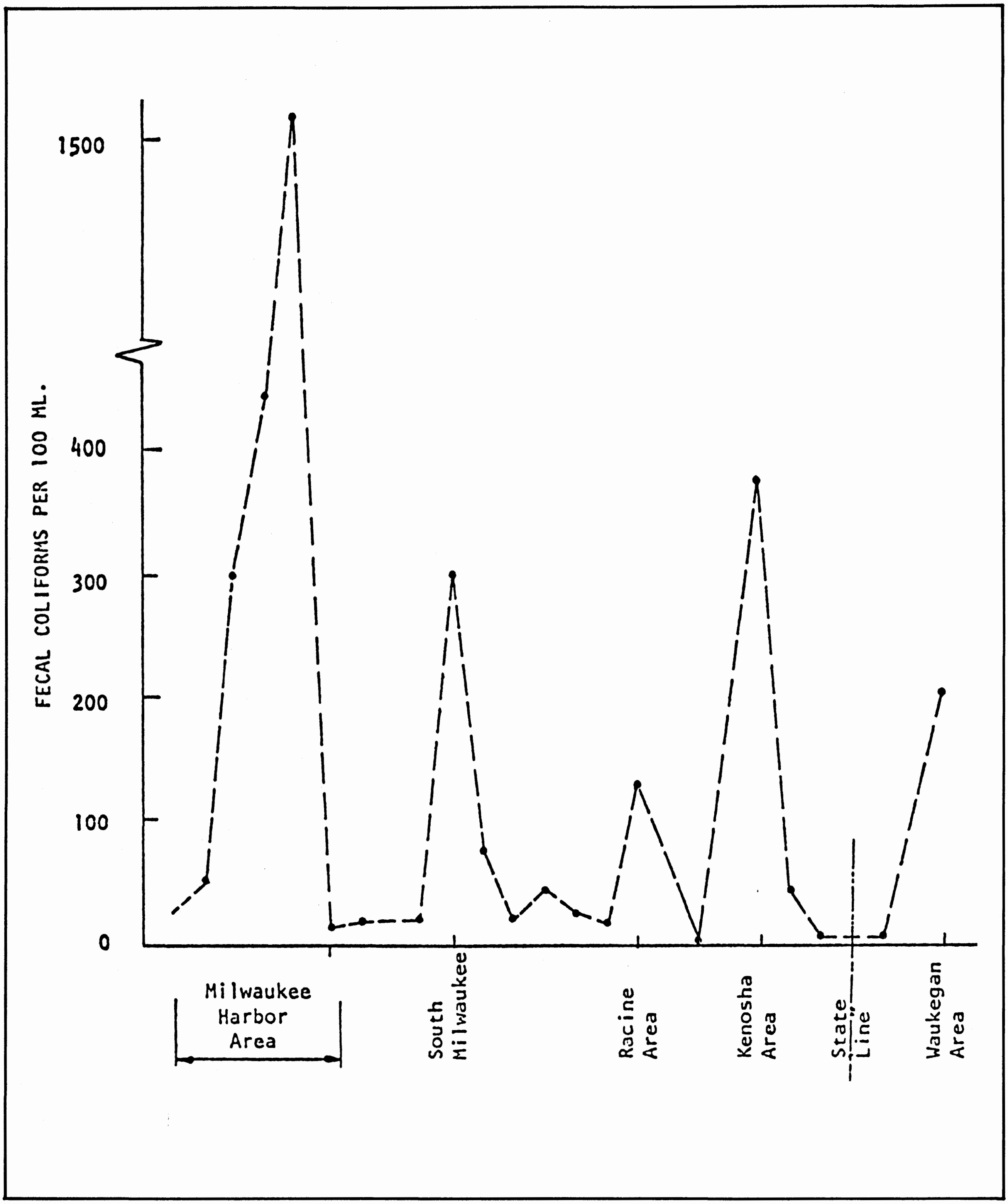

Figure 27. Fecal coliform counts per 100 ml along the southwestern shore of Lake Michigan, Milwaukee to Waukegan, Oct. 14, 1974, six hours after heavy rainfall. Shown is the average of a count taken at 250 feet and one 500 feet from shore, each 2 feet below the surface (source: Ref. 9; DE 86).

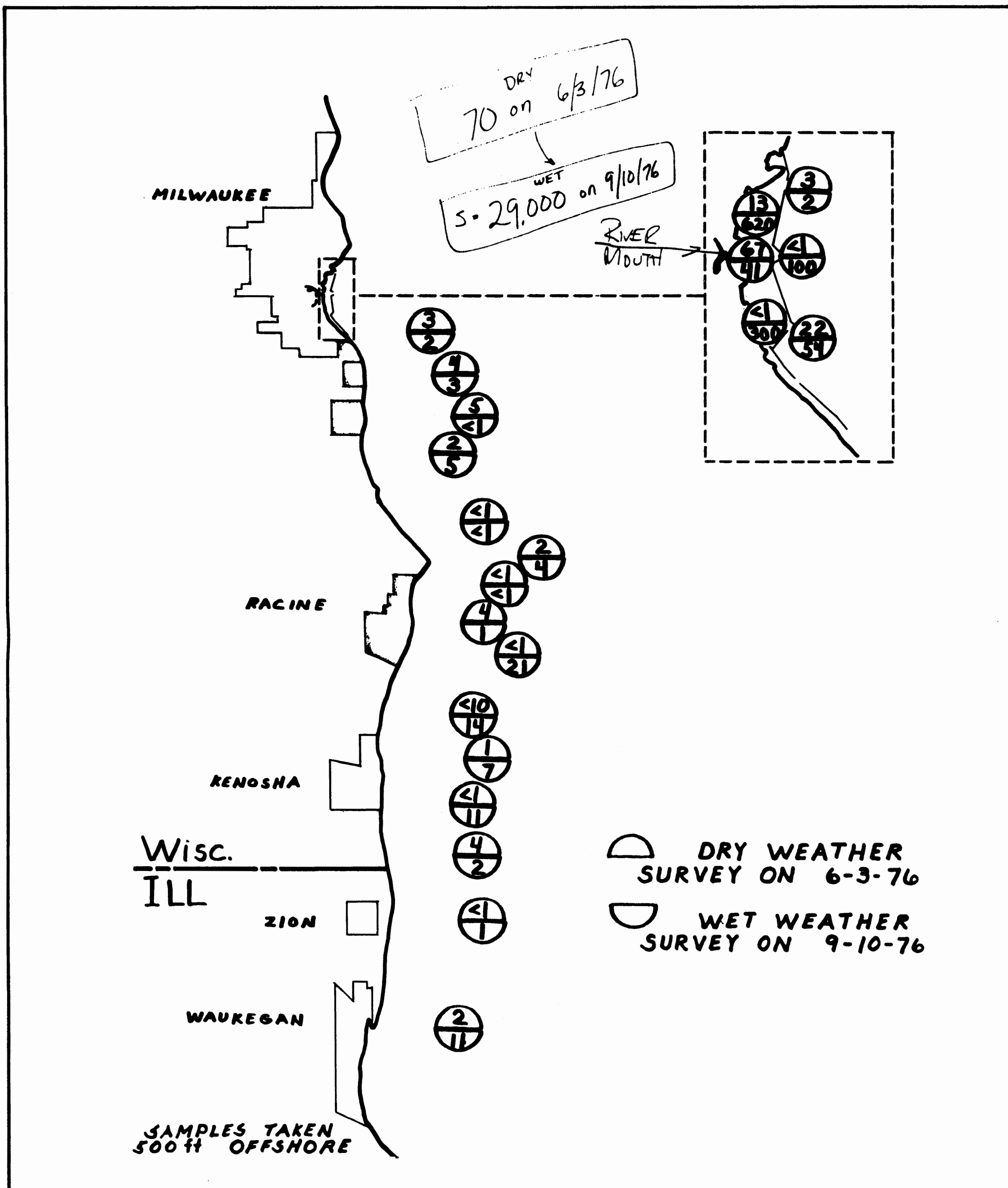

Figure 28. Copy of Defendants' Exhibit 490 (original in color): Fecal coliform counts per 100 ml in surface samples 500 feet offshore in Lake Michigan at various stations between Milwaukee Harbor, Wis., and Waukegan, Ill. Numbers in the upper and lower semicircles are for dry and wet weather surveys on June 3, 1976, and September 10, 1976, respectively (source: Envirex Report 1976).

The importance of <u>local</u> sources in determining the distribution of water quality indices along the coastal corridor in question was confirmed by an observer not in court -- that is, NASA's LANDSAT satellite on July 22-23, 1977 (Fig. 29), four and five days after the heavy rainfall on July 18 that produced the turbid plumes at Milwaukee illustrated in Figures 7-9. The cloud of turbid water could still be seen July 22 outside Milwaukee Harbor, from which it had not traveled very far at that time. Similar, but smaller, clouds could be seen in the coastal waters off Racine and Kenosha, Wis., and off Waukegan, Ill. The interpretation of such clouds of turbid water as products of river and harbor flushing after heavy rainfall is supported not only by the rainfall record, but also by the wind data.

For example, the wind at Milwaukee (Mitchell Field) was southwesterly (i.e., offshore) from July 18 until noon on the 21st, when it changed direction and blew from the north-northeast (i.e., onshore) until midnight on the 22nd. Wind speeds of 10-13 knots persisted from noon on July 21 until noon the next day. Waves produced by that onshore wind extensively resuspended nearshore sediments, which are seen as a strip of turbid water moving south around Wind Point on July 23. In the LANDSAT photograph, that very turbid strip is darker in appearance than the flood-produced clouds seen outside individual harbor mouths, including one in Illinois waters off Waukegan. (This evidence was not produced in court.)

Figures 7, 8, 9 and 29 cover a five-day interval after a major rainfall event of the kind that various witnesses had supposed could generate a south-moving plume, but no such plume is visible in the photographs for that episode. The distribution seen better fits the picture drawn by <u>A. Zanoni</u> under direct examination by Moerke for the defendants (tr. pp. 4,357-58):

> "From these four shore surveys conducted both during dry weather and wet weather, I was not able to discern in any way, based on this data, the concept that a slug of pollutants was originating from the Milwaukee metropolitan area and that this slug of pollutants was discernibly measurable all the way down along the shore; in other words, that we can monitor and follow its effect all the way down the shoreline. I saw no evidence of this in my interpretation of the data. I saw basically this sawtooth pattern."

Various weaknesses of the shoreline surveys were brought out under cross-examination of Zanoni by JVK. The frequency of the sampling was far too low (four surveys in 1974, two in 1976) to describe the time history and movement of pollution indices, and the witness admitted that he did not know whether his "wet weather" surveys coincided with peak river flow or with peak pollution (tr. pp. 5,340-41). Nevertheless, the concept of "sawtooth" distribution of pollution indices coupled to population distribution was not seriously challenged because the plaintiffs had carried out no surveys themselves. Better surveys could have been designed -- concentrating in detail, for example, on transport across selected sections perpendicular to the shore at Wind Point and north and south

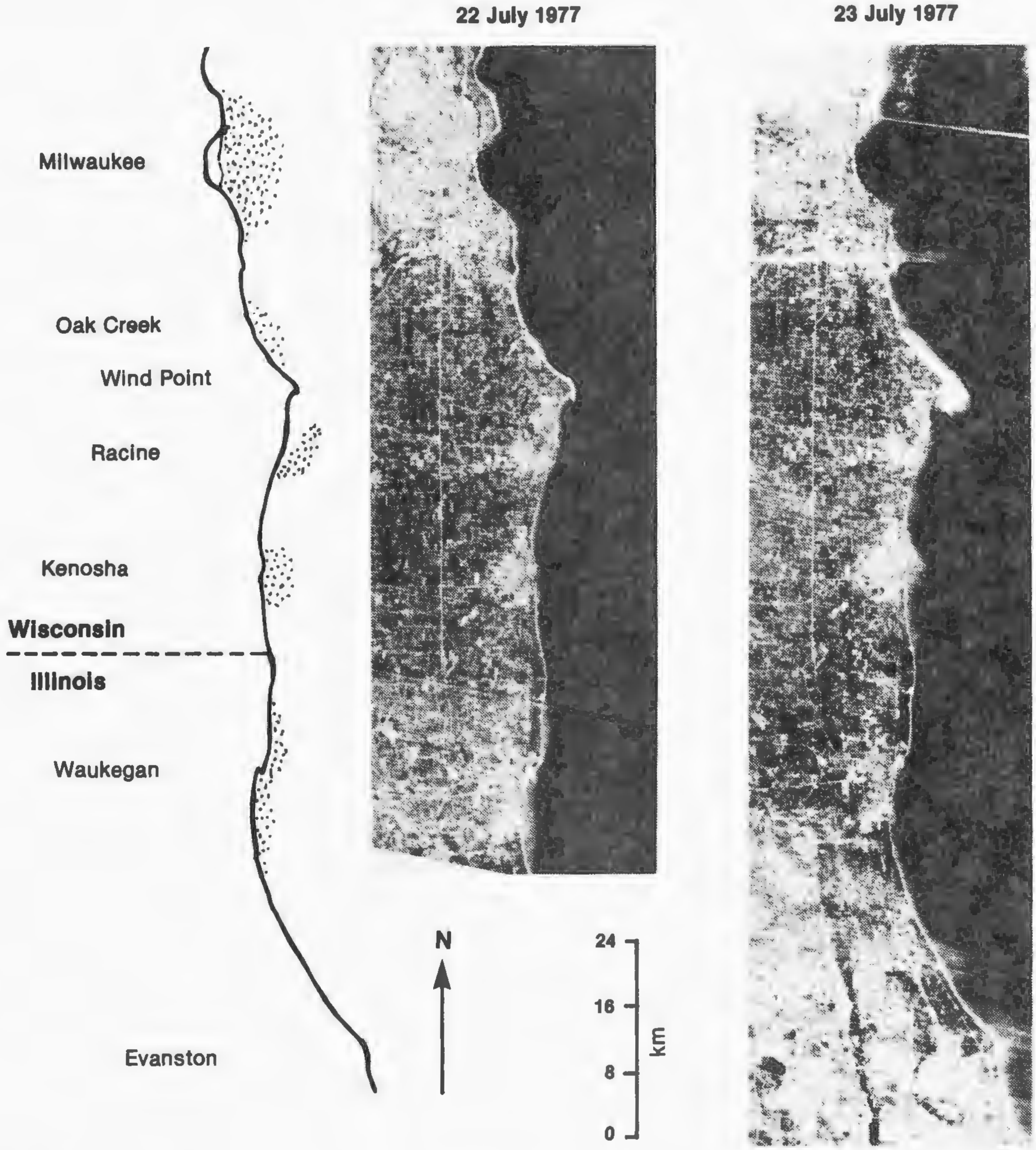

Figure 29. LANDSAT images of the southwestern shoreline of Lake Michigan on July 22 and 23, 1977 (i.e., 4 and 5 days after the July 18 flood illustrated in Figs. 7-9). Resuspension of nearshore sediments (incipient on the 22nd, fully developed on the 23rd), seen as a strip of "white water" moving southward around Wind Point, was brought about by strong north-northeast winds on July 22. Also seen on July 22 were patches of faintly cloudy water near each of the cities labelled in the figure and attributable to the turbid plumes that entered the lake July 18 and 19 after the flood. Those patches, very faint in the LANDSAT images, are shown as dotted areas in the sketch on the left. (Source: NASA.)

of Waukegan, Ill. -- but they would have been much more costly. A similar conclusion will be drawn with respect to the Cladophora surveys. However, it is of little value to speculate, with hindsight, whether additional effort could have won the defendants their case.

The coliform disappearance experiment, which, as described above, was critical to the defendants' argument, came under further scrutiny during direct examination of H. H. Carter by M. J. McCabe, counsel for the defendants, who asked whether those coliforms that do not settle or die or are eaten by predators "will dilute at the same rate that the dye dilutes?" Carter's answer (tr. p. 8,600) was:

> "Presumably [a word to which JVK raised immediate objections], the bacteria are distributed in the effluent. They are initially attached to the larger particles, and these probably fall out first, early in the experiment. But then they become attached to fine-grain material, and they stay in suspension and move, much like the water. So they should follow anything that is in solution."

He also referred to an earlier test (July 16, 1974, at SSSTP), which illustrates the difficulties of carrying out this experiment (tr. p. 8,625):

> "So what occurred with the first test was that, just prior to the 16th, the winds had been out of the northeast, and we had a considerable quantity of warm water lying on the western shore. Water temperatures on that day were between 68 and 70 degrees Fahrenheit from top to bottom. We didn't count on the fact that the primary effluent had a temperature of about 61 to 62 degrees, and when it came out through the diffuser, it just ran along the bottom. It never rose to the surface at all, and we had a very difficult time sampling it."

Cross-examination of Carter by JVK, counsel for the plaintiffs (tr. pp. 8,740-50), concentrated on the fact that only 15 seconds elapsed between the time that chlorination was halted and dye injection began. The dye was then injected for 4.5 minutes, and at the end of that time, another 15 seconds elapsed before chlorination was resumed. During its 15-minute passage to the lake, the dye slug experienced some dilution as a result of turbulent mixing in the pipe with undyed effluent ahead of and behind the slug. That dilution factor was measured and applied as an equivalent reduction in coliform concentration arriving at the outlet, and that reduced concentration was then taken as the intial in-lake concentration for the experiment. Carter admitted that he did not determine whether there was any residual chlorine in the effluent ahead of and behind the dyed slug, and further he was forced to admit that if some chlorine had penetrated the dyed slug during its passage to Lake Michigan, some of the coliforms could have been under stress or even moribund by the time they reached the lake.

JVK, cross-examining Carter (tr. p. 8,750):

> Q. "Mr. Carter, I am asking you to accept the following factual premises. If the chlorine in the effluent reaches the center of the dye patch, and if chlorine has some bactericidal effect -- I am not quantifying the amount -- isn't it correct that the amount of coliform that you or that Envirex measured in the lab, that you found in the lake, and the consequent calculations of the die-off would be affected by the bactericidal effect of the chlorine?"
>
> A. "If there were such an effect, it would affect our answer, no doubt about it."
>
> Q. "So that to the extent that the chlorine had a bactericidal effect, your estimate of die-off would be too rapid, isn't that right?"
>
> A. "That's correct."

It was also agreed (JVK, tr. pp. 8,782, 8,858-59) that on that calm day, coliforms attached to particles could have settled below the three-foot sampling depth and that, except at the outset of the experiment, no measurements were made to confirm that the water column remained stratified. Data interpretation was also criticized by JVK (tr. p. 8,855), because in estimating the slope of the trend by eye, some aberrant points had been rejected (see Fig. 26). If an appropriate statistical procedure had been applied to include the rejected points, and if different assumptions had been made about the initial conditions, the data would have fitted a line of lesser slope corresponding to a less rapid coliform disappearance rate. Carter replied that the rejection of aberrant points (NOTE: the scale in Fig. 26 is logarithmic) represents sound professinoal judgement in light of the high variability of coliform counts. Also, in his judgement, the effect of chlorine invasion in the pipe could be neglected.

4.3 Comments on the Coliform Disappearance Experiment and on the Neglected Role of the Sediment as a Transport Vehicle

The significance of the conclusions drawn from the experiment emerged when Carter used the Pritchard-Okubo diffusing plume model (described earlier), assuming a range of diffusion velocities and a range of coliform "die-off" (disappearance) estimates, to calculate the FCC at the Wisconsin-Illinois state line in the case of a 10-year (13,000 cfs, 368 m^3s^{-1}) and a two-year storm (7,000 cfs, 198 m^3s^{-1}) at Milwaukee (DE 1164, tr. pp. 8,680-89).

Carter's conclusions, summarized in Table 1, are revealing. For the diffusion velocity, w, Carter selected a high value (1.25, determined in Lake Michigan by Okubo; Ref. 15) and a low value (0.33, Lake Ontario, April, May, July, October, 1965, report by Pritchard and Carpenter to Rochester Gas and Electric) and also took the geometric mean (0.76) of those values. (Values estimated from dye dispersal during the SSSTP experiment were 0.6 to 1.5.) For the t_{90} values (the time for a 90% "die-off" of coliforms), he again picked a high value (96 hours; based on earlier testimony in this case by E.D. Geldreich concerning "jug" experiments in the laboratory with a t_{90} of 2-4 days, tr. p. 3,173) and a low value (6.3 hours; determined in the SSSTP experiment reviewed here), and also took the geometric mean (31 hours). Table 1 shows that the FCC at the state line is inversely proportional to $\underline{w}$ but much more strongly dependant, in a nonlinear fashion, on the value of t_{90}.

TABLE 1
FECAL COLIFORM COUNT AT THE WISCONSIN-ILLINOIS STATE LINE
PREDICTED BY PRITCHARD-OKUBO STEADY-STATE PLUME MODEL
(per 100 ml)

Diffusion velocity (cm s^{-1})	90% die-off rate (t_{90}) in hours		
	96	31	6.3
0.33	377 [203]	36 [20]	< 1 [< 1]
0.76	164 [88]	16 [9]	< 1 [< 1]
1.25	100 [54]	10 [5]	< 1 [< 1]

In each case it is assumed that (1) the flow out of Milwaukee Harbor is steady at 10,000 or 7,000 cfs (corresponding to a 10-year or a 7-year rainstorm), (2) the fecal coliform count in that flow is 10,000 per 100 ml and (3) the plume enters a steady southward current of speed 36.3 cm s^{-1}. Bracketed values refer to the 2-year storm (7,000 cfs, 198 $m^3 s^{-1}$). (Source: H.H. Carter, DE 1164).

In DE 1164, Carter labels the regions to the left and right of the middle column in Table 1 as "highly improbable" and "most probable," respectively. It should also be noted that the assumed velocity of 36 cm s^{-1} for a persistent Lake Michigan current is improbably high. A realistic choice of half that speed would greatly reduce FCC at the state line. More recent experimental data from dye plumes in the Great Lakes (Ref. 21) also distinguish between diffusion relative to the center of the plume, as was done in Table 1, and total (or absolute) diffusion, which includes the effects of meandering behavior imposed by large eddies. Diffusivity estimated for absolute diffusion is about double that estimated for relative diffusion. Allowing for this would also reduce FCC at the state line.

I have described the coliform disappearance experiment and the criticisms leveled at it in some detail not because that experiment illuminated one of the principal limnological themes of the trial, but because it points to a neglected, yet important, transport vehicle: storm-mobilized bottom sediment carried by currents during resuspension events. The FCC, in spite of variability inherent in the method, is a sensitive indicator of pollution sources and pollution transport by water and by sediment. Although it was not explored during the above experiment, it is probable that much of the *in situ* disappearance of coliforms in Lake Michigan arose from settling (attached to particles) and from ingestion of free and attached bacteria by filter-feeding zooplankton. Through settling in calm weather, the particles contribute to the nearshore sediments, as do the faster-settling zooplankton fecal pellets, which perhaps contain some surviving coliforms. Wave action during episodes of strong onshore wind resuspends, reworks and sorts the nearshore sediments, inducing a slow, hopping mode of transport alongshore and an offshore drift of the finer suspended particles into deeper water, where eventually they settle and become buried in deep-lying sediments. Finely suspended sediment also increases the density of the ambient water mass, sometimes to the point where it sinks and flows along the lake bed into deeper water as a turbid (nepheloid) layer (Ref. 22).

Many pollutants -- including toxic organic chemicals, metals, bacteria and viruses -- are attached to or associated with particles, or come to be associated with particles, even though those pollutant species enter by way of water (rivers, effluent pipes) at the lake edges or by way of the atmosphere at the lake surface. Therefore, the extensive resuspension and sorting of nearshore sediments, repeated with every north-to-northeast storm along the Wisconsin-Illinois littoral, must have a profound cumulative effect on pollutant transport and on nearshore water quality. Much of the resuspended material is mineral, derived from progressive erosion of the glacial deposits that make up much of Lake Michigan's shoreline. When the sediment cloud settles after a storm, several pollutant species are probably carried to the bottom, thereby cleansing the water column.

The considerable extent of such a resuspension event after a strong northeast wind is illustrated by the satellite photo in Figure 30 (Aug. 21, 1973). The outer edge of the turbid water mass, lying along the shore from Milwaukee to Chicago, coincides fairly closely with the 9 m (30-foot) depth contour. The area of resuspension in shallow water off Chicago and its northern suburbs is extensive, and one may speculate that such resuspension events will exert a direct influence, beneficial or otherwise, on the water quality of the beaches and water intakes of that region.

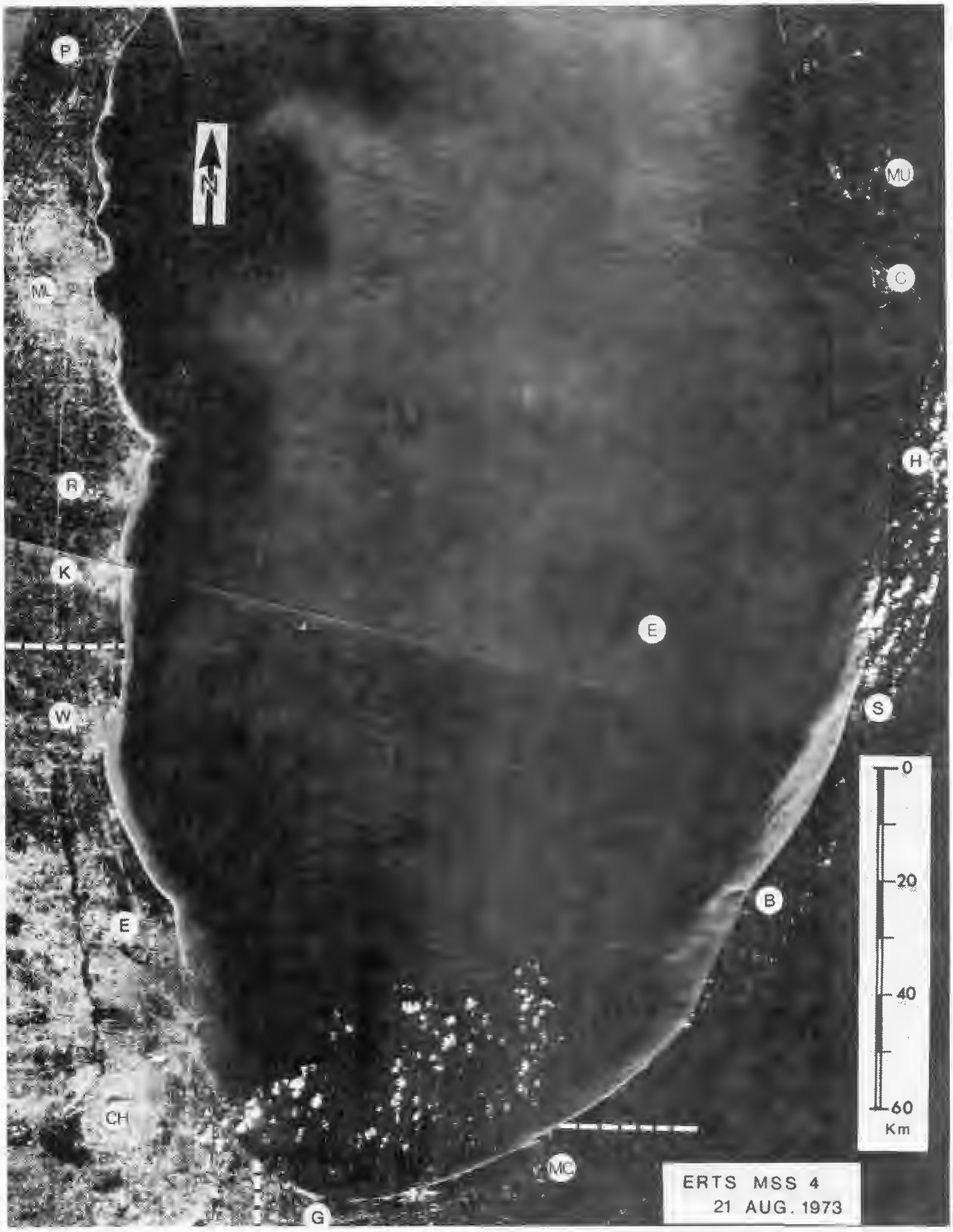

Figure 30. ERTS satellite image of southern Lake Michigan, August 21, 1973, after northerly wind. Letters refer to principal cities. Resuspension of nearshore sediments is seen south of R and S; E marks a presumed eddy; further details in text (source: NASA).

The wind that led, through wave action, to resuspension of shallow-water sediment in Figure 30 also brought about extensive upwelling of cold water along the eastern shoreline (Ref. 23, which contains meteorological data). A dynamic circulation process in open water, involving eddies of size order 10 km, is illustrated by the swirls of white water offshore in Figure 30. This "whitening" (appearing in the original print different in texture from the turbid zone of resuspension near shore) has been attributed (Ref. 24) to the precipitation of calcium carbonate, associated with high water temperature and algal uptake of dissolved carbon dioxide. The whitening is seen only in summer and only in those Great Lakes (Michigan, Erie, Ontario) that are close to the saturation point for calcium carbonate and in which algal production is high.

4.4 Evidence from the Distribution of Bottom-Living Animals

As shown above, the pattern of contamination (or lack of it) disclosed by water sampling is subject to the changing influences of wind, currents, wave action and turbulent mixing. Therefore, biologists have looked for bottom-living organisms that, because they are relatively fixed in location, might be used to "indicate" an average degree of pollution of the overlying water at that location. An early attempt along these lines was made (Ref. 25) to use the bottom-living amphipod *Pontoporeia* as an indicator of "clean" water and certain oligochaete worms as indicators of "polluted" water in Lake Michigan. The distribution of the abundance ratio of amphipods to oligochaetes inside and outside Milwaukee Harbor is illustrated in Figure 31. That pollution index is highest inside the harbor and in a restricted "tongue" outside the main entrance. But the distribution probably depends not only on the organic nutrients supplied by pollution, but also on the physical properties of the substrate, on current patterns, on temperature and on how often the substrate is distributed or swept clear by wave action or by ships.

Through their witness R. G. Otto, the defendants (direct examination by McCabe, tr. pp. 10,040-131) presented a similar argument, using the amphipod *Pontoporeia affinis* and the oligochaete *Stylodrilus heringianus* as "clean water" indicators, and the oligochaetes *Limnodrilus hoffmeisteri*, *Peloscolex multisetosus* and *Tubifex tubifex* as indicators of pollution.

The results in Table 2 indicate heavy pollution inside Milwaukee Harbor, much less outside, minimal pollution at the state line, and a slight increase in pollution off Waukegan (south of the state line). A more thorough analysis, as A. M. Beeton pointed out under direct examination by JVK for the plaintiffs (tr. p. 12,833), should take the distribution of substrate properties into account. Beeton also suggested that the benthos off Waukegan, Ill., were occasionally swept away by wave action (tr. p. 12,961, questioned by JVK):

> Q. "You and I had a case in Waukegan, did we not, involving United States Steel in Waukegan?"

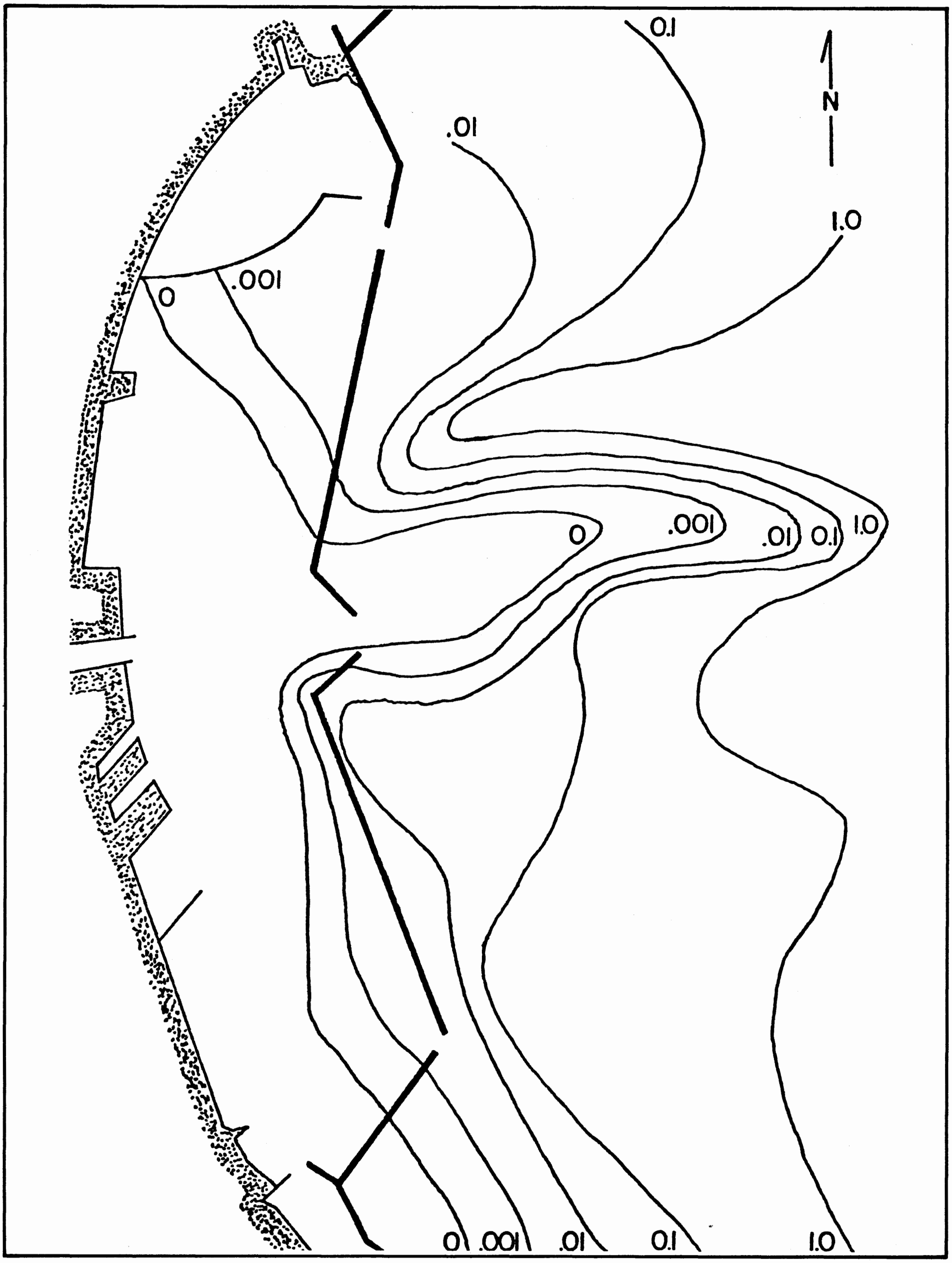

Figure 31. Isopleths of the ratio of the number of amphipods to the number of oligochaetes (details in text; from Ref. 25).

A. "That is right, and there, although we knew there were a lot of things coming out of that discharge from that plant, we couldn't find anything in the benthos to demonstrate that. This is because the sediments, any deposits from that plant, were just swept away by currents and wave action...Amphipods have a much greater possibility of being moved by the current because they spend part of their time at the muddy water interface. Some kinds of amphipods, such as Pontoporia affinis, are known to migrate up off the bottom. At times they are found clear up at the surface. Even though they are a benthic organism, they do migrate off the bottom, so there is a good opportunity for them to be affected by any water movement."

Q. "Doctor, from the data at Zion that you have examined and the data in Hausman, do you think it scientifically appropriate or does that data show any way that Milwaukee is or is not affecting the water quality of Lake Michigan in Illinois waters?"

A. "I don't think you can draw a conclusion."

Q. "Either way?"

A. "Either way."

Q. "Would it be fair to say that one of the problems in benthic analysis on the western shore is because of this scouring effect in many locations?"

A. "I think the physical factors are very important."

TABLE 2
ABUNDANCE OF SELECT "INDICATOR" ORGANISMS
(number per m^2)

Data Sources:	Ref. 26		Ref. 27 (DE 1319)	
	(1)	(2)	(3)	(4)
Location:	Inside Harbor	Outside Harbor	State Line	Offshore Waukegan
Depth (m):	7.3-11.6	4.3-16.2	9-12	9-12
Taxon	(number per m^2)			
Pontoporeia affinis	0	7 (Amphipoda)	3303	1590
Stylodrilus heringianus	15	108	180	370
Limnodrilus hoffmeisteri	22,856	99	55	1013
Peloscolex multisetosus multisetosus	16,123	19	1	329
Tubifex tubifex	13,616	17	1	1

4.5 Evidence from the Distribution of Dissolved Substances

Another sensitive indicator of recent pollution from untreated and treated domestic sewage and from certain industries is the ammonia-nitrogen content, which was not systematically reviewed during the trial. The U.S. EPA (then the Federal Water Pollution Control Administration, Region V, Chicago) carried out extensive surveys in Lake Michigan during 1962-63 (Ref. 28). The lake was divided into blocks, of which there were seven in the 10-mile-wide coastal strip from Milwaukee to Indiana. The 1962-63 average values of NH_3-N are presented in milligrams per liter in Figure 32. Near Milwaukee and near Chicago, the concentrations were in the 0.09 to 0.14 mg/l range. In the intervening stretch, the concentration was less (0.02 to 0.08), while the highest average concentration (0.15-1.1) was found just south of Chicago near Indiana Harbor. That distribution does not point to Milwaukee as an important pollution source for Chicago. However, results from a forthcoming EPA report (Ref. 29) do show higher concentrations near Milwaukee than elsewhere in southern Lake Michigan on one occasion (August 20-25, 1977; Fig. 33) but not on another (June 11-16, 1977). Figure 33 suggests that ammonia distribution is very variable, with the highest concentrations found nearshore. In general, the concentrations were much lower than those found in 1962-63.

4.6 The Cladophora Story (wherein a law clerk doubles as a weekend botanist)

Other chemical evidence of pollution, or of sources of treated sewage, is provided by the distribution of plant-nutrient elements contributing to eutrophication. In Lake Michigan, the most important of these elements is phosphorus, because its availability sets a limit to the growth of the algae (planktonic and bottom-attached) that is at the basis of biological production in the lake. Other important nutrients are nitrate and, in particular, silicate. Again, the 1962-63 EPA survey (Ref. 28) showed higher average concentrations of soluble phosphate near Milwaukee and near Chicago and lower concentrations in between (Fig. 34). But more detailed surveys off and to the south of Milwaukee Harbor (Ref. 30; PE 144) showed a more complex picture: high concentrations of soluble reactive and total phosphorus inside the harbor and near its mouth, and (on one occasion) an isolated "slug" of high-phosphorus water about 9 km to the south (Fig. 35).

Because the dissolved chemical species follow the complex patterns of the lake's circulation, it would be useful to have an attached plant as an indicator of the average distribution of nutrient-enrichment supplies (largely derived from domestic sewage) along the Milwaukee-to-Illinois shoreline. According to defendants' witness G. P. Fitzgerald, such an indicator in Lake Michigan is the attached alga Cladophora glomerata. It grows on rocks, piers and firm surfaces, but not on shifting sand. Its abundance is a sign of nutrient enrichment (eutrophication), and its phosphorus content in culture experiments (Ref. 31; DE 350) showed a nearly linear relationship over the range 0.05 to 1.2 mg/l PO_4-P in the culture medium (Fig. 36a). In the field also, for example, in Green Bay (Fig. 36b), the phosphorus content of the Cladophora (percent dry weight as P) mirrors the phosphate concentration in the water along the gradient from high values in the Fox River input to low values at the confluence with Lake Michigan (see also Ref. 32; DE 346; tr. p. 8,000: note the high value [0.52%] near Algoma, a local source of sewage-derived nutrient).

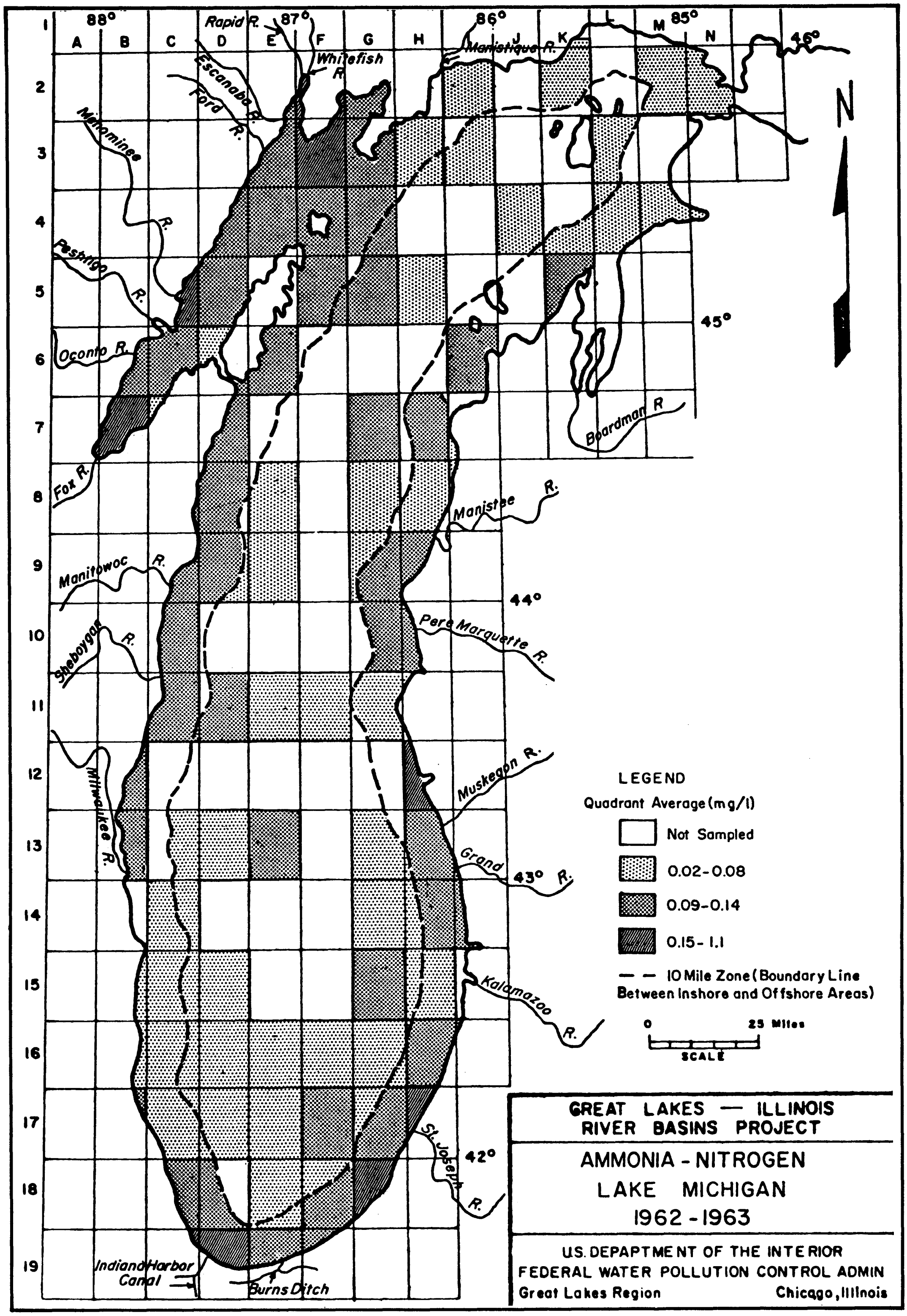

Figure 32. See legend in bottom right-hand corner (source: Ref. 28).

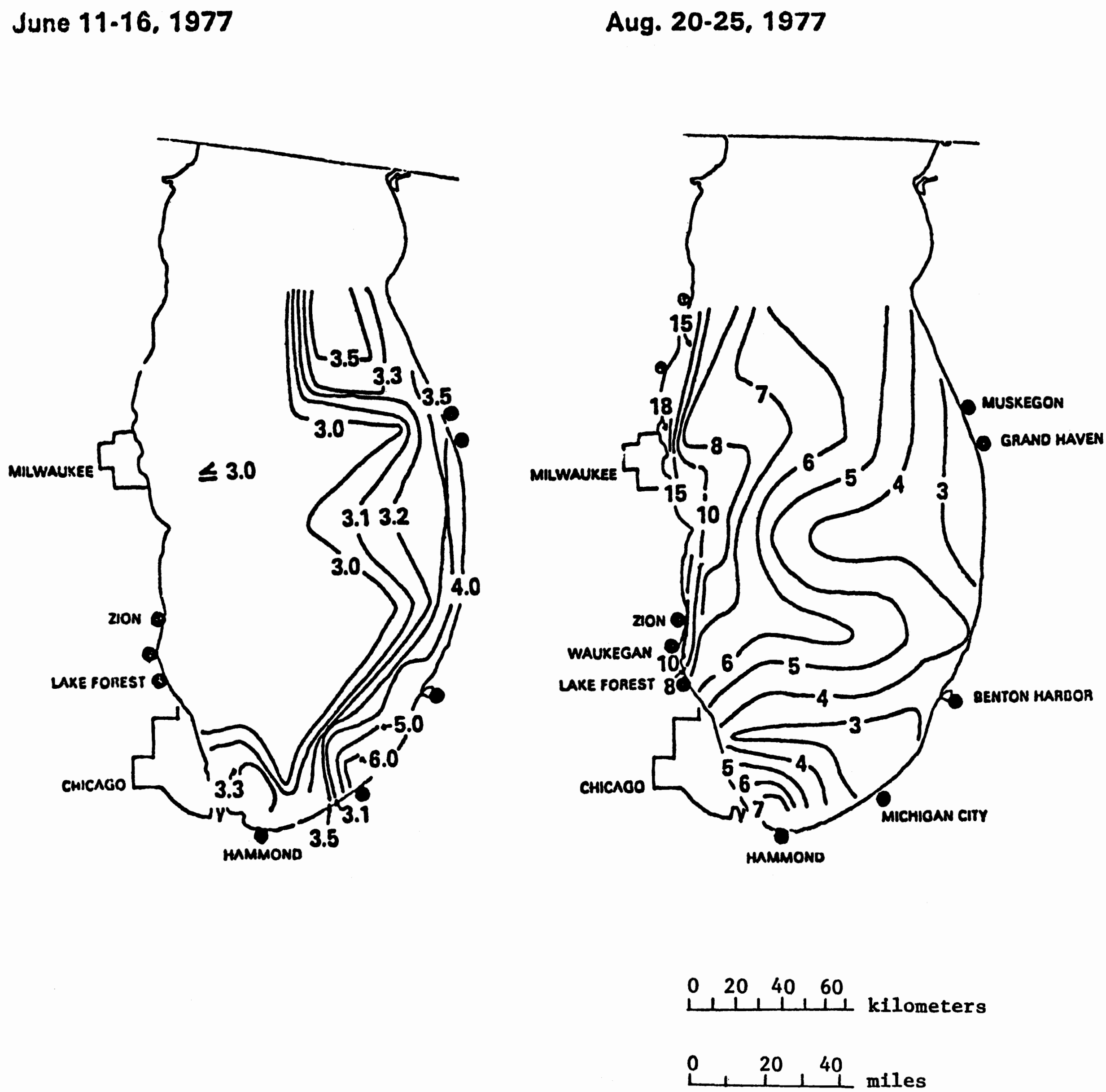

Figure 33. Distribution of total ammonia (ug/l, NH_3-N) in the upper 20 m of southern Lake Michigan, June and August 1977 (assembled from draft figures for Ref. 29 supplied by EPA Great Lakes National Program Office, Chicago).

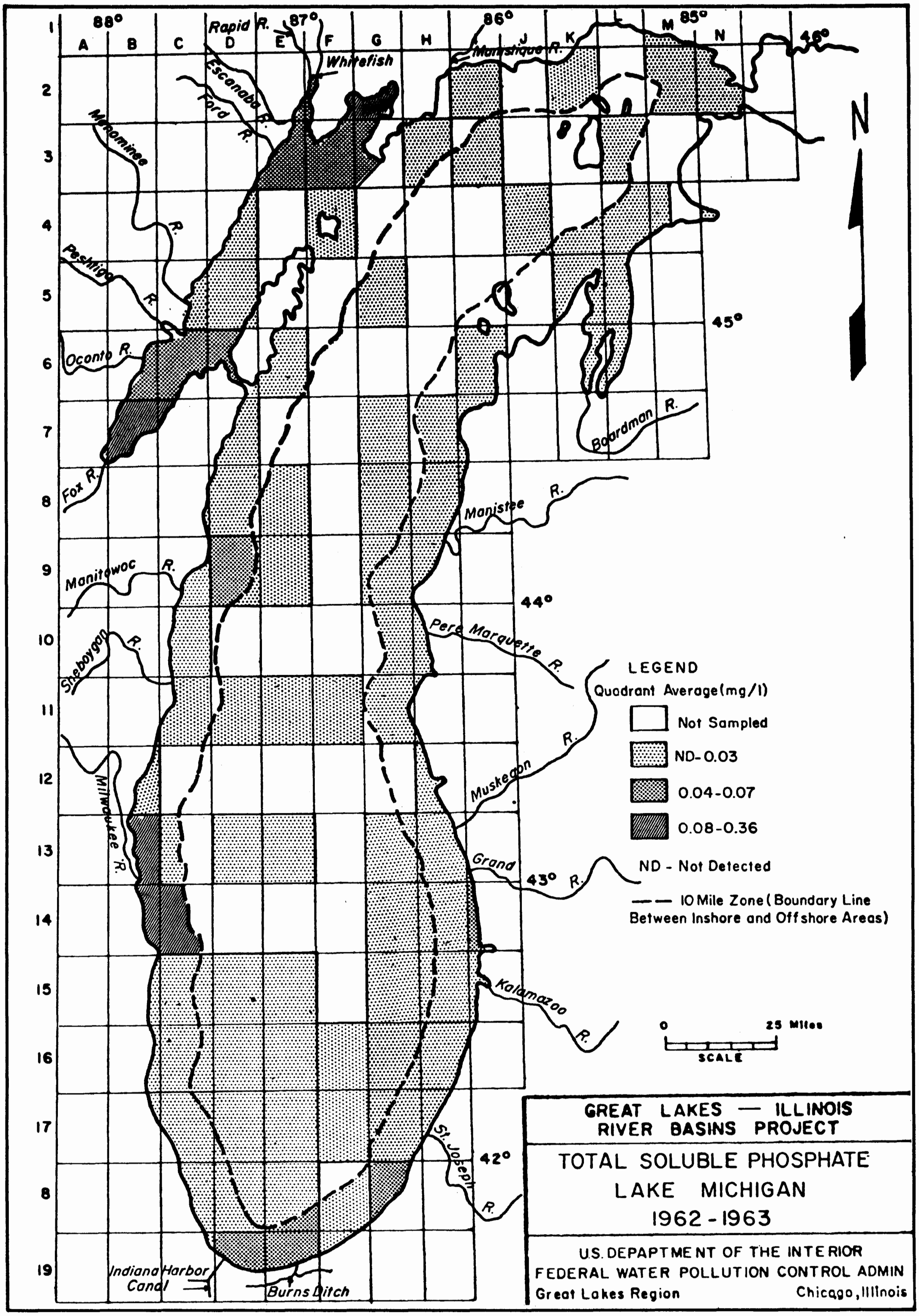

Figure 34. See legend in bottom right-hand corner (source: Ref. 28).

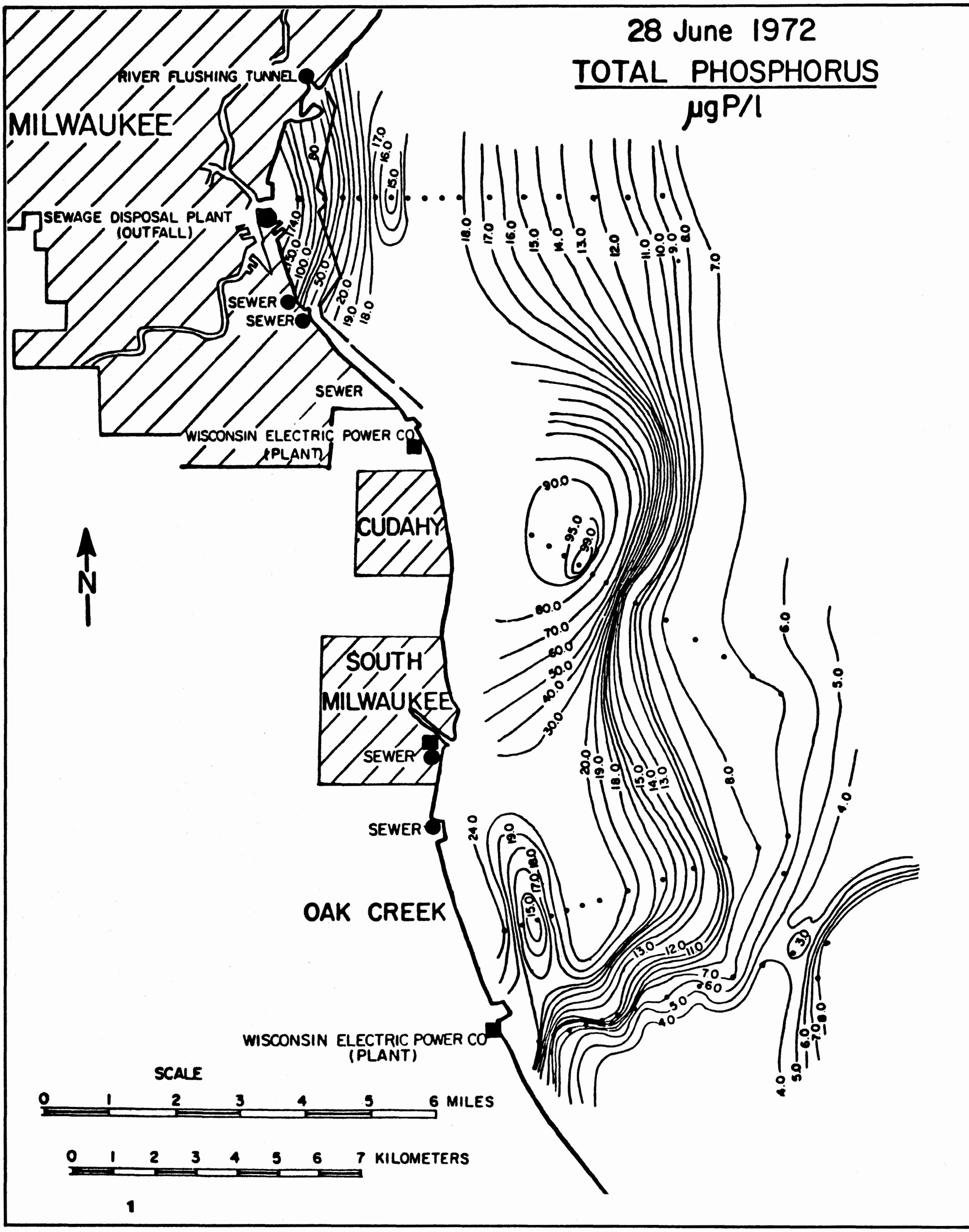

Figure 35. Lake Michigan: distribution of total phosphorus, June 28, 1972 (source: Ref. 30).

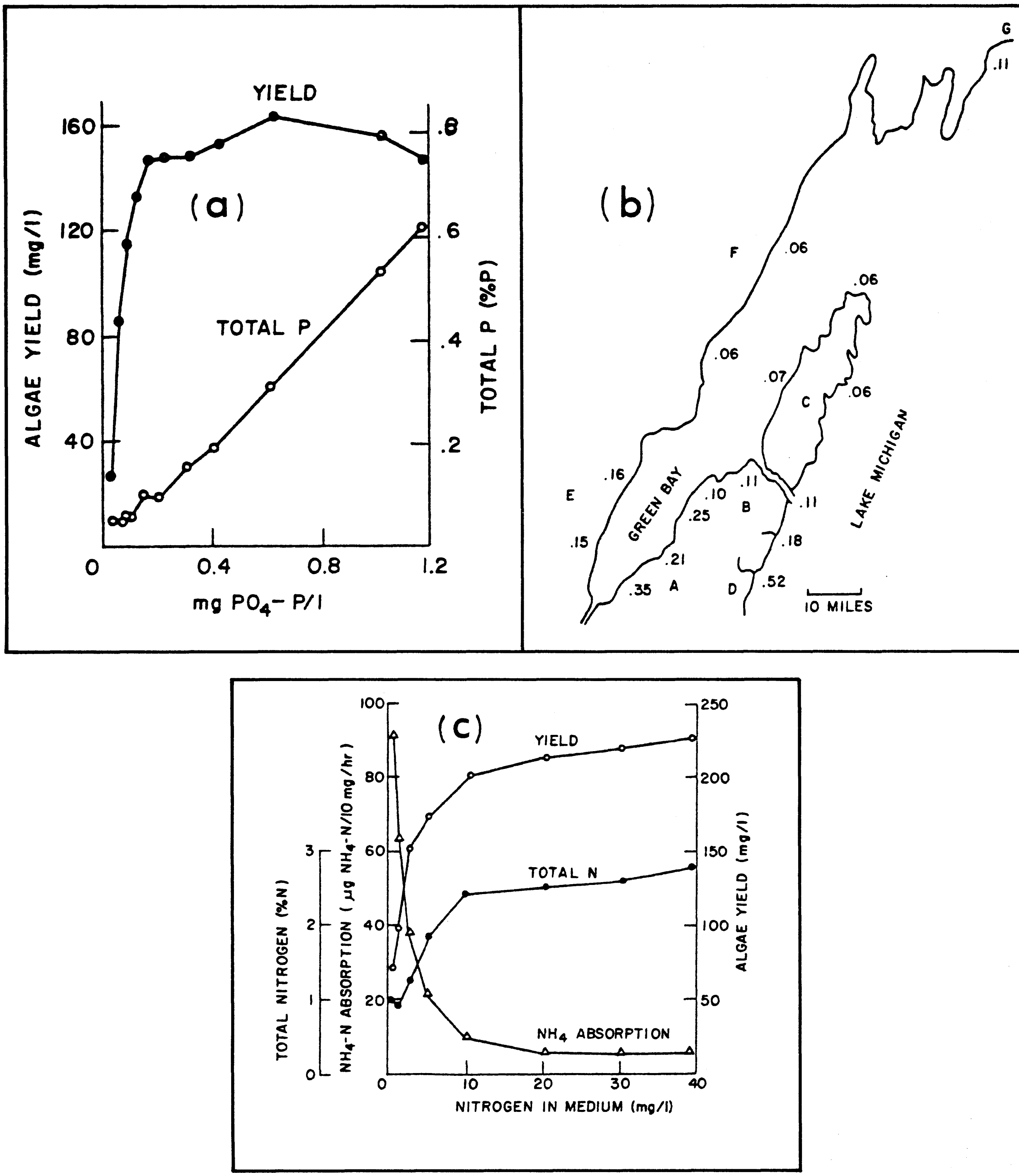

Figure 36. (a) Comparison of yield and total P concentration of Lake Michigan Cladophora sp. after a 17-day culture period insolutions varying in P concentration; (b) distribution of Cladophora total P in Green Bay and adjacent Lake Michigan; (c) comparison of yield, total N in the algae and rate of NH_4-N uptake in the dark when Cladophora sp. was grown at different solution concentrations on NO_3-N (source: Ref. 31, 32; DE 350).

When phosphorus is not a limiting factor, the growth rate of Cladophora is regulated by the inorganic nitrogen supply (ammonia and nitrate) when the concentration in the medium falls below 15 mg/l (as N; Fig. 36c). A sensitive bioassay test (Ref. 33) for the status of nitrogen nutrition is the uptake of ammonia by Cladophora in the dark. Nitrogen-starved cells take up the ammonia rapidly. Alkaline phosphatase activity and the amount of orthophosphate extracted by boiling water are also sensitive tests for the status of phosphorus nutrition. The color of the alga further provides a rough index of nutrient status: green means rich; yellow means poor.

With these results in mind and armed with the cited field techniques for bioassay, Fitzgerald surveyed 23 stations along the coast from north of Milwaukee to Waukegan (south of the state line) on September 29, 1976 (DE 1145), and again in October (DE 1146; results from a 1974 survey were also presented, as DE 504). He testified on behalf of the defendants as follows (from DE 1145; see also tr. pp. 8,112-16):

> "Small amounts of Cladophora sp. (about one handful) were collected from the rocks or cement piers along the shore of Lake Michigan at 21 sites from northern Milwaukee County to Waukegan, Ill. It was significant that no algae could be found at an area with suitable rocks in Ozaukee County (Virmond Park), this indicating there was probably a lack of nutrients in the area. Nitrogen, phosphorus and iron are the nutrients that have been shown to limit the growth of algae in Midwestern lake waters.
>
> "The color of the Cladophora at the sampling sites is used to substantiate chemical analyses of the algae. Cladophora of a bright green color is healthy and usually contains plenty of the essential nutrients. Where phosphorus limits the growth of algae (less than 0.2% total P in dried algae samples), the algae usually are yellow in color, but yellow color does not necessarily mean the algae only lack sufficient phosphorus; a lack of nitrogen or iron also causes crops of Cladophora to be yellow. However, the presence of epiphytes on the Cladophora indicates that these algae had adequate or surplus nitrogen.
>
> "The facts that no Cladophora was found north of Milwaukee County and only sparse growth was found in northern Milwaukee County indicate that Lake Michigan waters away from known sources of nutrients (usually associated with cities) do not normally support abundant growth of this alga. The low phosphorus content of the algae from the first three sampling sites (0.17-0.19% P) indicates that phosphorus could be the limiting factor since two of the sites had many epiphytes present, so nitrogen was not a limiting factor. Only special tests would indicate if iron was adequate in this area.
>
> "The difference between analyses of Cladophora from the outer side of the Milwaukee breakwater (0.24% P) versus the harbor side (0.42% P) shows that the phosphorus of Milwaukee Harbor is not generally distributed in this area so as to fertilize the total Milwaukee shore area.

"The relatively low phosphorus content of algae from as near as South Milwaukee (0.18%-0.25% P) indicate that the phosphorus of the Milwaukee Harbor area does not excessively fertilize this area. In contrast, the Racine, Kenosha and Waukegan areas contain algae of relatively high phosphorus content (0.25%-0.42% P), showing that local sources of phosphorus are relatively high.

"The sparse growth of Cladophora and its low phosphorus content in the Zion, Ill., area (0.10%-0.18% P) shows that the phosphorus contributed to Lake Michigan by Kenosha or other cities further north does not contribute to the excessive fertilization of this area of Lake Michigan."

The above conclusions were illustrated in court (DE 487, 488; September and October surveys) by wall displays of dried Cladophora samples, spaced in vertical order along the coastline from north of Milwaukee to Waukegan, Ill., and horizontally according to percent dry weight phosphorus. Even in the dried samples, corresponding color differences can be seen (Fig. 37). But while the value of Cladophora as an in situ indicator of the present and previous nutrient status of the surrounding water is apparent, its presence or absence at a given site depends also on the availability in that vicinity of suitable substrates for attachment and growth. On a sandy beach, for example, attached Cladophora would not be found unless there were suitable offshore stones, boulders or even twigs (tr. pp. 8,366-67) upon which the alga could grow, and it would only turn up on the beach if it had become detached by wave action in rough weather.

Fitzgerald explained (tr. p. 8,022) that Cladophora is a warm-water alga that does not grow on the shore until June and then "stays until the fall." In cross-examination for the plaintiffs, JVK questioned (tr. pp. 8,181-82) the validity of sampling so late in the season because if, as expected, a Cladophora bloom had depleted the nutrients in the water, the cells would then start using up their reserves and would begin to show signs of nitrogen and phosphorus starvation. Fitzgerald agreed. The importance of this point emerged later in the trial. JVK also pointed to a difference of opinion between the authors of Reference 31 concerning the "critical concentration" for phosphorus, Fitzgerald saying it was 0.2%; Gerloff, 0.06% (tr. pp. 8,025, 8,028-29) -- an example of careful "homework" on the part of the plaintiffs' team.

In further cross-examination, JVK made valid points concerning competition for phosphorus between Cladophora and other algae (tr. p. 8,232; Fitzgerald undertook to "check it"), and between algae and sediments (tr. pp. 8,250-51, 8,253-54). JVK also questioned the adequacy of the sampling network -- only three points in Illinois in September, five in October (tr. p. 8,287):

Q. "And without any shore measurements in between, you did not attempt to obtain, either through boat samples or otherwise, samples of cladophora that may be underneath the water on substrates a distance from shore?"

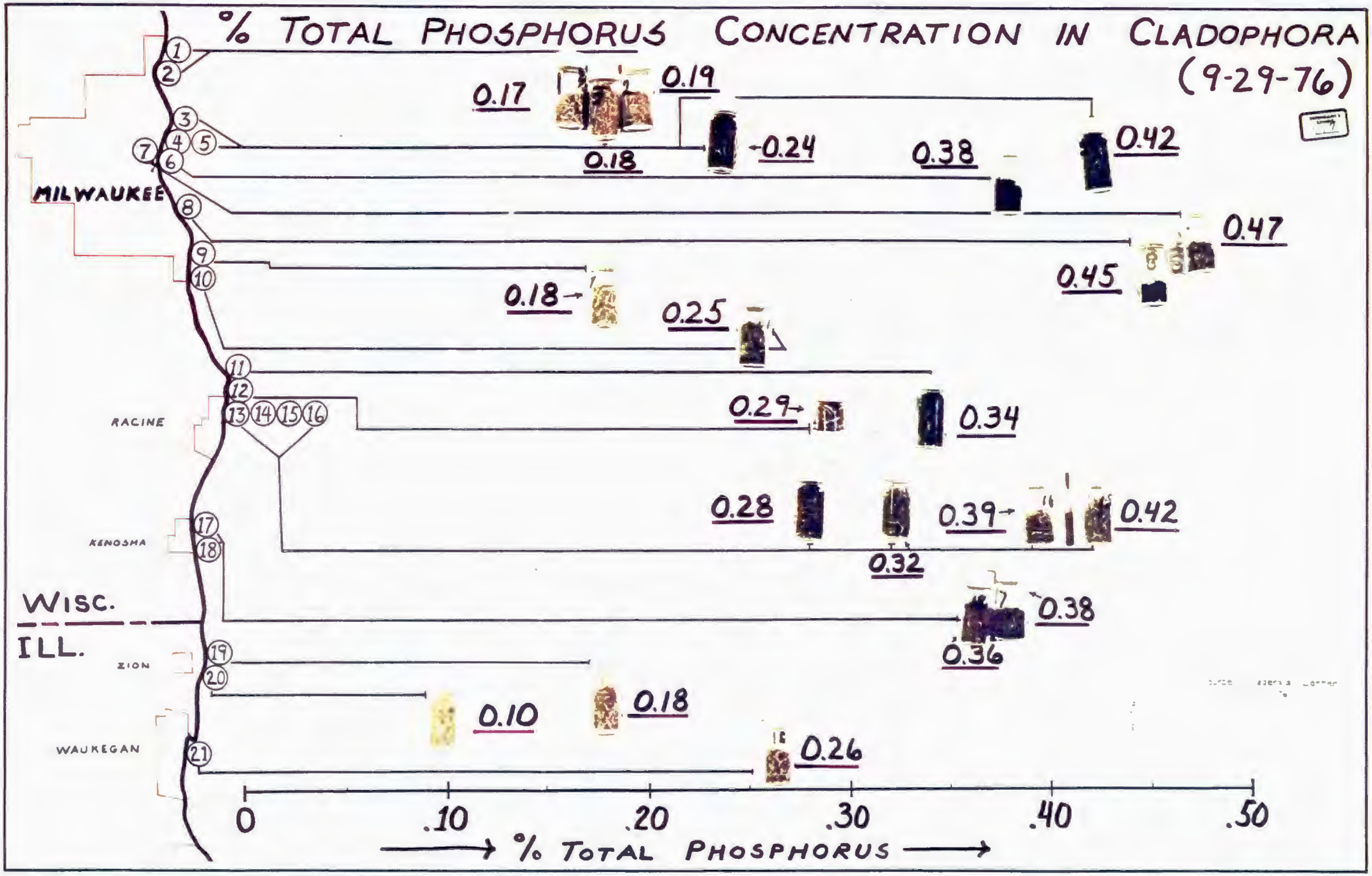

Figure 37. Defendants' Exhibit 487: samples of Cladophora collected on Sept. 27, 1976, at shore stations between Virmond Park, Wis., (north of Milwaukee) and Waukegan, Ill., and mounted on a wall diagram according to location and total phosphorus content (percent dry weight). Original shows colors noted in text.

A. "No. Our correlated studies in other lakes, lakes Mendota, Monona and Wingra, have shown that Cladophora samples taken on the shoreline and further and further out into the lake -- we have made large studies of the comparative physiology, and we found that the Cladophora on the shoreline represent the Cladophora in the entire similar environment."

But the most dramatic act of rebuttal came on a weekend nine months later, in July, when JVK sent his law clerk, J. Renz, who happened to hold an undergraduate degree in botany, to collect Cladophora at or near the very sites (Nos. 19, 20, 21) south of the state line at which Fitzgerald had found the alga to be "sparse" and "yellow" or "yellow-green" (i.e., nutrient-poor) in September and October of the preceding year. Renz found "abundant" algae washed up on the Zion and Illinois State Park beaches, collected large quantities of floating algae by wading into the water and found an ample supply of green-colored algae attached below the waterline on both sides of the Waukegan breakwater (i.e., as close as he could get to the site described by Fitzgerald). The jars of samples, which had not been treated with a preservative, were opened in court at its next session (tr. pp. 13,174-75) to the accompaniment of JVK's commentary: "I don't know whether the court wants to note its observations, but one of the things this material does do is give off an incredibly foul odor of decomposition." (The judge's comments were not recorded.) Because of the late timing of this little drama -- during the rebuttal phase of the trial -- the defendants were unable to send their experts into the field to check Renz's findings and to determine the origin of the loose Cladophora on the beaches.

4.7 Comments on the Attempt to Use Cladophora to Demonstrate the Localized Character of Pollution

Hindsight confirms what foresight should have discovered: namely, that more thorough and more frequent surveys were required to prove the value of Cladohpora as an indicator of local average nutrient availability. The concept behind the attempt was (I believe) sound, but the execution (and funding?) was inadequate because the surveys did not extend into deeper water (to explore growth on stones and boulders outside the immediate beach zone), did not cover the whole growing season and did not take interactions of substrate properties and wave turbulence into account. Thus the defendants were left with only one line of evidence (i.e., the one provided by the "sawtoothed" coliform distribution and the rapid in situ disappearance of coliforms) with which to combat the argument that there is an uninterrupted, monotonic gradient of pollutants and nutrients along the shoreline from which a direct transport connection between events in Milwaukee and harmful effects in Illinois could be inferred. The concept of using Cladophora as a "permanently" attached "litmus paper" to test the distribution of nutrient sources along a given shoreline is sound if there is a suitable substrate and if the average ambient nutrient concentration falls below the limits defined by culture experiments (Ref. 31). But expert opinions differed on the level of phosphorus limits, and the percentages of phosphorus that Fitzgerald found in *Cladophora* along the Wisconsin-Illinois shoreline were above Gerloff's limit of 0.06% dry weight (see Fig. 37). North of Milwaukee, lower concentrations were found. In some parts of the Great Lakes region, excessive growth of *Cladohpora* has constituted a nuisance when washed up on beaches. A more recent review (Ref. 34) noted that "although *Cladophora* growth is believed to be related to the general level of phosphorus enrichment, there is presently an insufficient scientific understanding of the role of *Cladophora* in the Great Lakes ecosystem. More research is needed before effective control strategies can be developed."

Section 5:

Eutrophication Scenarios

5.1 Biological Production Controlled by Phosphorus Input

The plaintiff's case was designed to not only justify the complaint that Milwaukee's discharges to Lake Michigan constituted a health threat to Illinois citizens, but also to establish that Milwaukee Metropolitan Sewerage District (MMSD) was a major contributor to progressive plant nutrient enrichment (eutrophication), with undesirable biological consequences for the lake ecosystem as a whole. Because phosphorus has been identified as the limiting plant nutrient in the Great Lakes and in freshwater in general, and because there are practical methods of controlling it, the arguments centered on the phosphorus and, to a lesser extent, organic and suspended solid loads that Milwaukee discharged to Lake Michigan. Contributing to the total phosphorus load are a number of sources, principally treated and untreated sewage (with a substantial contribution from laundry detergents), agricultural runoff, and lawn and garden fertilizers.

The defendants took pains to point out (Envirex estimates; DE 506, 508, 511) that the MMSD's contributions were small compared with those from point and nonpoint sources in the entire Lake Michigan drainage area. But there was considerable debate about the reliability of those estimates and the manner in which they were arrived at. For example, the point sources used in the calculation of phosphorus loading included cities many miles from the lake. Would such cities have the same impact (proportional to population) as those on the shore of the lake (tr. p. 12,883)? At the end of the debate, Milwaukee stood identified as a substantial source of phosphorus loading, and this will still be true when it meets the present DNR effluent standard of 1 mg/L P. Several experts declared that the DNR limit should be reduced by a factor of 10; others felt that, besides the advanced technology that would be required, such a low standard for treated sewage effluent would have little effect on the lake as a whole. The most recent post-trial assessment of phosphorus loading to Lake Michigan is given in Table 3 and footnotes (from Ref. 34, in which the references to Munro 1977 is an internal IJC manuscript report). The MMSD contribution makes up a substantial fraction of the "Wisconsin direct municipal" entry in Table 3, but is only 3 percent of the whole-basin combined totals for tributary and atmospheric sources (see Ref. 51).

The nonspecialist reader may well ask why it is a bad thing to fertilize a lake; won't the fish grow faster? Limited fertilization can indeed be beneficial (many fish ponds are fertilized regularly to increase the crop); but over-fertilization, or eutrophication, changes the composition of the biological community in ways which many lake users see as undesirable. In the microfloral community, diatoms are replaced by blue-green algae, the excess growth of which forms surface scum that decomposes with a foul odor.

TABLE 3

1976 TOTAL PHOSPHORUS LOADINGS TO LAKE MICHIGAN

(metric tons per year)

Source	Wisconsin	Michigan	Illinois	Indiana	Total
Direct Industrial	4[1]	6[1]	3[1]	32	45[1]
Direct Municipal	965	19	67[1]	(No Data)	1042[1]
Tributary-Monitored	870	1902	(No Data)	407	3179
Tributary-Unmonitored					715
Atmospheric					1690
TOTAL (Excluding shore erosion and re-entry from sediments)					6671 (5553)[2]
Shore Erosion (from GLBC) acid extractable[3]	1500			Total	3700

[1]Indicates value different from that in 1976 GLWQB report (see Munro 1977 for details).

[2]Total load assuming 1 mg/L effluent standard for all municipal discharges greater than 1 mgd.

[3]As determined by extraction in 0.05 normal HCl; not to be confused with available P. The fraction of total P that is available for biological uptake is likely much less than that measured as 0.05 N HCl extraction of shoreline samples.

Water clarity declines, and fish species generally regarded as desirable are replaced by coarse fish. Fortunately, that description does not, as yet, apply to the main basin of Lake Michigan. But signs of eutrophication are seen in Green Bay and in nearshore regions at the southern end. (For later reference, note that diatoms require an additional nutrient -- silica as dissolved silicate in the water -- to build their skeletal structures. Diatoms make up the bulk of the first bloom of plant growth in the spring, thereby starting off the annual cycle of biological production in Lake Michigan.) Appearing as a rebuttal witness for the plaintiffs, A. M. Beeton gave the court a general account of the progress of eutrophication in the Great Lakes, describing events in Lake Erie and evidence that suggests that Lake Michigan may be following a similar course. Under direct examination by JVK, Beeton noted (tr. p. 12,510) that:

> "In the '20s, it was mentioned that the Charlie Fish report said that Lake Erie is oligotrophic, and also in that same report there was a fellow named Munter, M-u-n-t-e-r, that commented on the pollution near shore, and he said that pollution from Cleveland and, I believe it was, Erie and Buffalo really do not effect the open lake because it is confined primarily to shore.

"Then in the report that was published on the 1929 and the '30 data by Stillman Wright, he expressed the same thing, that pollution really wasn't affecting the lake. It was just in the bay and nearshore areas, and if anything, it was probably food for the fish population because the fish population needed, could benefit from, the nutrients."

Beeton then went on to describe the biological and chemical changes that later occurred in Lake Erie, earning for it in the popular press the sobriquet "dead."

Beeton's general lecture on the symptoms and progress of eutrophication in the Great Lakes and on the chemical and biological status of Lake Michigan (tr. pp. 12,471-669) came late in the trial, in the rebuttal phase. Earlier, the principal eutrophication witnesses for the plaintiffs and the defendants, C. L. Schelske and J. Shapiro, respectively, presented their own opposing interpretations and predictions of chemical and biological developments in the lake.

5.2 The Silica Depletion Scenario

Under direction examination by JVK for the plaintiffs, Schelske outlined this scenario (tr. pp. 2,835-36):

A. "I like to look at this in several stages. Actually, the first stage comes as you increase the supplies of nutrients in the upper Great Lakes. The nutrient that is required to increase the standing crop is phosphorus.

"If you supply enough phosphorus to the system, that will enable the diatoms that are present to grow to large standing crops. These crops get large enough with the diatoms, use up all the silica that they require that is present in the water, creating an environment that they no longer can live in. At that point they have to be replaced by blue-green and green algae.

"The next step in the system is when the blue-greens and the greens get large enough standing crops where they have depleted the nitrogen supplies that are present in the water. Then the only organism, the plants, that can live there are the nitrogen fixers; in other words, the ones that can get nitrogen from atmospheric sources."

Q. "So the eutrophication process is a progression of the diatoms first exhausting the silica, and then the blue-greens becoming the dominant species, and the blue-greens multiplying in numbers to the point that they exhaust their limiting nutrients, and then a certain species of blue-green becoming able to fix nitrogen from the air, is that right?"
A. "That is generally true. We might have other actors in this, but the principals are certainly the same."
Q. "When you say the diatoms exhausting their need for silica, are diatoms an organism, that is, a phytoplankton, which has a peculiar need for silica that others do not have?"
A. "Most of the diatoms have an absolute requirement for silica. They have, if we can call it that, a hard shell, an outer shell, that is composed of silica. It is the frustule."

Continuing (tr. pp. 2,845-46), Schelske presented evidence that suggested to him that this scenario, seen in Lake Erie, is also being acted out in Lake Michigan (Ref. 35), starting in nearshore waters and at the south end of the basin:

"There are actually two things that come to mind immediately on that. One is the increased algal abundance that has been observed at the water filtration plant at the city of Chicago over some 50-year span.

"The other, more convincing story, and one that encompasses the whole lake, is the phenomenon that we have called silica depletion in the lake. This relates back to what we discussed earlier, that as the diatom standing crops get larger and larger in the lake, they consume more and more of the silica that is present in the lake, until eventually you have depleted the silica, creating a situation where silica is limiting in the lake.

"We see this manifested in Lake Michigan."

He noted that the nearshore phosphate concentrations observed in June 1972 at stations in and south of Milwaukee Harbor (Ref. 30, PE 144) were similar to those found in Lake Erie and in Green Bay (tr. p. 2,877).

Under cross-examination, Schelske was asked by McCabe (for the defendants) whether he had made any studies to determine the effect of Milwaukee discharges on Illinois waters. He replied (tr. p. 3,016):

A. "What do you mean by a study?"
Q. "Any measurable impact; whether or not, for instance, if Milwaukee were to remove all of its phosphorus discharges, to what extent the problems which you indicated various types of algae would cause would be reduced in Illinois?"

A. "The answer that I will give for that question is: I haven't tried to collect any data or haven't been involved with any people who have tried to collect data to establish this. I guess I should make clear what I mean by collect data. That means go into the field and actually take water samples out of the lake and analyze them in our own laboratories."

When questioned on the evidence that phosphorus in Lake Michigan had been increasing or decreasing in recent years, Schelske (tr. p. 3,019) and later Beeton (tr. p. 12,646) agreed that the evidence was insufficient to determine whether the phosphorus trend was upward or downward. Fitzgerald, under cross-examination by JVK, was unable to accept Schelske's hypothesis because, if increased phosphorus input was in fact responsible for silica depletion, which in turn caused a change-over to blue-green algae, then diatoms should be growing heavily near Milwaukee. But that was not the case, and silica concentrations were higher there than in the southern regions of the lake (tr. p. 8,294). Also, Shapiro argued, under redirect examination by McCabe (tr. p. 11,973), that the numbers of blue-green algae in Lake Michigan were still relatively low (ca. 200 cells/ml), as Schelske and Stoermer themselves had shown.

5.3 The Alewife Invasion Scenario

Shapiro, under direct examination by McCabe for the defendants, gave his opinion that there was no statistically significant evidence that silica had been declining in Lake Michigan (tr. p. 11,835):

Q. "Now with respect to the Defendant's Exhibits 1366, 1367, 1368, the Chicago Water Department silica data, and 1373, the Powers and Ayers article,* does the Powers and Ayers article reflect a hypothesis, so to speak, that the amount of dissolved silica, the amount of silica in Lake Michigan, is going down, let's say, for the last 40 or 50 years?"
A. "Well, I have reviewed all of these articles very carefully and given this matter a lot of thought and analysis. My conclusion is that the commonly held belief that silica has been decreasing in Lake Michigan for the last 50 years is not true. Silica in Lake Michigan has not been declining."

Shapiro contended that the annual mean silica concentrations at Chicago water intakes (DE 1374, Fig. 38), to which a downward trend had previously been fitted in support of Schelske's hypothesis, could equally well be fitted to two horizontal lines (indicated as broken lines in Fig. 38) if the extraordinarily high and probably erroneous values before 1930 were ignored and if for some reason a sudden drop in the mean occurred in 1948. That reason was to be sought, Shapiro believed, in a change of the analytical laboratory (from the Chicago Department of Health to the Water Department) that was made that year (tr. p. 11,842). A discontinuity in the annual mean chloride values is also to be seen in 1948 (tr. p. 11,843). Shapiro further argued that even if a silica decrease was in fact

* Reference 36.

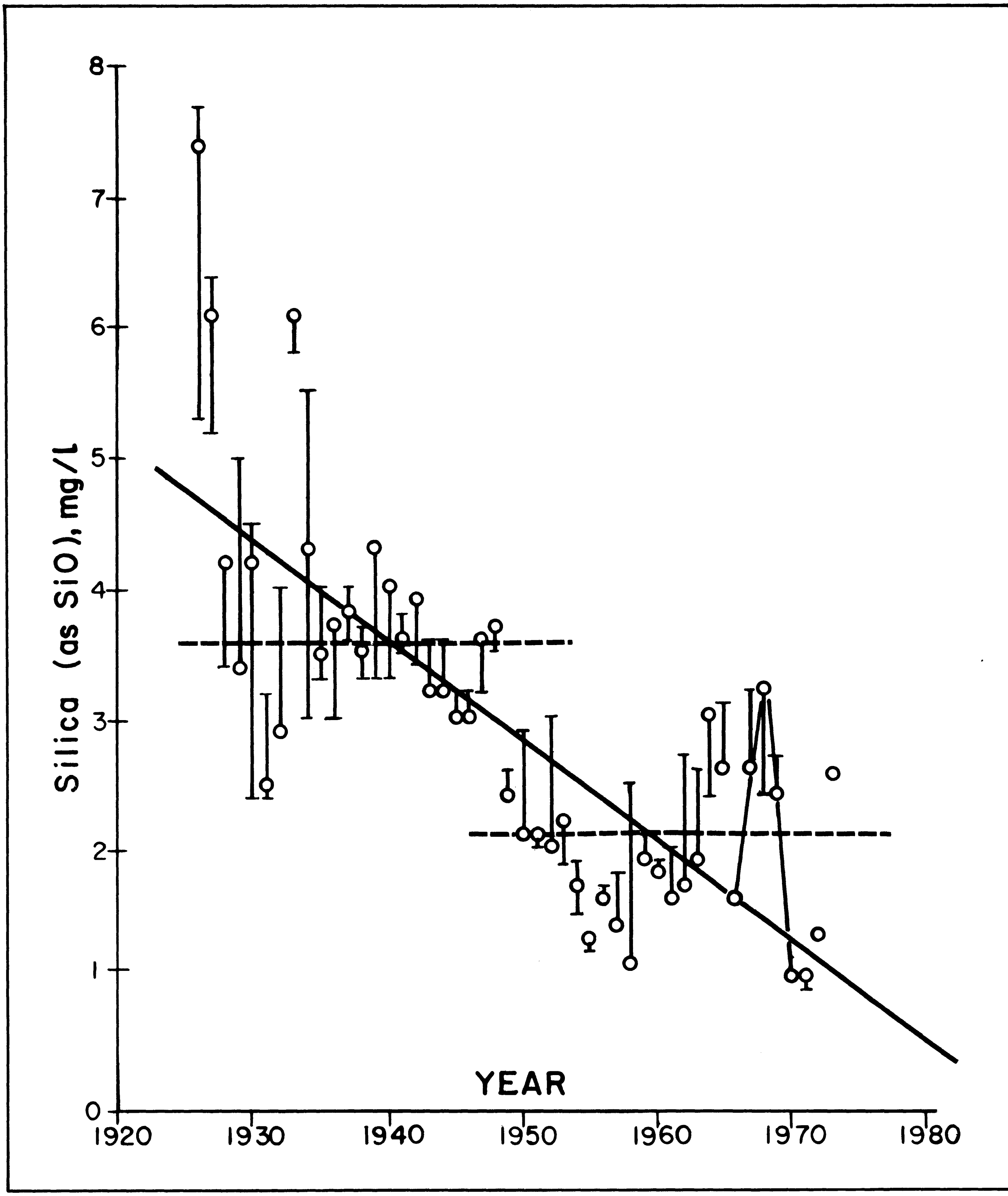

Figure 38. Lake Michigan: annual mean concentration of dissolved silica at a Chicago filtration plant intake (open circles). (Source: Chicago Water Department; from DE 1374, redrawn here with horizontal broken lines added; the significance of the vertical lines was not made clear in the court record -- perhaps they indicate annual range.)

in progress, diatom proliferation resulting from increased phosphorus loading was not the only, or indeed the most likely, explanation. The greatest biological change in Lake Michigan in recent years had been the invasion and mass multiplication of alewives (a herring-like fish of marine origin), which brought about profound changes in the zooplankton population. Between 1954 and 1966, the larger zooplankton species declined sharply, some becoming extremely rare. Some small and medium-sized species increased in numbers. The evidence strongly suggests that those changes were "due to selective predation by alewives,"(Ref. 37). If the total effect was, as Shapiro supposed, a marked reduction in grazing pressure on the diatoms, they in turn would increase in numbers and reduce the available silica.

5.4 Comments on Eutrophication Trends in Lake Michigan

Because phosphorus is the nutrient element that exerts overall control of the production of total biomass in Lake Michigan, the answer to the question of Milwaukee's contribution to lake eutrophication is to be sought in its contribution of phosphorus. Table 3 was quoted earlier to display estimates of phosphorus contribution to Lake Michigan by state and by sources categories. More recent, slightly modified estimates are contained in Table 4 (Ref. 38), in which Lake Michigan's phosphorus load is compared with those of the other Great Lakes basins.

TABLE 4
"BEST" ESTIMATE OF 1976 PHOSPHORUS LOAD
(metric tons)

LAKE	DIRECT MUNICIPAL	DIRECT INDUSTRIAL	TRIB-UTARY TOTAL[1] [2]	DIRECT URBAN RUNOFF	ATMO-SPHERE[3]	UP-STREAM LOAD	TOTAL	SHORE-LINE EROSION
Superior	72	103	2,455	16	1,566	-	4,212	3,800
Michigan	1,041	38	3,595	-	1,682	-	6,357	3,700
Huron	126	38	2,902	16	1,129	657	4,867	794
Erie	6,292	275	9,950	44	774	1,080	18,425	10,526
Ontario	2,093	82	4,047	324	448	4,769	11,803	1,280

[1]Includes land use, atmospheric and point source contributions entering the lakes through tributaries. It excludes direct urban runoff to the lakes which is listed separately.

[2]Indirect point source contributions (metric tons per year) as estimated by PLUARG are: Lake Superior - 233; Lake Michigan - 1,705; Lake Huron - 473; Lake Erie - 1,242; Lake Ontario - 790. The difference between these figures and the tributary total provides a conservative estimate of land use contributions to tributary loads.

[3]Atmospheric inputs directly onto lake surface.

(Source: Reference 38.)

Of the Lake Michigan total -- 6,357 metric tons for 1976 (not including the phosphorus delivered from shoreline erosion, which is considered to be primarily in a form "unavailable" for biological production) -- a fourth is introduced from the atmosphere directly onto the lake surface, nearly three-fifths enters through tributaries, and the remaining one-sixth comes from direct municipal (and industrial) sources, of which the MMSD is the largest. About 80 percent of the phosphorus from municipal sources is considered to be "biologically available," while only about a third of the phosphorus associated with suspended sediments in the tributaries is in available form. The net effect is that only "about half" of the total phosphorus load is considered to be biologically available (Ref. 38), and a substantial part of that comes from treated sewage effluents, with MMSD as the largest single point source. The additional effect of CSO, where present, is modest compared with the other load sources, but it is not negligible. "In some cases, these overflows occur frequently and, though variable in impact, can increase the annual phosphorus load from large urban areas by as much as 10 percent" (Ref. 38; emphasis added).

Present phosphorus control strategies call for a 1 mg/L P effluent standard for all municipal discharges greater than 1 million gallons per day (mgd) in volume, and Judge Grady's order repeats the same DNR stipulation for Milwaukee. The effect of compliance with this standard on the annual mean concentration of total phosphorus in each of the Great Lakes has been estimated by means of a model in Reference 39 and Figure 39. For Lake Michigan, compliance with the 1 mg/L standard is expected to bring the annual mean concentration into the desired oligotrophic range of biological production, while complete elimination of phosphorus in municipal effluents (a very costly procedure) would have little additional effect. However, it was noted in Reference 34 that a limit of 0.5 mg/L is achievable in many plants at little extra cost. That, it would appear, is a reasonable limit to strive for. This is a clear example of the need for realistic cost-benefit analysis of the effects of various pollution control strategies on the trophic status of Lake Michigan, and it raises the much-debated question of whether phosphorus is best controlled at the municipal effluent pipe, or at the major sources (detergent manufacture, agricultural fertilizer use), or both. The authors of Reference 39 conclude that western Lake Erie, lower Green Bay (Lake Michigan) and Saginaw Bay (Lake Huron) may require nonpoint source controls as well.

As Milwaukee is taking steps to comply with the DNR stipulaton on phosphorus, Table 4 and the Figure 39 model suggest that Judge Grady's judgement will have little impact on the overall trophic status of Lake Michigan -- although a significant impact may be felt (through CSO control) in Milwaukee Harbor and vicinity. Whole-lake surveys of total phosphorus in surface waters during the summers of 1976 and 1977 (Fig. 40; Ref. 29) disclose values that generally lie within the oligotrophic range defined in Figure 39, though it should be noted that the scale in that figure is for annual mean concentrations. In 1976, the highest concentrations were seen near the mouth of the Grand River near Michigan City, in the Waukegan-Chicago region, and well north of Milwaukee along the Door County (Wisconsin) shoreline. That distribution, and also that in 1977, does not point to Milwaukee as the prime source of phosphorus found in Illinois waters.

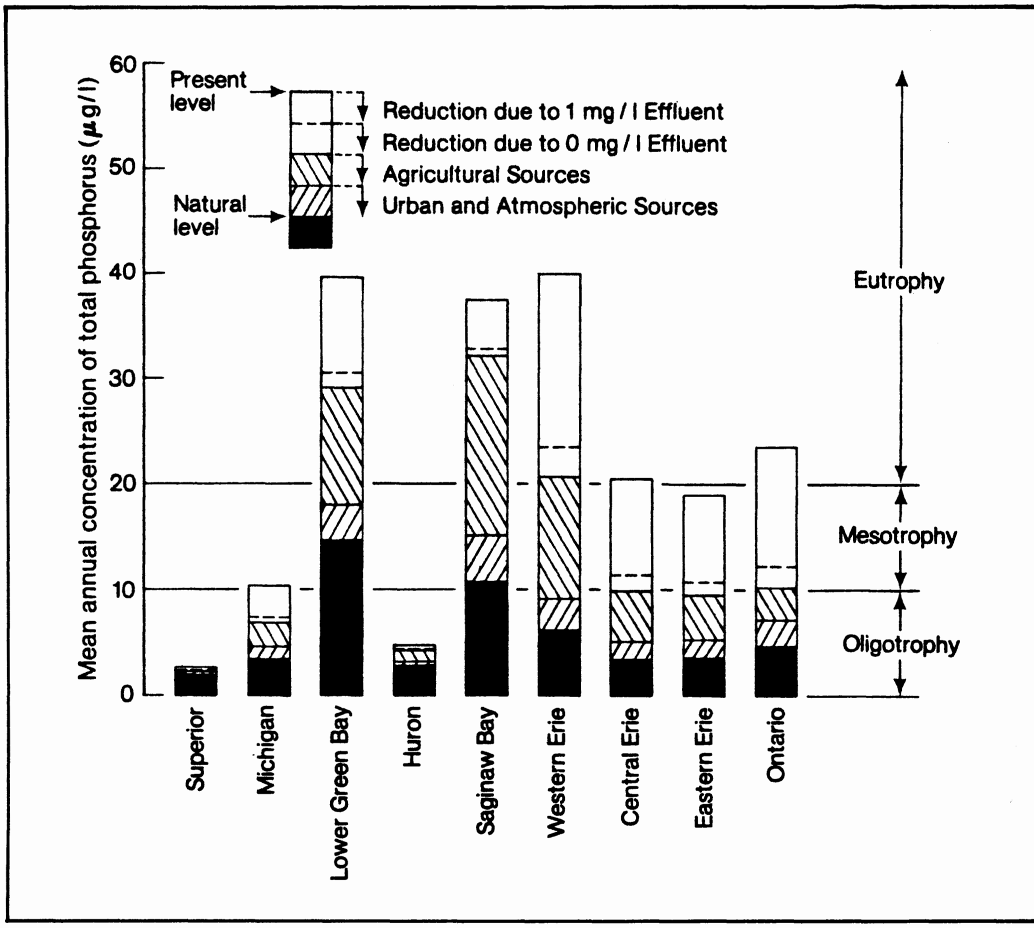

Figure 39. Model predictions (Ref. 39) of "total in-lake phosphorus concentrations" (micrograms per liter) for Lakes Superior, Michigan, Huron, Erie (western, central and eastern basins), Ontario and for lower Green Bay (Lake Michigan) and Saginaw Bay (Lake Huron).

The argument relating to the alleged precipitous depletion of dissolved, reactive silica -- which Schelske interpreted as a warning signal that diatoms will be replaced in Lake Michigan by much less desirable blue-green algae -- stands or falls on evidence or lack of evidence of significant change in the winter concentrations of that substance, essential for diatom growth. The winter data are decisive because, as in many lakes worldwide, surface concentrations in other seasons are depleted by diatom growth and vary widely. It is the winter recovery of silica -- from inflows and from regeneration processes in the water column and sediments -- that sets the stage for growth in the following spring. Unfortunately, winter data have not been systematically collected over a period long enough to define a trend. The mean late-winter concentrations determined in 1971 and 1976 (1.3 and 0.7 mg/L SiO_2; Figs. 41 and 42, respectively) are consistent with a decreasing trend; but data from more winters are needed to demonstrate significant progressive change. Reference 40 is based on surface samples taken during 1970-71 at five stations spaced on a line (railroad ferry route) between Milwaukee and Ludington, Mich. Nutrient concentrations, including silica, occasionally rose to high peaks at Station 1 (thick line in Figure 41) near the Milwaukee shore. The water

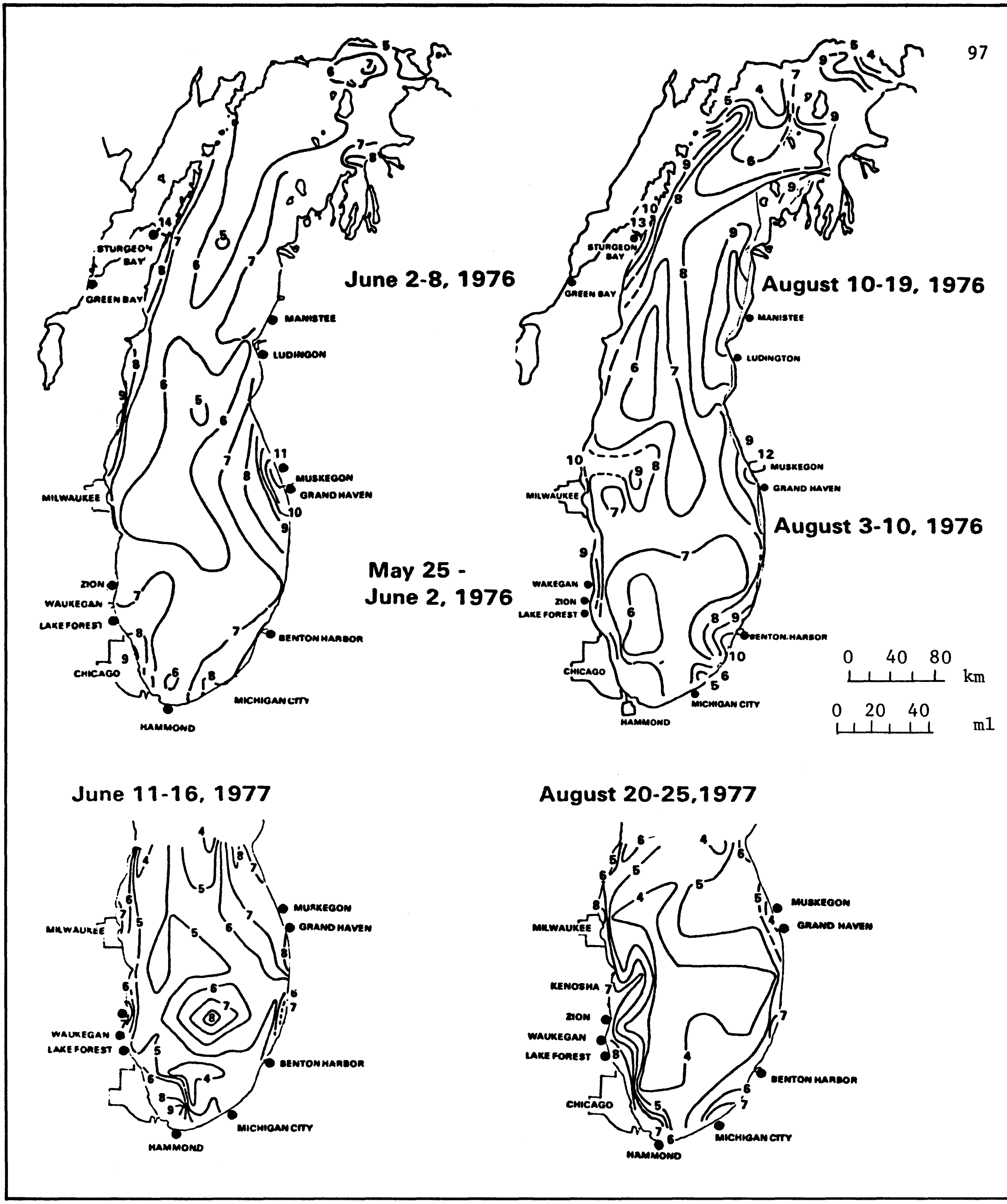

Figure 40. Distribution of total phosphorus (ug/L P) in the upper 20 m of Lake Michigan during the summers of 1976 and 1977 (assembled from draft figures for Ref. 29, supplied by EPA Great Lakes National Program Office, Chicago).

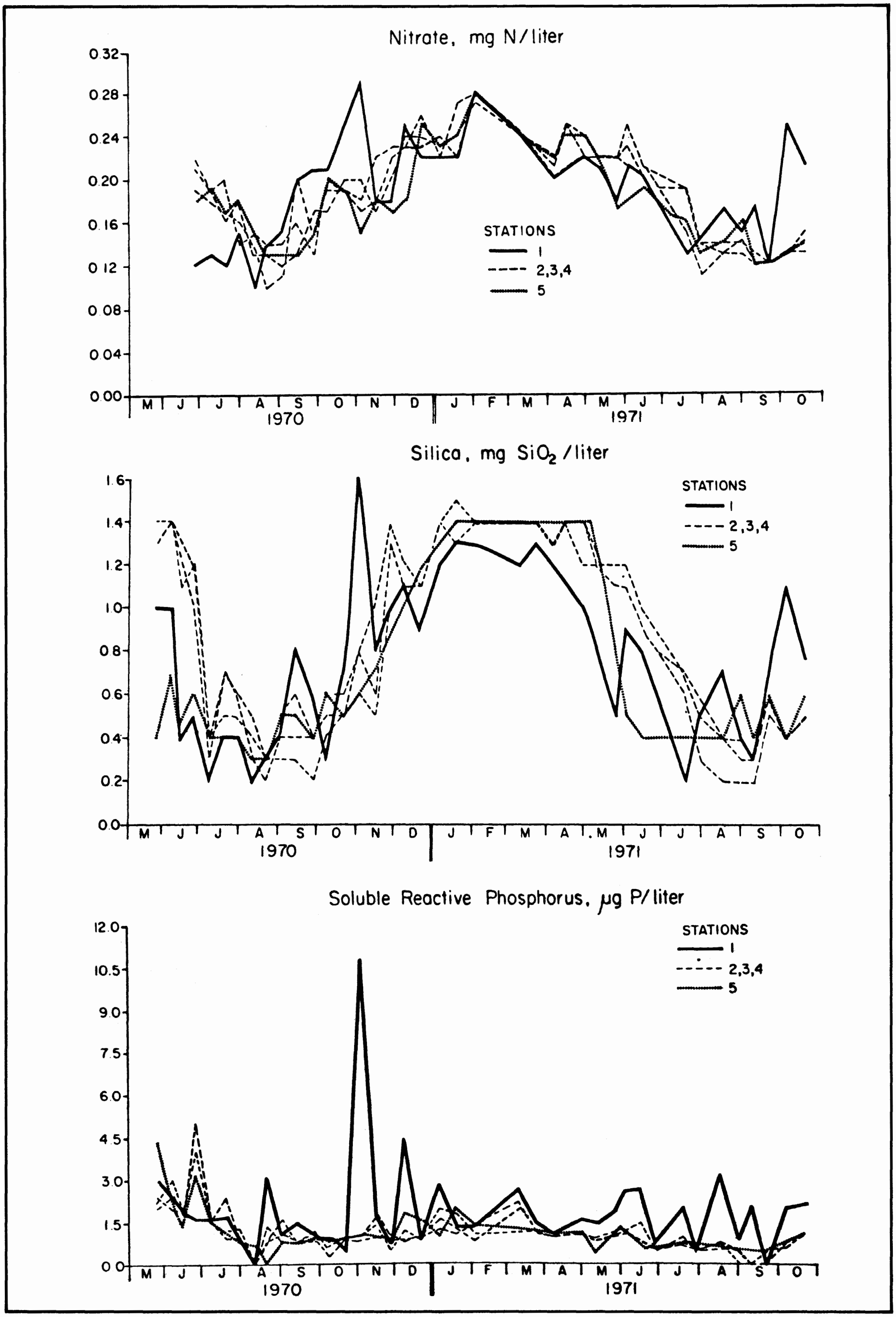

Figure 41. Lake Michigan, 1970-71: nutrient concentrations in surface water at five stations on a line (car ferry track) from Milwaukee, Wis., to Ludington, Mich. (source: Ref. 40).

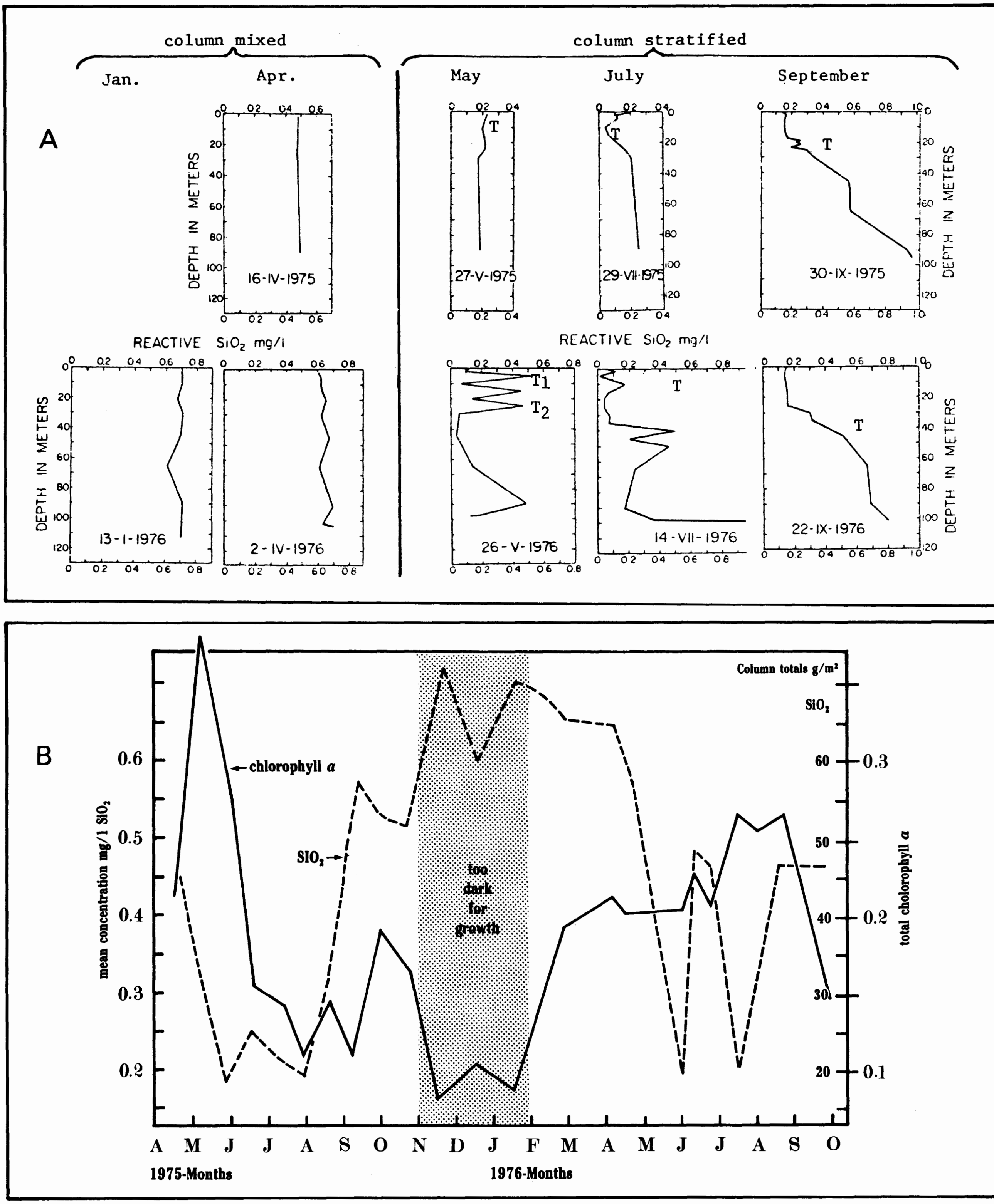

Figure 42. (a) Depth distributions of dissolved reactive silica (mg/L SiO_2) at a Lake Michigan station (depth 100 m) 43 km (27 miles) northeast of Milwaukee, Wis.; (b) content of total chlorophyll a and dissolved silica in the 100 m water column. T indicates approximate depth of the thermocline, when present. (Adapted from Ref. 41).

silica concentrations at all stations were close to 1.3 mg/L SiO_2; summer concentrations averaged about 0.4 mg/L, but with more scatter than in winter and with generally lower values at Station 1.

Reference 41 describes seasonal changes in the vertical distribution of silica in the whole (100 m) water column during 1975-76 at a single station not far from Station 2 of Reference 40. Thermal stratification (passage of the thermal bar; see Ref. 11) had began at that station by the end of May, and the silica concentration (previously almost uniformly distributed at about 0.6 mg/L; Fig. 42a) fell to about 0.2 mg/L above the thermocline. That decrease, brought about by diatom growth during May and June, was accompanied by a large increase in chlorophyll _a_ concentration (Fig. 42b). Above the thermocline, the silica concentration remained low throughout the summer and autumn,* but concentrations increased below the thermocline, particularly near the bottom, where they reached values near 0.8 mg/L in September. Complete mixing of the water column during December and reduction in diatom growth because of a lack of light (the consequence not only of reduced sunlight, but also of the mixing motions that carried the cells away from the light for much of the time) combined to produce relatively uniform depth-distribution of silica at about 0.7 mg/L SiO_2 from January until early April.

If the difference of about 0.5 mg/L SiO_2 between winter and summer concentrations is maintained by silica regeneration every year, a large crop of diatoms can be supported every spring. For a typical species like _Asterionella formosa_ (Ref. 42), the silica content per cell is relatively invariant -- about 0.14 mg SiO_2 per million cells. Therefore, 0.5 mg/L would correspond to an average _Asterionella_ population density of 3.5 million cells per liter. Schelske's hypothesis -- diatom replacement by blue-green algae because of silica starvation -- is less plausible if winter replenishment (on the scale demonstrated in Refs. 40 and 41) is maintained. But there is evidence (Fig. 43, from Ref. 29) of a general decline in average silica concentrations in surface waters of southern Lake Michigan since 1954. Though, unfortunately, winter determinations are lacking prior to 1971, isolated determinations in March and December 1954 (Ref. 43; Fig. 43) provide the only evidence of winter concentrations three times greater than in 1976. It should be noted, however, that such high values (4 mg/L SiO_2) are extremely uncommon in diatom-dominated lakes of the world. Also, in such lakes the common seasonal pattern shows an outburst of diatom growth in the spring, causing the silica to be depleted to very low levels (less than 0.1 mg/L SiO_2), followed by a summer succession of other algae (greens, blue-greens). The picture in those lakes with moderate (mesotrophic) production is generally not one of catastrophic takeover by blue-green algae, unless phosphate input increases substantially. It remains to be seen how Lake Michigan (presently oligotrophic in its open waters) will behave in this respect if phosphate input can be controlled.

On the evidence made available to the court, Shapiro's alternative -- attributing an increase in diatom numbers (and consequent silica depletion) to selective predation by alewives on large zooplankters (diatom-grazers) -- is also speculative. And as long as silica regeneration during winter continues at present levels, Schelske's scenario (Ref. 35) remains, in my opinion, equally speculative -- but that was the scenario which Judge Grady regarded as "the more logical and natural explanation" (tr. p. 14,232).

* See also Conway et. al. 1977. _J. Fish. Res. Bd. Canada_ 34:537-44 (published while the court was in session).

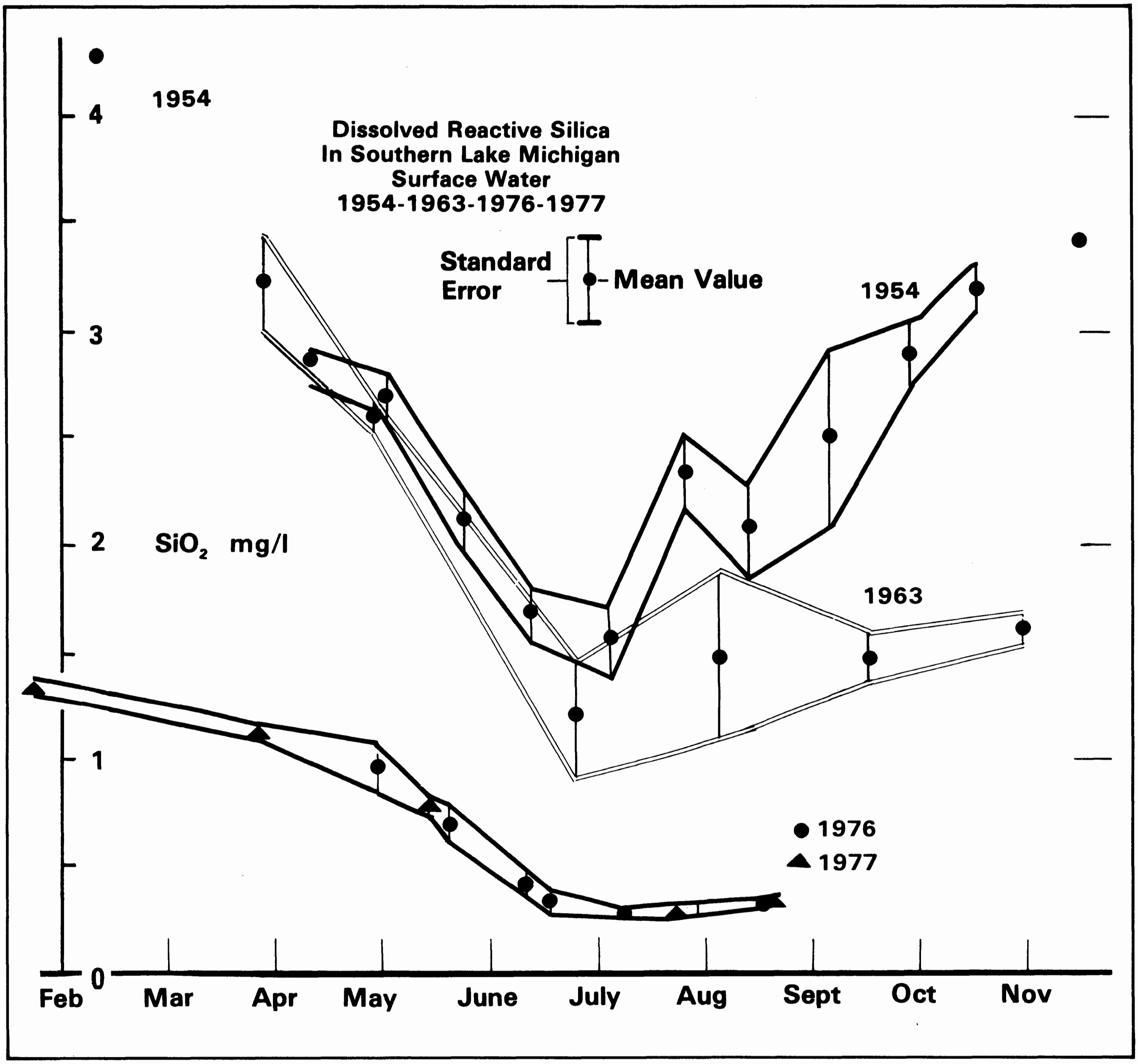

Figure 43. Dissolved reactive silica in the surface waters of southern Lake Michigan in 1954, 1963, 1976 and 1977 (arranged from draft figure of Ref. 29, supplied by EPA Great Lakes National Program Office, Chicago).

NOTE: It has been pointed out (Ref. 57) that if a large decrease in dissolved silica had been brought about by diatom uptake during the past two decades, a substantial fraction must still be present somewhere in Lake Michigan in the form of skeletal remains, because the hydraulic retention of the basin is about a century. However, no accumulations of the magnitude required to explain the 1954-1977 drop in dissolved silica (Fig. 43) have as yet been found in the water column or in recent sediments.

Section 6:

Viruses and Public Health Hazards

Eutrophication of Lake Michigan and the MMSD contribution to it was the last limnological issue to be addressed in the trial. At that point, the possibility of the infection of Illinois citizens by pathogenic bacteria or viruses emanating in Milwaukee, which had been debated earlier, was beginning to emerge as the key issue. Neither side had made any tests for the presence or survival of pathogens and viruses in Lake Michigan. The defendants' estimate of the disappearance rate of fecal coliform bacteria in the SSSTP experiment, described earlier, was held to be inconclusive because viruses have been detected in waters "where there have been no fecal coliform by standard tests" (G. Berg under direct examination by JVK, tr. p. 12,084). Also, chlorination of primary sewage effluent to a point at which the FCC is reduced to zero can, Berg said, "still leave a certain proportion of the originally existing virus viable and demonstrable." In the absence of test results from Lake Michigan, both sides marshalled the opinions of the nation's experts in this field.

The virus question was first introduced by the plaintiffs through their witnesses J. Melnick and F.M. Wellings. It was treated further by the defendants' witnesses M.A. Bernarde, D.O. Cliver and O.J. Sproul, and it was heavily emphasized by the plaintiffs' rebuttal witnesses W. Mack, Berg and Wellings. Though the arguments lie more in the field of environmental public health than in the field of limnology, they clearly had weight in Judge Grady's decision and are therefore briefly reviewed here.

6.1 Pathogenic Viruses in Surface Waters and Sewage and Their Removal by Treatment Plants

The standard method of determining the microbiological safety of drinking water and bathing beaches relies on the FCC as a measure of the probability of the presence of other pathogens of human origin. A recent review (Ref. 44) states:

> "Municipal wastewaters usually contain a variety of pathogenic bacteria, viruses, protozoans and helminths excreted by clinical cases and carriers associated with the enteric diseases endemic in the community. The type, concentration and distribution of these microbial pathogens in drinking water sources is difficult to determine and usually remains unknown. Many agents of the following enteric diseases are in municipal wastewaters: bacillary and amoebic dysenteries, cholera, typhoid and paratyphoid fevers, *Salmonella* gastroenteritis, tapeworm infections, shistosomiasis, ascariasis, and viral diseases, including poliomyelitis."

The demonstration that some of the hardier enteric viruses may pass through treatment plants raises questions about the minimum dose needed to infect a susceptible person and the adsorption of these viruses onto particles passing through the plant. Such adsorption may reduce the efficiency of chlorine disinfection, but it "may also reduce the infectivity of the viral particle, [thus] decreasing the net potential danger. The present position is very unclear" (Ref. 44; emphasis added).

Removal and inactivation of viruses take place at each treatment stage, during primary settling, activated sludge removal, final settling and chlorination. The overall effect at JISTP and SSSTP was estimated by Sproul to be 99.5 to 99.9 percent removal (tr. pp. 10,470-73), but the plaintiffs' witnesses argued that on bad days (with solids "spewing" out) the removal rate may be much less. Viruses become incorporated in suspended materials, the removal of which therefore also removes viruses. Typical numbers of viruses entering the plant in raw sewage is 7,000 plaque-forming units (PFU), as determined by a tissue-culture method. The number at any given time is highly variable and depends on the number of "virus-shedders" (in feces) in the population. Also, some of the disease-causing viruses (e.g., hepatitis; Cliver, tr. p. 10,193) cannot be enumerated by the culture technique commonly used (Berg, tr. p. 12,011). The plaintiffs argued that the EPA effluent standard for suspended solids (30 mg/L) is not satisfactory. Present sampling techniques do not measure the effects of clumping and adsorption on solids (rebuttal testimony by Wellings under examination by JVK, tr. pp. 12,373-74). For effective virus removal during final chlorination, the standard should be reduced to 5 mg/L (Wellings, tr. pp. 12,398-403). This may have prompted Judge Grady's later stipulation of that standard.

6.2 Persistence of Enteroviruses in Lakes and Incidence of Reportable Disease in Waterfront Communities (Milwaukee to Chicago)

Viruses cannot multiply away from a host organism; therefore, if carried into Lake Michigan, they do not multiply there. Multiplication only occurs after infection of a susceptible host through beach contact or through drinking water. There is evidence (from an experiment in Lake Wingra, DE 38, Ref. 45, Cliver, tr. p. 10,225) that enzymes produced by bacteria in lake water (not *E. coli*) can hasten the deactivation of viruses; but there is also evidence of long persistence, "months" during winter (Cliver under cross-examination by JVK, tr. p. 10,315), but only one-half to 1.5 weeks at summer temperatures (65°-70°F; Cliver, direct examination by Moake, tr. p. 10,181). In view of this persistence, coupled with the transport picture developed earlier in the trial, the plaintiffs' counsel urged the court to not rule out that small numbers of enteroviruses of Milwaukee origin occasionally arrive at water intakes in Illinois, and that the absence of coliform bacteria is no proof that viruses are absent (Melnick, direct examination by JVK, tr. p. 2,201). On the other hand, the defendants' witnesses pointed out that all available studies of large municipal water treatment plants have failed to show viruses (not even the most resistant ones) present in the treated water (Cliver, tr. p. 10,201, 10,214). But the plaintiffs' witnesses argued that treatment plants sometimes fail and that it is safer to remove viruses at the source

(Melnick, tr p. 2,191; Berg, p. 12,082) by imposing the highest possible standards of solids removal in sewage treatment plants.

The defendants used 1973-75 county records of reportable, potentially waterborne diseases to demonstrate (Fig. 44; DE 492, 493, 498, 499) the absence of evidence that disease is being transmitted by water from Milwaukee to communities further south (also, Bernarde presented evidence, under direct examination by Moake for the defendants, that infectious hepatitis over a 10-year period had ranged from 11 to 29 per 100,000 in Milwaukee County and from 18 to 45 per 100,000 in Lake County, Ill., tr. pp. 9,124-26). But this evidence, the plaintiffs argued, does not rule out the possibility that disease is being transmitted to Illinois from Milwaukee via Lake Michigan. Reported disease statistics relating to enteroviruses (according to Wellings, tr. pp. 13,183-227) are notoriously unreliable because of misdiagnoses, failures in reporting, the failure of patients to visit doctors, the failure of doctors to send stool samples for testing and difficulty in relating infection to a single source (e.g., water).

Arguments also hinged on the number of viral units that must enter the human body to cause disease. In Cliver's experiments with pigs (Cliver, direct examination by Moake, tr. p. 10,261), dosage levels had to be increased to 1,000 PFU/L to achieve 25 percent infection, and no animals became sick. But another experiment was cited (Berg, direct examination by JVK, tr. p. 12,266) in which a single (denatured) polio virus caused infection in an infant. In Berg's opinion, 10 PFU/L in swimming water is more than children should be exposed to (tr. p. 12,094). Recently, the World Health Organization has suggested a maximum of 1 PFU/L for virological safety in water (Ref. 46).

Though the testimony on viruses proved to be the most influential in the case and though so much hinged on it, neither side could refer to investigations of the occurrence of viruses in Lake Michigan or to epidemiological studies in communities along the coastline. No one followed it up, but Cliver did propose a safe and statistically sound research plan (tr. pp. 10,249-51):

> "My choice would be to try to get volunteers who customarily swam in that body of water, and the way that these studies are designed is to do a work-up on each volunteer, first to determine whether he or she is presently infected but also to get what one might call demographic data on them -- age, sex, area of the community in which they live, et cetera.
>
> "Then one attempts to find a matched individual that shares as many of those properties as possible but does not swim or doesn't swim habitually in the water in question.
>
> "If then the sets of matched individuals were willing to allow or submit fecal specimens on some periodic basis, one could by quite standard virologic procedures test these to determine whether there was any significant difference in the incidence of intestinal infection with viruses in the group that swam as opposed to the group that didn't swim."

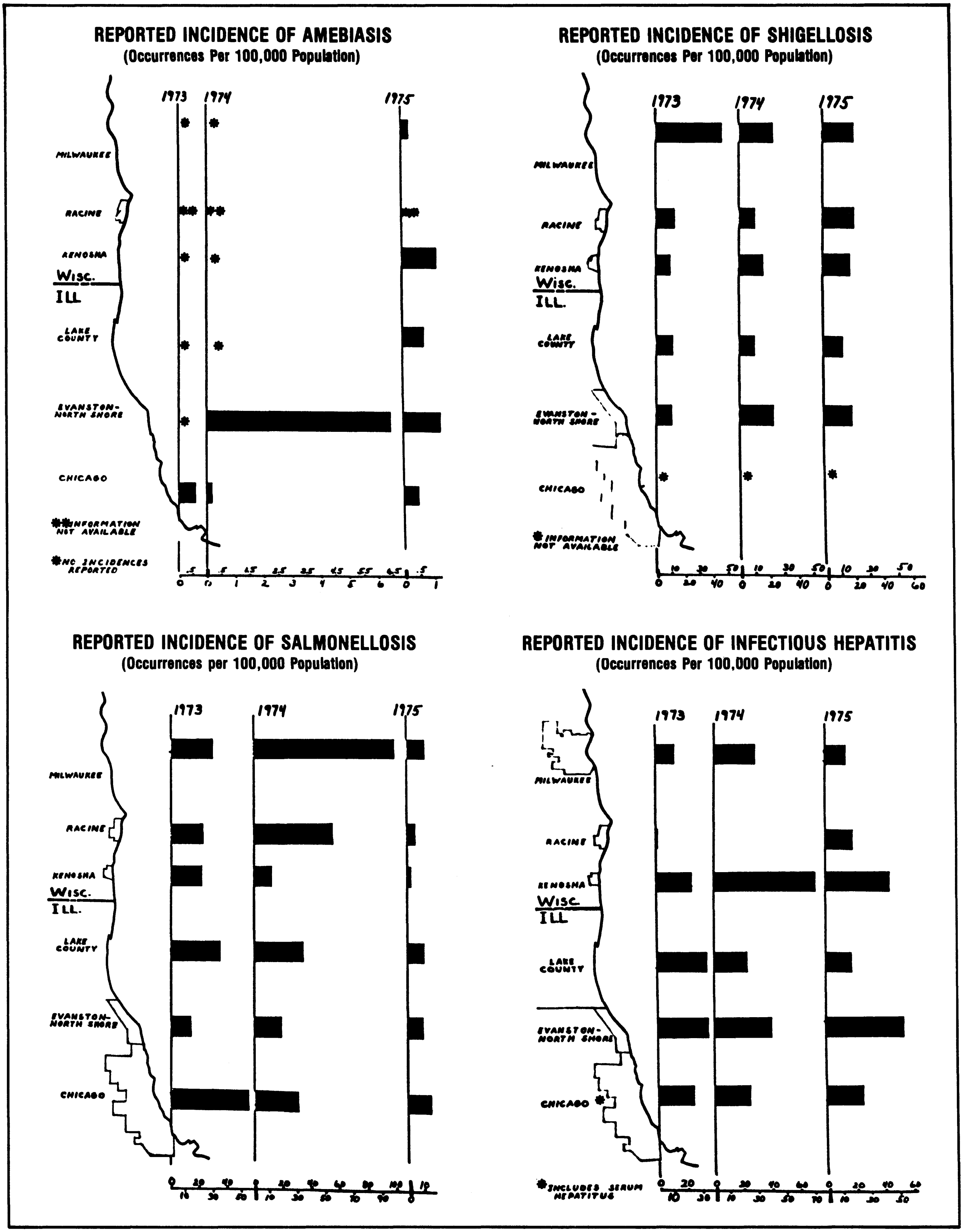

Figure 44. Reported cases of potentially waterborne diseases in counties bordering on Lake Michigan (source: DE 492-93, 498-99).

GRADY: "The old identical twin test."
JVK: "Your Honor, the Court can take judicial notice. There are people who live up in the Waukegan-Zion area. Are there any volunteers?" [i.e., the judge perhaps?]
MOAKE: "That sort of test would not place the person who was swimming at any greater risk of infection than they otherwise have by undertaking their normal daily routine, would it?"
CLIVER: "No, it was a given that these people who habitually swim, and we assume that they habitually defecate, and so there is no real effort on their part other than saving the evidence for laboratory analysis."
MOAKE: "In your opinion, doctor, in 1977, today, are waterborne viruses in general a public health hazard in the United States?"
CLIVER: "They are something that we continue to watch for, but I don't think we ought to generalize to all of water in a case like this. We are not, in the specific instance here, seeing recorded outbreaks of disease associated with the recreational use of waters, and in the respect of public water supplies that have over the past few years been associated with outbreak of disease, it has been found, I think, virtually without exception, that the source of the virus was through the contamination of the finished water in the distribution system rather than the virus had come through the water treatment plant. This relates only to public water supplies. I am not getting off into private water supplies or semipublic, but public water supplies within the definition of the Safe Drinking Water Act of 1974."

6.3 Comment on the Significance of Viruses in this Case

The almost total lack of consensus among the experts, coupled with the absence of virus investigation in Lake Michigan and epidemiological studies among local communities, emphasized the need for research -- but it gave Judge Grady little firm guidance. Predictably, perhaps, his judgement swung to that side which minimized the perceived, but ill-defined, risk.

Section 7:

Counsels' Closing Arguments and Judge Grady's Findings

The main points of the case have now been reviewed. This section will rely almost entirely on extensive quotations, from the transcript and Appendix VII, to illustrate the final positions taken by plaintiffs' counsel, defendants' counsel and the judge on the issues raised in Sections 2-6 of this review and on wider issues concerning burden of proof. The transcript extracts, taken out of time sequence, are presented as a triangular debate -- a special kind of debate,* however, in which one participant (Judge Grady) had the final word, based on the arguments summarized in Appendix VII. Additional quotations, illustrating the evolution of the judge's reasoning, are presented in Section 8. The overall debate may be crystallized into the five questions introducing the following subsections.

7.1 What Are the Sources of Effluents to Lake Michigan, and Can the Lake Assimilate these Effluents?

An important component of the dispute involved Lake Michigan's performance as a waste sink. The defendants argued that it is well-mixed, well-oxygenated, and therefore capable of assimilating effluents treated to national (EPA 30/30) standards. McCabe pointed out that the Illinois 5/4 standards that the plaintiffs sought to impose on the defendants were put in place to protect sensitive rivers from oxygen loss, which is not a critical factor in Lake Michigan. Where necessary under similar circumstances (e.g., a Waukesha treatment plant, tr. p. 13,983), Wisconsin also imposes a 5/4 standard. The fact that Chicago is able to divert its sewage treatment plant effluents out of Lake Michigan into oxygen-sensitive rivers should not give Illinois a long legal arm to impose on a distant municipality in another state a standard higher than it would have imposed on itself, if diversion from the lake into rivers had not taken place.

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* The participants in the debate were Joseph V. Karaganis (JVK) for the plaintiffs, Ewald Moerke for the Sewerage Commissions of the County and City of Milwaukee (defendant), Michael J. McCabe for the City of Milwaukee (codefendant), and Judge John F. Grady.

McCABE (tr. pp. 13,983-84):

"So again, both states recognize the fact that rivers cannot take as much in terms of deoxygenating wastes as other bodies of water.

"With respect to Lake Michigan, we have a 30/30 standard to the lake in terms of deoxygenating waste. Illinois has a 5/4. There is no testimony in this record to indicate why they would have a 5/4 in terms of the deoxygenating wastes. I suggest that considerations other than deoxygenating wastes are involved there."

McCABE (tr. p. 14,187):

"I think there has been a suggestion from plaintiffs that because their standards -- either their phosphorus standard or their coliform standard -- is violated, and because we are putting something in the lake, therefore we are guilty.

"First of all, I don't think it follows. I don't think the proof has shown that. And the fact that a state, through circumstances beyond its control, is able to put its sewage in a river does not suddenly give that state the right to bind its neighbor state to a standard it would not have set forth itself but for that fact."

And why, Moerke asked (tr. p. 13,913), did Illinois not complain against the EPA 30/30 standards when they were promulgated?

Moerke also suggested that the court had a duty to make sure that the plaintiffs are not themselves substantially contributing to the nuisances of which they complain, for example, by overflows in Chicago.

MOERKE (tr. pp. 13,927-29):

"Can the plaintiff really meet this burden of proof in the face of the evidence in this case?

"One, the massive infusion from time to time of sewage effluents when the locks are opened in the river system to permit pollution to directly enter Lake Michigan, the latest of which, of course, as a matter of public knowledge, was June 30th of 1977.

"In the face of the fact that the Waukegan plant is still putting effluent into the lake, and since the complaint has been filed in 1972, there have been five other plants which have just only recently been taken out of Lake Michigan. In other words, at the time the complaint was filed with the Supreme Court of the United States and then later filed in '72 with this court, there were at least five or six different plants in the State of Illinois which were putting their sewage effluents into Lake Michigan.

"We have heard all sorts of testimony about street runoff and the pollution that it contains. How can Chicago say it does not have a responsibility? How can Illinois say it does not have a responsibility when they still have not, to my knowledge of the record in this case, taken the backwash water filtration materials out of Lake Michigan?

"How can the State of Illinois argue that Milwaukee has the total responsibility for all the problems of the State of Illinois when it has in the city of Chicago over 5,000 miles of combined sewers carrying storm and sanitary sewage, covering 100 percent of the City of Chicago, and which bypass more or less regularly into the river system and then into Lake Michigan?

"Your Honor, the City of Milwaukee has 27 square miles. I understand the City of Chicago is 375 square miles. We only have 27 square miles of combined sewers in the City of Milwaukee. As the court knows, we are making every effort to find out what can be done about the problem and eliminate it. There is a commitment to do."

JVK pointed out that Illinois -- for example, at the Chicago and North Shore treatment plants -- has found it possible to use advanced technology to meet the stringent state limits, and that even the Glencoe water filtration plant (JVK, tr. p. 13,819)

"...was forced to get rid of its backwash from its filters. Follow with me, if you will, the logic of this. Remember the filters are concentrating whatever contaminants are coming in from the lake, and that becomes a pollutant unto itself of which there is great concern, and there would not be great concern, among other things, if we cleaned up the lake. But the City of Glencoe -- this is the irony of it -- a small village dealing with water treatment plant filter backwash has got to go to best treatment, or zero discharge, when the City of Milwaukee, by far the largest discharger of municipal wastes in Lake Michigan, gets along with 1910 technology -- and I mean 1910 technology. What may have been a 'Seventh Wonder of the World' back then is certainly not a 'Seventh Wonder' now."

With regard to the question that began this section, Judge Grady's findings do not specifically address the defendant's argument that Lake Michigan is satisfactorily assimilating the wastes continuously entering it in the form of treated effluents and occasionally in the form of CSO. But the judge does refer (tr. pp. 14,214-17) to discharge of "insufficiently treated sewage" and "disease-causing bacteria and viruses." He notes (tr. pp. 14,209-10) that there is agreement between plaintiffs and defendants that

"...parcels of water from the Milwaukee area do travel past the state line to the south and do transport materials from the Milwaukee area to the state of Illinois. As another example of an important fact that is not in dispute, the defendants and the plaintiffs agree that sewage overflows and discharges of raw sewage into the lake are undesirable."

Judge Grady had been convinced by the evidence that though the defendants were attempting to conform to the 30/30 standard, they also discharge "disease-causing bacteria and viruses" into Lake Michigan during wet weather overflows and in the form of "insufficiently treated sewage" from JISTP and SSSTP (tr. pp. 14,214-17).

GRADY (tr. p. 14,215):

> "The defendants attempt to conform their effluent to a standard of 30 parts per million of suspended solids and BOD, but they rarely achieve that standard and concede that before they can meet it with any consistency, a substantial amount of additional plant renovation and updating will have to be done. But even if a 30/30 standard were met, it is my finding that the standard would still result in the discharge of staggering numbers of pathogens to Lake Michigan."

To the defendants' pleas: (1) that it is unfair to require them to upgrade their sewage collection and treatment facilities at great cost when corresponding benefits to Lake Michigan cannot be demonstrated; (2) that, irrespective of controls imposed on point sources, large and uncontrollable inputs from nonpoint sources will continue, and (3) that deterioration of Illinois waters (if it is occurring) should be primarily attributed to discharges in that state, Judge Grady's responses were:

GRADY (tr. pp. 14,243-44):

> "I would like to discuss the defendants' argument that the Illinois discharges into Lake Michigan are somehow a defense to the defendants. First of all, it is a fact that most point sources in Illinois are now out of Lake Michigan. To say that the once-a-year discharge that is contemplated by the Waukegan plant of the North Shore Sanitary District is to be considered in the same light as Milwaukee's discharge of 320 million gallons a day, plus overflows, is not, I think, a valid argument."

GRADY (Memorandum Opinion; see Appendix VII, p. 17):

> "If defendants' argument were to be adopted, it would be impossible to impose liability on any polluter. If any one point source can defend successfully on the ground that its discharge alone is not causing the problem and that without its discharge, the problem would still exist, then that defense would have to be equally available to all point sources. What is a good defense for Milwaukee would have to be a good defense for any other point discharger, especially since Milwaukee is the largest point discharger."

In his Memorandum Opinion of March 1978, Judge Grady further reinforced this opinion, citing legal precedent (App. VII, pp. 18-20), and the argument that the existence of nonpoint sources is somehow a defense of discharge from point sources was rejected (App. VII, p. 18).

7.2 To What Extent Are Milwaukee's Discharges Harmful to Illinois?

Emphasizing the large dilution steps in fecal coliform counts, which four years of records show to occur between CSO outfalls and Milwaukee Harbor and between the harbor and the lake, McCabe cited representative numbers to demonstrate a "tremendous drop within about a mile of the breakwater" (tr. p. 14,003). If, as was the case, no problems with drinking water treatment had arisen in Milwaukee, why should they arise in Illinois? Furthermore, two years of testing on Milwaukee's North Shore beaches had not shown them to be adversely affected; why, then, should such an effect be expected in Illinois?

McCABE (tr. p. 14,025):

> "I invite the court to look at the average which Mr. Kupfer came up with on the North Shore beaches. I think once in the last two years they got more than 10 percent of the counts over 400, and I believe that exceeded it by one day. As a result of all of these counts, these beaches are all going to be open regardless of wet weather in the future. So if in fact Milwaukee discharges are not adversely affecting Milwaukee citizens -- in other words, are not depriving them of the use of the lake -- I think we are stretching far beyond the bounds of credibility when we suggest that they are in fact being detrimental to the State of Illinois and [its] citizens."

And why, Moerke asked, had no one from the Chicago water treatment plants (which have comprehensive intake quality controls) come forward to testify concerning the alleged harmful effects of Milwaukee's discharges?

MOERKE (tr. p. 13,910):

> "We haven't seen any personnel from any of the water plants, except the village of Glencoe, to show the effect of Milwaukee-originated sewage or effluents, or for that matter, from Racine, Kenosha or South Milwaukee, on the efficiency or operation of any water treatment plants between the state line of Wisconsin and the state line of Indiana, or on the ability of those plants to produce potable water."

On the other side, JVK asserted that Csanady's plume models show that the transport distance without safe dispersal can occasionally reach 100 km.

JVK (tr. p. 13,730):

> "Let's talk about the fecal contamination that gets out into the lake. Let's start with whatever number the court would like to start with. We will play a dilution game out here.
>
> "I will be the first to acknowledge that there may be days in which it is totally dispersed within the environment. There are days out there that you could put in a carload of cyanide and nobody would know the difference. But I suggest to the court there are also other days in which, because of the tremendous variability of the lake...the range of a pollutant transport, without safe dispersal, is on the order of 100 kilometers, I believe it is, which is on the order of 70 to 75 miles."

Noting that, while some salient facts are agreed upon by the parties, Judge Grady concluded (tr. pp. 14,209-10):

> "There are more facts, however, that are in dispute than are agreed upon, and the nature of the factual dispute is such that I have found it necessary to rely upon expert witnesses to a far greater degree than is normally required in an ordinary lawsuit and even in the typical suit involving matters of science and technology."

The judge said that he attached "almost no weight" to the defendants' fecal coliform surveys in and near Milwaukee Harbor and along the Wisconsin-Illinois coastline (tr. pp. 14,218-19):

> "They were conducted without adequate information as to the prevailing conditions, so that the results were impossible to interpret. I refer specifically to the fact that these studies, designed to show that currents running to the south would not carry materials to the south, were conducted by people who did not know which direction the currents were going in at the time they conducted the studies and took their samples. Neither did the persons who conducted the studies know where on the hydrograph and where on the pollutograph they were at the time they conducted their wet weather studies.
>
> "Furthermore, to the extent that these studies show an apparent decrease in the number of fecal coliforms contained in the top three feet of the water, they demonstrate nothing about the number of viruses that might have been in that top three feet of the water. The evidence is clear on both sides that you can have zero fecal coliforms and many viruses in the same parcel of water.
>
> "Moreover, the number of samples taken was insufficient. And the depth at which the samples were taken was insufficient to reflect the probable counts which might have been found at other levels."

Judge Grady also found the coliform experiment at SSSTP "inconclusive at best" (tr. p. 14,210). On the question of plume dilution, Grady favored Csanady's model.

GRADY (tr. pp. 14,216-17):

> "The experts are in conflict as to the amount of dilution and even as to the proper scientific principle to be applied to determine the amount of dilution. Notwithstanding that dispute -- which I resolve in favor of the plaintiffs on the basis of what I perceive to be the greater credibility of their witnesses on the subject -- there still is not sufficient dilution to eliminate the viruses and the bacteria from the water which we know arrives in Illinois from Milwaukee on some occasions during the course of the year. There is no reason not to believe that bacteria and viruses numbering literally in the millions are transported live and intact from Milwaukee to Illinois waters."

7.3 Should Determination in this Case Rest on Proven Nuisance or Potential Hazard?

Moerke referred to earlier interstate pollution disputes that came before the U.S. Supreme Court (tr. pp. 13,922-24):

(1) New York v. New Jersey, in which that court stated:

> "Before this court can be moved to exercise its extraordinary power under the Constitution to control the conduct of one state at the suit of another, the threatened invasion of rights must be of serious magnitude and must be established by clear and convincing evidence."

(2) Missouri v. Illinois (first case, 180 US, 1901), in which that court said:

> "If evidence be conflicting and the injury doubtful, that conflict and doubt would be a ground for withholding an injunction, and that where interposition by injunction is sought to restrain that which is apprehended would create a nuisance of which its complainant may complain. The briefs must show a state of facts as will manifest the danger to be real and immediate."

(3) This opinion was repeated again in a second Missouri v. Illinois case (200 US, 1906):

> "A nuisance must be made out upon determinant and satisfactory evidence. It must not be doubtful, and the danger must be shown to be real and immediate."

The Missouri v. Illinois cases and this Illinois v. Milwaukee case have in common the protection of Lake Michigan. The 1901 and 1906 cases arose because of the proposed diversion (now in operation) of Chicago's sewage effluent from Lake Michigan and the St. Lawrence drainage into the Illinois River and thence to the Mississippi River. That diversion, beneficial to Lake Michigan, was possible because the watershed divide is close to the southwestern shore of Lake Michigan.

Rejecting the relevance of Missouri v. Illinois to defendant arguments that Illinois sources were also polluting Lake Michigan, JVK suggested (tr. p. 14,101) that

> "...the law is very clear that co-tort-feasors, the fact that there are other tort-feasors with respect to this, does not relieve the defendant of liability."

McCabe countered with reference to earlier pollution of Lake Michigan by the North Shore Sanitary District and Waukegan plants in Illinois, since corrected or in the process of correction.

McCABE (p. 14,189):

"Well, the first thing that you learn in torts is that if you are responsible for 60 percent of the damage or 80 percent of the damage -- at least in Wisconsin -- you are not going to recover from the other person, and that is what we have in terms of the State of Illinois.

"Their own people say, 'We cleaned up our plants on the north side and now we can have our beaches open.' The damage was there."

McCABE (tr. p. 14,190):

"I can appreciate why counsel wants to shy away from the nuisance, the definitions of nuisance.

"He stated he thinks he has proved the case. I think otherwise, and I think the discussion this morning indicates why there in fact has been no nuisance.

"That is what this case is, interstate pollution, common law nuisance. It is not a question of doing the best that you can. No government is required to do the best that it can. It is only required not to harm the next state down the line. That is all it is required to do, and the evidence in this case shows, first of all, there is no evidence that we are harming them in any sense, and I think with respect to the lake question, the witnesses have been in agreement that although anything that one puts into a lake affects it in a theoretical sense, that if you can't determine in terms of tests what the effect of Milwaukee would be on the whole lake, then it has no effect legally."

Judge Grady, however, ruled differently. He referred to pages 242 and 244 of Missouri v. Illinois (180 US, 208) (see also App. VII, pp. 14-15).

GRADY (tr. pp. 14,226-27):

"The position of the State of Illinois at this juncture of that particular litigation was that there had been no showing of any harm as yet, and the Supreme Court of the United States said:

"'In the first place, it is urged that the drawing, by artificial means, of the sewage of the City of Chicago into the Mississippi River may or may not become a nuisance to the inhabitants, cities and towns of Missouri; that the injuries apprehended are merely eventual or contingent, and may, in fact, never be inflicted. Can it be gravely contended that there are no preventative remedies, by way of injunction or otherwise, against injuries not inflicted or experienced, but which would appear to be the natural result of acts of the defendant, which he admits or avows it to be his intention to commit?'"

GRADY (tr. p. 14,228):

"It seems to me that in some of the arguments the defendants have presented in this case, they have confused two things. One is the elements of the cause of action which the plaintiffs must prove, and the other is the standard of proof by which those elements must be proved. The defendants contend that the evidence must be clear and convincing. I am adopting that view for purposes of this case.

"The second question is, What must the clear and convincing evidence show? The defendants take the view that because the evidence must be clear and convincing, it must show an actual injury. Otherwise, it is not clear and convincing. It is my view and my understanding of the law that what the plaintiffs must show by clear and convincing evidence is the existence of a hazard, whether or not that hazard has in fact eventuated in an injury. The hazard itself is the injury justifying injunctive relief in this kind of case.

"I find from what I regard as clear and convincing evidence that the discharge of sewage by the defendants into Lake Michigan constitutes a health hazard of serious magnitude to the residents of the State of Illinois and that, unless enjoined by this court, that danger will continue to exist."

GRADY (tr. p. 14,244):

"The defendants cite the cases of Missouri v. Illinois (200 US 496, 1906), and the New York v. New Jersey (256 US 296, 1921). Neither of those cases is applicable to the facts we have here. In both of those cases, the evidence showed that the pollution of which plaintiff was complaining already existed by virtue of plaintiff's own activities. The waters which it was seeking to protect were already so polluted by its own discharge that it could truly be said that any activity of the defendants would not add materially to the condition.

"In the case of New York v. New Jersey, New York was discharging raw sewage from its entire population into New York Bay, a badly polluted body of water, and it was seeking to enjoin the discharge of primary effluent, which had at least received primary treatment, by the State of New Jersey into the same bay. Clearly, that situation is distinguishable from this one, where we are dealing with a body of water that is still relatively clean..."

Judge Grady's answer to the question heading this section is summarized in his Memorandum Opinion of March 1978 (Appendix VII, p. 8):

"It was incumbent upon the plaintiffs, of course, to prove not simply that Milwaukee is contaminating its own drinking water, but that the Milwaukee discharges have an effect upon the residents of Illinois and Michigan. I have found from clear and convincing evidence that the Milwaukee discharges do adversely affect the residents of these other states, and I will explain briefly what the evidence has shown. There are two aspects of this: first, the public health problem, and second, the problem of eutrophication."

These two aspects are discussed further in the memorandum (see App. VII, pp. 8-13).

7.4 To What Extent Is Eutrophication (and Milwaukee's Contribution to It) Harming Lake Michigan?

This question, of course, begs another: Harming Lake Michigan in what way and for which use? One can consider the effect on the fishery or recreational enjoyment, or the effects on desired features in a "balanced ecosystem." The plaintiffs and defendants in this case did not attempt to define harm or to quantify blame.

JVK feared there was a parallel between the present state of incipient degradation in waters near pollution sources in Lake Michigan and the early stages of the degradation of Lake Erie -- and he feared the same attitude toward it as well: "We need not worry about the effects because they are local and the lake is large enough and well-mixed enough to assimilate the wastes" (tr. pp. 13,693-94, 13,695-96, 13,704).

JVK (tr. p. 13,693):

> "If you review the record -- I have gone through every one of the defendants' biological witnesses. Invariably the argument is that it is a local problem; it need not concern us; Lake Michigan will self-purify itself -- every one of them a local problem, every one of them; no need to concern ourselves with the lake as a total environ.
>
> "When I say the lake is a total environ, let me emphasize that contrary to the image given by the defendants, we don't have that whole lake out there to assimilate. I think this is one of the things that was most interesting in the trial, is that both biologically as well as physically, the lake is divided between inshore and offshore zones. All of the Great Lakes are divided between inshore and offshore zones."

JVK (tr. p. 13,695):

> "What we see is that the cutoff point, when we can say there will be a problem or won't be a problem, is incredibly difficult to describe. What we see is that despite the claims of, I am sure, eminent biologists and eminent sanitary engineers -- I think many of the people we are dealing with here are -- how should I say it, and I don't mean this in any disparaging way -- they believe in, they adhere to, they espouse what is referred to as an engineering philosophy. This is the core of the concept of 'we can plan the world; we can manipulate what will go into the environment without concern of any harm'."

JVK's contention was that the time for reasoning was past and that the time for action had come.

JVK (tr. p. 14,124):

> "We reasoned ourselves into a very bad situation with respect to Lake Erie. We reasoned ourselves into a potentially disastrous situation with respect to Lake Michigan.

"When we are talking about Lake Michigan, Your Honor, I listened to Mr. McCabe this morning talk about his various theories of Lake Michigan. I can expound on them some more. The fact is that the scientists who work on Lake Michigan are very concerned. Dr. Schelske and Dr. Beeton are the only scientists who work on Lake Michigan on a day-to-day basis that have testified in this courtroom. They are very concerned.

"Dr. Shapiro said, 'If I had my druthers, I would remove as much phosphorus as possible.'"

For the defendants, Moerke and McCabe attempted to summarize the opinions of the plaintiffs' counsel (including T.J. Emery for the State of Michigan) on eutrophication as follows.

MOERKE (tr. pp. 13,933-34):

"As I understood the argument of both Mr. Karaganis and Mr. Emery, they are saying to this court, in effect, 'We don't know what the problem is in Lake Michigan.' They are also saying, 'We don't even know if there is a problem.' Mr. Emery says, 'I don't want to wait until I find out whether there is a problem or not.'

"I submit to the court that that is a very, very flimsy basis upon which to order the defendants and indirectly down the line perhaps order other people on the lake, if this court issues such an order, to do certain things and expend certain monies.

"This is an issue, it seems to me, which we could directly address. I will repeat again that our clients would be willing to make their share of the money available for such a purpose, if this court should agree, to determine precisely what the level of phosphorus should be and what the relationship is of the various chemicals which are in the lake. Let's find out once and for all. Let's do it on a scientific basis."

McCABE (tr. pp. 14,025-26):

"Concerning now the phosphorus eutrophication question, at the beginning of the trial when the word 'eutrophication' was explained to all of us, the questions would generally be quipped to plaintiffs' witnesses, 'Well now, we are not just concerned about local effects, are we? We are concerned about the entire lake.' And the witness would respond, 'Yes,' appropriately.

"However, when witness after witness after witness, including Dr. Beeton, testified that although they would like to see Milwaukee's phosphorus out of the lake, as indeed they would like to see all phosphorus out of the lake, when they were asked whether or not there would be any demonstrable change in the lake as a result of removing Milwaukee's phosphorus entirely, they all answered 'No,' that although there would be obviously a theoretical improvement to the lake vis-a-vis eutrophication, it is not something that can be tested.

"I suggest to the court that if, with all our sophisticated scientific apparatuses, if we cannot determine the effect, if we cannot measure the effect of an alleged polluter, then I think we are light-years away from having proved a nuisance."

McCABE (tr. pp. 14,036-37):

"There was never any attempt by the plaintiff to quantify any effect of Milwaukee upon Illinois. Without an attempt to quantify it, I suggest that there is absolutely, that there has not been a serious attempt to prove a nuisance. If you cannot quantify a change that you are asking for, then there is no nuisance being generated by what you are trying to remove."

Judge Grady's conclusion was that "the amount of phosphorus in Lake Michigan is increasing" (tr. p. 14,230) -- although, in fact, witnesses had been unable to define what the change had been in recent years -- and that "accelerated eutrophication" was now in progress (the scenario of Ref. 35):

GRADY (tr. p. 14,231):

"The evidence of the accelerated eutrophication is the decrease in dissolved silica, which I find is due to its utilization by diatoms, a decrease in the diatom population and an increase in blue-green algae, both in the inshore zone and the offshore zone."

GRADY (tr. pp. 14,235-36):

"There is no evidence that any specific algal problem or any specific taste and odor problem experienced by residents of Illinois or Michigan is attributable to Milwaukee's sewage as opposed to the nutrients discharged by any other point or nonpoint source. This, indeed, is the nature of this problem. It is not possible to segment nutrient inputs and ascribe this part to one source and another part to another source. All point and nonpoint sources combine to create the totality of nutrient inputs to the lake."

GRADY (tr. pp. 14,238-39):

"We know that Milwaukee is the biggest point source on the lake and that of the total point sources on the lake, the Milwaukee discharges constitute a substantial percentage.

"Now, does the fact that we have little or no ability to control nonpoint discharges to the lake mean that we ought to ignore the point discharges? I think the answer to that is no."

GRADY (tr. pp. 14,235-36):

"This case has to be looked at in a temporal way differently than the ordinary nuisance case is looked at...and, therefore, the parameters of a nuisance in regard to that lake must have a temporal aspect consistent with that long-term human need for the use of that lake."

GRADY (tr. p. 14,243):

"While it might be argued that the deleterious impact of eutrophication is of a far lesser magnitude than the danger presented by pathogens in the water, I believe that the results of eutrophication are serious enough to be an enjoinable nuisance." (See also App. VII, pp. 16-18.)

7.5 Does Presumption of Health Risk Merit a Legal Remedy in the Absence of Case Histories of Disease?

A down-to-earth negative answer to this question was given by Moerke.

MOERKE (tr. p. 13,910):

"...I would like to see one person get on the stand here and say, 'I got a rash on my skin because I swam at Illinois Beach State Park,' whether it is related to Milwaukee or not.

"I would like to see one person get on the stand here and say, 'I got diarrhea, and I think it is from drinking water.'

"I would like to see one doctor come in with a clinical case relating myocarditis to a virus that was transmitted from a waterborne source. I would like to see one person on the stand with a bellyache.

"We haven't seen any of those kinds of witnesses. And I am not asking for dead bodies; I am not asking for heart attacks. I am just asking for one bellyache, that's all, and there hasn't even been that on the stand."

JVK drew a parallel to the U.S. vs Reserve Mining case (discussed further in Section 7.6), in which the health risk issue was the possibility that asbestos-like fibers in taconite tailings are carcinogenic and get into the Duluth, Minn., water supply (Refs. 45, 46).

JVK (tr. p. 14,122):

"They haven't done any data. They had scientists testify. That trial went on for 375 days on the question of what the asbestos health risk was. They couldn't develop a link, but somebody had some common sense at the district court level, Judge Lord and now Judge Devitt. But with respect to the Eighth Circuit, they had the common sense to say that on a risk basis, we can't take the risk. They have ordered a complete cleanup.

"In the meantime, Your Honor -- this is, again, hearsay on my part, but the EPA tells me that up there the citizens of Duluth have been drinking bottled water because of an undefined, less-proven risk than we are dealing with here.

"I am not suggesting that the citizens of Illinois drink bottled water. I am suggesting that we get about the job of making sure that everybody who discharges into Lake Michigan does an adequate job."

JVK (tr. p. 14,121):

"Because I think the level of harm that is shown in terms of potential harm, Mr. Moerke would agree and all the briefs agree, that the standards set out by the state common law and the federal common law is that a nuisance is established if you present threatened harm. It doesn't have to be actual harm; it can be threatened harm."

Judge Grady did not accept the defendants' argument that the "mere possibility" of an Illinois resident contracting a waterborne disease did not, in the absence of evidence of that disease, justify the relief sought by the plaintiffs. The judge responded to Moerke's pleas for just "one bellyache" as follows.

GRADY (tr. p. 14,226):

"If the defendants want that kind of evidence, as they do, they will never receive it. It is impossible to produce.

"The second problem with that approach is that it ignores the fact that exposure to a hazard, whether or not that exposure results in the actual contraction of a disease, is itself actionable. On the virtually undisputed evidence in this case, there is some degree of hazard to the residents of Illinois from Milwaukee's sewage. It is the degree of that hazard which is in dispute." (emphasis added.)

GRADY (tr. p. 14,223):

"Despite the large percentage of viruses which are deactivated and removed in the process of sewage treatment, there is no question that large numbers of them do get through and are discharged to the lake because of the insufficient treatment of the solids in the effluent.

"I am satisfied from the testimony of Dr. Wellings and other witnesses in the case that unless there is a good removal of solids and a free chlorine residual, there is not adequate kill of viruses. There is evidence in the record on both sides of the case which I find convincing on that point. The defendants never have a free chlorine residual by the amperometric test, which I find from the evidence is the more valid of the two methods of measuring a chlorine residual."

GRADY (tr. p. 14,215-16):

"These pathogens, once they are discharged to the lake, are on occasion transported by the currents to the waters of the State of Illinois...The bacteria live on the order of four to eight days in the water, and there is a phenomenon known as regrowth, which can result in a substantial replacement of bacteria which die by the birth of new bacteria during the southward flow. Viruses, which I regard as the more serious of the two principal types of pathogens with which we are concerned, live for a week and a half or two weeks in warm water and can live for months in colder water."

GRADY (tr. p. 14,224):

"The defendants also argue that there is no evidence of any outbreak of water-related diseases in Illinois, and this is true. However, I am persuaded by the expert testimony that the diseases caused by the pathogens in sewage are mostly of the kind, if not all of the kind, that are not likely to be reported, and if reported, are not likely to be diagnosed as a viral disease or even as a bacteriological disease related to water...

"Therefore, I find that the absence of any reported outbreak of enteroviral diseases, or of shigellosis or salmonellosis or any of the other bacterial diseases, does not demonstrate that such diseases are not being contracted by residents of Illinois by reason of their exposure to waters of Lake Michigan which contain pathogens."

In summary, Judge Grady noted that the defendants, in seeking an answer to the health risk question, argue that "because the evidence must be clear and convincing, it must show an actual injury. Otherwise, they say, it is not clear and convincing. I believe what plaintiffs must show by clear and convincing evidence is the existence of a hazard, whether or not that hazard has in fact eventuated in disease. It is the exposure to the hazard which is the injury justifying injunctive relief in this kind of case" (tr. p. 14,228, longer quote in Section 7.3; see Appendix VII, p. 15).

7.6 Parallels with the U.S. v. Reserve Mining Corporation Case

The parallels between this case and the other Great Lakes landmark case, U.S. v. Reserve Mining, are evident. The chief determining factor in the final judgement in both cases was the possibility of a threat to public health posed by agents (asbestos-like fibers in the Reserve Mining case, viruses in the Milwaukee case; Refs. 47, 48) whose mode of action could not be quantified and to which no reportable disease could be attributed. The limnological issues in both cases turned out to be of secondary importance in the judges' rulings. Indeed, in the Reserve Mining case much of the limnological evidence was never brought into court. In the later appeal stages of that case, however, there was a shift in judicial opinion, and the protection of Lake Superior reemerged as a major issue (Ref. 47). From Appendix 5 of the June 4, 1976, decision of the Eighth U.S. Circuit Court of Appeals:

> "...the proof of a health hazard requires more than the mere fact of discharge; the discharge of an agent hazardous in one circumstance must be linked to some present or future likelihood of disease under the prevailing circumstances."
>
> "A fair review of this impartial testimony by the court's own witnesses -- to which we necessarily must give great weight at this interim stage of review -- clearly suggests that the discharges by Reserve can be characterized only as presenting an unquantifiable risk, i.e., a health risk which either may be negligible or may be significant, but with any significance as yet based on unknowns."

"After our examination of the relevant portions of the lengthy record in this case, we come to these conclusions:

(1) it is unlikely that Reserve will prevail on the merits of the pollution issues and overcome the trial court's determination that pollution of Lake Superior must be abated;
(2) it is also unlikely that Reserve will overcome the trial court's determination that the air emission must be controlled; but
(3) Reserve, as we have demonstrated, may well prevail in its contention that its emissions into the air and water have not proven to be a substantial health hazard."

In the Illinois v. Milwaukee case, the final outcome of seven months in court and voluminous preparations was condensed in Judge Grady's Judgement Order of November 15, 1977, and Memorandum Opinion of March 9, 1978 (reproduced in full in Appendices VI and VII, respectively). The latter document is the clearest summary of the judge's reasoning and a distillation of his judgement.

Section 8:

The Process of Environmental Litigation and Policymaking: Can It Be Improved?

In environmental and public health matters, society has evolved a variety of procedures for arriving at authoritative decisions for implementing them. Such mechanisms include public debate, legislation, rule-making, and monitoring and enforcement by federal and state agencies, backed by the authority of the courts of law. Increasingly in recent years, litigation has enabled individuals or groups of citizens to intervene in the decision-making process and to control the actions of particular polluters. The public interest and the environmental preservation causes have also been championed by state governments through their attorney generals. As Francis T. Mayo (formerly the EPA regional administrator in Chicago) pointed out in introducing JVK at a banquet in 1978 (Ref. 49), the Illinois Attorney General

> "...enjoys some environmental latitudes that most attorney generals do not. The office has the opportunity to initiate actions of its own, whereas in most states they come to the attorney general's office through an environmental agency.
>
> "Bill Scott in Illinois has had a deep personal concern for environmental issues and a pretty astute political perspective. With Bill Scott's initiative and Joe Karaganis' talents, they have built a very, very enviable reputation for dealing with the giants of industry and taking on the big ones in some very, very difficult and very challenging environmental issues."

In this context, Milwaukee was also perceived to be a giant, though of a different species (JVK, tr. p. 14,125): "Milwaukee happens to be the biggest discharger by far. They are the prime target. They have been ever since this litigation was initiated."

8.1 The Emerging Question

Five years elapsed between the initiation of Illinois v. Milwaukee (May 1972; see Section 1.1) and the issuance of the final judgement in 1977. The mass of court documents -- 14,257 pages of transcripts and a corresponding body of exhibits -- constitute the script of a seven-month-long courtroom drama containing plums of technical and human interest embedded in a great deal of tedious dough. It leaves the lay reader with some understanding of the way in which the adversarial and judicial process arrives at a judgement. But an insistent question remains: Is there a more effective way of directing the powerful legal and technical energies expended during a trial of this nature toward clearer definitions of scientific truths (or probabilities) and therefore toward fairer and wiser judgements in strongly disputed environmental matters?

It would take a great deal of time and effort to review the wide spectrum of institutional and procedural modes that have been or could be suggested for the resolution of legal conflicts in resource management and environmental protection. Modes in that spectrum include:

(1) the creation of administrative agencies, each with its own legal and technical experts, to make and enforce rules* and to act collectively as a judge in matters under dispute;

(2) judicial panels of expert umpires whose standing and distinction would imbue their verdicts with necessary authority (e.g., the science court proposed by Arthur Kantrowitz);

(3) inquisitional tribunals in the continental model, comprised of both legal and technical "judges;" and

(4) hearings by a single, law-trained judge, without a jury, of the evidence and arguments presented by the protagonists' counsel and expert witnesses.

The Illinois v. Milwaukee and U.S. v. Reserve Mining Corporation cases are examples of the last (#4) procedural mode. Therefore, the following suggestions are directed at and confined to possible improvements in that particular procedure. These suggestions envisage (1) the retention of adversarial modes (with counsel and experts on either side); (2) a broadening of the judicial components (by adding court-appointed impartial experts or creating a judicial panel), and (3) the addition of an investigative function, when appropriate, to the court's other functions.

8.2 Optimizing the Use of Experts

In making a judgement in complicated technical cases tried without juries, the judge has a twofold task: interpretation of the law and interpretation of the scientific or engineering evidence. A judge is on home ground in the first task; in the second, however, the judge is heavily dependent on experts (and on their interactions with counsel) to get at the truth, to define areas of ignorance and to assess hazard or risk. In this task the judge is, in effect, a one-person jury (the question whether that authority should be shared is discussed later), and it is the responsibility of the experts and of counsel (through skilled examination and cross-examination) to ensure that data are properly described, statistical limits defined, hypotheses clearly stated, assumptions clarified and areas of ignorance confessed. In ideal procedures, that is what occurs. However, I suspect (and the Illinois v. Milwaukee record shows) that there is often a mismatch between the modes of thought of the lawyer and that of the scientist or

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*see later reference (Ref. 52) to judicial review of administrative decision-making and developments in integration of law and technical policy analysis.

engineer. Lawyers are nurtured on rules of evidence and are more comfortable with clear-cut alternatives, while technical experts are conscious of the complexities of their narrow fields and tend to preface answers with "it depends." Such apparent lack of articulation does not make a "good" expert witness, as Schelske (a witness with whom Judge Grady felt "comfortable") agreed under cross-examination by F. M. Van Hecke (tr. p. 2,430):

> Q. "You stated that the effects in Lake Michigan that are nearshore are moving offshore, and you said something that kind of interested me. You said, and I think I am quoting your exact words, that 'a case can be made' that this is happening. Does this indicate that, in your opinion, a case can be made that this has not happened?"
> A. "I think, when I make statements like that, it is the scientist talking, as you would when you present scientific evidence to a scientific audience, and I probably should make those kinds of statements much more strongly, because there is no question about that case, about being able to make that case."

However, other experts in the case reached a different conclusion (see Section 5).

The dependence of the judge on experts was stated with unusual explicitness by Judge Grady (tr. p. 14,210): "The nature of the subject matter here, however, is such that my own experience and observations in life are of relatively little use to me."

GRADY (tr. pp. 14,210-12):

> "What I have to do, though, because of the problem, is to rely to a very large extent upon expert witnesses whose credibility impressed me favorably. Both sides have produced in this case expert witnesses whose credentials were impressive, if not overwhelming...
>
> "These people devote their lives to a study of the questions which confront us here. In doing that, they necessarily come to conclusions and reach points of view and become members of schools of thought on subjects pertinent to this inquiry. That, standing alone, does not make the witness biased in any invidious sense. I have found some witnesses in this case who, despite their obvious commitment to particular points of view, were, in my opinion, honest, forthright, reasonably objective and who, in my opinion, made a genuine effort to be helpful to me in the resolution of these difficult problems...
>
> "I believe it will be helpful to the parties in understanding the basis for my decision, and helpful to the reviewing courts in passing upon the validity of the decision I make, to know what I thought of the witnesses...
>
> "Without the benefit of all those observations, it seems to me that it will be a very difficult task for a newcomer to the case to have the kind of grasp he would like of the probable credibility of the various witnesses."

Not intending to be "unkind or to denigrate anyone unnecessarily," Judge Grady classified the witnesses as follows: four (all plaintiff witnesses) were "outstanding," another five (3 defendant and 2 plaintiff) were "almost equally helpful" and six (5 defendant, 1 plaintiff) were "biased in the undesirable connotations of that term" (tr. p. 14,213), "combative and unwilling to concede points that they should have conceded because they were so obvious" and on occasion were "evasive and doctrinaire."

The limnologists, the judge said, were "in a class by themselves":

GRADY (tr. p. 14,213):

> "It was perhaps accidental, but nonetheless significant, that they were even treated as a separate class in that they were permitted to sit through the testimony of other witnesses. The limnological testimony was the least conclusive, the least satisfying, the least convincing of any of the testimony in the case. This is no reflection upon the witnesses who gave it, but rather a statement describing the state of the art. What we do not know about what goes on in Lake Michigan far exceeds what we do know, and all of these persons readily acknowledged that. The limnologist whom I found most helpful and upon whom I rely with the greatest feeling of comfort is Dr. Schelske."

Such commentary on expert witnesses, while displaying welcome candor on Judge Grady's part, also highlight a potential danger. The danger is that a judge's personal perception of the "credibility" of a witness may play an overly dominant role in a complicated technical decision, and *ad hominem* arguments will therefore be given too much weight. The key to reform, if necessary, appears to lie in better use of expert witnesses and in changes in the judge's interaction with them.

The potential danger referred to here arises not so much from the fact that few judges are trained to cope with complex scientific and technical issues or with risk assessment at the frontiers of many specialities (geophysics, toxicology, nuclear physics, microbiology and ecology, to name a few), but from the conscious or subconscious pressure on partisan witnesses to put their side's case in the best light with the minimum of hedging and with no gratuitous disclosure of facts or qualifiers that would weaken the point that the witness and his/her counsel are attempting to leave with the judge. A perceptive judge will, of course, make allowances for the differences between legal and scientific modes of thought and experience and will recognize attempts at oversimplification by partisan witnesses.

But the gap between the legal and scientific modes of thought is likely to widen (at least in the environmental field) with increasing reliance in the future on complex mathematical models to simulate or predict events in nature. It is difficult to carry out a thorough examination of the assumptions and the statistical reliability of such models by questioning and cross-examination in a court of law. Even many scientists find it difficult to conduct a dialogue with modellers at scientific conferences.

Is it surprising, therefore, that lawyers should sometimes show impatience with them? Consider Judge Grady's reaction to Pritchard's exposition of various diffusing plume models by means of colored graphs and a pocket calculator (tr. pp. 6,992-93):

> GRADY: "Let me say one more time that I am either going to decide here that is it like the black one or like the red one or like the blue one or like none of them. But when I decide that, then one of you who is knowledgable in the use of one of these little calculators can do the rest for me."
> JVK: "It has to be a number that goes into it."
> GRADY: "And none of your mathematics is going to convince me which one of those patterns to select. Rather, the mathematics will merely help me interpret the facts once I decide what the facts are."

Some of the potential difficulties arising from mismatch, partisanship or involved technical arguments can be removed if in such difficult cases the judge designates his/her own experts as "friends of the court" to serve as impartial sources of review and evaluation. This was done to good effect by Judge Lord in the U.S. v. Reserve Mining case. The testimony of the court witnesses in that case was given considerable weight in the June 4, 1974, review by the Eighth U.S. Circuit Court of Appeals (see Ref. 47). Judge Grady elected not to appoint court witnesses in the Illinois v. Milwaukee case, although he extensively questioned some witnesses, thereby temporarily turning the court into a seminar. Judge Grady must have also sought technical advice before arriving at the stipulations of his Nov. 15, 1977, Judgement Order, but the record does not state which experts were, in fact, the source of that advice.

In conclusion, the appointment of impartial court witnesses could assist (and often speed up) the proceedings in complex environmental cases, and their input would be valuable in mediation attempts. As a practical matter, the fee structure for witnesses should ensure that the judge has access to experts of the highest caliber and that fee competition not favor one side or the other at the expense of the court. A further development of the court-witness concept is worthy of consideration, and that is the creation of a judicial panel with both legal and technical members. By apportioning judgement responsibility, such panels would decrease the danger that one person's perception of witness credibility or degree of risk will carry too much weight. It can, of course, be argued that the appeal procedure will achieve the same end, but often on appeal (as in the Illinois v. Milwaukee case) the technical issues are not reopened.

8.3 Courts as Pacesetters in Risk Regulation

The Illinois v. Milwaukee case is an example of a class of environmental cases in which a risk was identified but not quantified, and in which the judgement nevertheless imposed a substantial expenditure on the defendant in an attempt to reduce the risk. For Milwaukee, the imposed expenditure and timetable went beyond the requirements of state and federal agencies. Judge Grady's order contained not only a factual determination, but also a risk assessment (a value judgement), and therefore became an instrument of risk regulation. The different contributions of scientific fact, inference and value judgement in risk regulation have been examined by Senior Circuit Judge D. L. Bazelon (Ref. 50):

> "Scientist, regulator, lawyer and layman must work together to reconcile the sometimes conflicting values that underlie their respective interest, perspectives and goals. This cooperation can be achieved only through a greater understanding of the proper roles of the scientific, political and legal communities in addressing the public regulation of risk. Only then can we achieve a program of risk regulation that accommodates the best of scientific learning with the demands of democracy.
>
> "The starting point is to identify the fact and value questions involved in a risk regulation decision. In determining questions of fact, such as the magnitude of risk from an activity, we as a society must rely on those with the appropriate expertise. Judges and politicians have no special insights in this area. Where questions of risk regulation involve value choices, such as how much risk is acceptable, we must turn to the political process."

Judge Grady's order leaves no value choice for the taxpayers of Milwaukee, who are unlikely to see a substantial improvement in the condition of Lake Michigan or in the health of Illinois citizens as a result of the extra expenditure imposed by the order. Could that money have been better spent* to improve health and well-being elsewhere? The expenditure of resources for the reduction of public risk cannot continue indefinitely. A point will be reached at which "greater improvement in health and safety is to be expected from a more stable and viable economy than from a reduction in pollution or the rate of accidents" (Ref. 51). But before that point of political decision has been reached, environmentalists are effectively resorting to the courts to determine questions of value as well as of fact, and thereby to increase the pace of environmental protection and risk regulation, and this has been most readily achievable when public health issues were involved. JVK, in the context of the U.S. v. Reserve Mining case, expounded the strategy in Reference 49:

> "I happen to be a public health advocate. I have yet to find the expert today anywhere who can sit back and say to me that I can safely rely upon the forces of nature to correct the problem, or to rely upon the municipal officials to take the water in and to treat it so it will not cause any hazards, or who can give the kind of guarantees that I feel I am entitled to as an average citizen in consuming public waters as a resident of the Chicago metropolitan area. And I am an advocate for maximal controls, maximum

*See Section 8.5.

elimination of pathogenic organisms at their source. Containment is a philosophy that I have followed...

"Then along came public health. We lawyers always look for this. I mean we have to have it. It's a blood-and-guts issue; no question about it. Public health has sex appeal. Public health is something a judge or any decision-maker can relate to. Very few decision-makers want to be the subject of cancer. Very few decision-makers want to be subject to a debilitating disease. So if you can say to them, 'Look, you or your children or your relatives (or whatever the case may be -- you do not say that to them directly, but the level of analysis is there, they are thinking this) are clearly going to be subject to a serious health risk,' you have come a long way in establishing the basis for abatement of a discharge." (emphasis added)

Though one may deplore the dramatics and the implied manipulation, that technique wins cases and provides welcome environmental protection for reasons not entirely based on scientific logic.

8.4 Circumstances under which Courts Might Initiate Research

The Illinois v. Milwaukee case was notable for the fact that the defendants were put in the position of having to prove by their own field investigations that they were not causing harm to Illinois. As noted in previous sections of this report, counsel for the plaintiffs predictably seized upon the defects in those investigations, but provided no counterbalancing experimental evidence himself. JVK also appeared to have ignored earlier proposals from the defendants for a joint study to arrive at the truth:

MOERKE (tr. p. 13,896):

"If there is a water quality issue, if Lake Michigan is being degraded and eutrophied as has been argued here today, if there is a health hazard which finds its way to Illinois territorial waters and finds its way over to Michigan -- then why is it that we are put in the position of defending the negative?

"...We asked counsel to join us, as a matter of fact, prior to the start of this litigation. We said, 'Let's study this matter. Let's not study it on the narrow issue of whether it is a nuisance to Illinois or not. Let's see if we can find out what is happening to Lake Michigan. We will bear our share if Illinois and Michigan will bear their share.'

"We heard nothing in response to that."

During his final rebuttal speech, JVK was questioned by the judge on this point (tr. p. 14,098):

GRADY: "All of the things that you criticized the Envirex tests for -- and I think in large part those criticisms were valid -- could have been remedied in tests of your own. For

instance, Envirex did not even know which way the current was going."
JVK: "Exactly."
GRADY: "Well, you can certainly find out which way the current is going."
JVK: "Excuse me, Your Honor, and this is one of the things -- if I may explain some of the problems that you have with respect to Lake Michigan."
GRADY: "I have heard four months of testimony about the problems in Lake Michigan. You do not have to tell me anything about that."
JVK: "Well, Your Honor, our advice was with respect to --"
GRADY: "What you are saying to me is that it is impossible to come up with any empirical data better than is in this record? Is that what you are telling me?"
JVK: "That is correct."
GRADY: "I do not believe that."

In his findings, Judge Grady again criticized the plaintiffs' failure to produce experimental evidence, but that lack did not alter the outcome.

GRADY (tr. p. 14,221):

"Now, the State of Illinois had an opportunity to conduct its own study of the kind that Envirex conducted. It elected not to do so. In so electing, it is my opinion that the state chose to produce less evidence than it should have. My guess as to why they elected not to conduct their own study is that they were afraid of a negative result. Conducting such studies is dangerous because, of course, they cut both ways. But if the position of the State of Illinois is correct, as I believe it is, a properly conducted study should have resulted in some circumstantial evidence that would tend to confirm that theory.

"The test would have had to be conducted without the infirmities that I have mentioned in regard to the Envirex studies, and that could have been done. In fact, negative results would not have been fatal to the plaintiffs' case."

Under certain circumstances, a complicated environmental dispute may be resolved more satisfactorily and perhaps more quickly if critical questons that have emerged or have been left unanswered during the proceedings can be answered by a court-ordered investigation. Subject to agreement on costs, such an investigation would be appropriate if:

(1) one or both parties to the dispute fail to submit critical evidence that could reasonably be expected;
(2) fresh information raises new questions during the trial, and
(3) such an investigation can be completed relatively quickly.

An example is the investigative team that Judge Lord sent to Duluth, Minn., during the U.S. v. Reserve Mining case. Examples for the Illinois v. Milwaukee case would have been to correct and repeat the crucial coliform disappearance experiment at SSSTP, adding to it virus determinations, and also conduct the potentially definitive study of the health of Illinois swimmers proposed by defendant witness Cliver. If the judge had appointed impartial court witnesses, they could have played valuable roles in planning and evaluating such research and in selecting impartial agents to perform it. Furthermore, if the disputing parties had been brought to the point of agreement on cost-sharing and on which questions should be studied, the chances for mediation after the results were in would probably have improved. Here, the court-appointed experts could also perform a valuable service as individuals or as members of a mediation panel.

In any case, investigation of critical evidence will bring the scientific facts and probabilities into sharper focus and increase confidence in the final judgement. In appropriate circumstances, the judge could make a more direct approach to the truth of the matter through an experiment rather than balancing his/her perceptions of the credibility of partisan experts. It is the quality and equity of the result that counts, and judges should be encouraged to be flexible and innovative in molding the process to that end. Senior Circuit Judge Bazelon put it well (Ref. 50; emphasis added):

> "I have never believed that procedures per se are a cure-all for solving regulatory problems. Rather, procedural safeguards serve an instrumental role, and <u>it is the fullness of the inquiry that is paramount</u>. If the inquiry is comprehensive and conscientious without additional procedural safeguards, it provides the best record we can hope for in making the difficult choices we now face. Conversely, even when all the procedural niceties are observed, if there is no commitment to a candid exploration of the issues, the predicate for good decision-making will be lacking."

Judge Bazelon's view appears to have evolved in the course of debates with other judges on the relative weight to be given to adherence to statutory procedures, or to "fitness of inquiry" in judicial reviews of <u>rule-making</u> by experts in administrative agencies (a topic reviewed in Ref. 52). In one particular case (<u>Vermont Yankee Power Corp. v. Natural Resources Defense Council, Inc.</u>, 435 US 519, 1978; discussed in Ref. 52), Judge Bazelon's finding was reversed by the U. S. Supreme Court. That case, however, involved a review of <u>administrative</u> rule-making, not judicial rule-making, which we are examining here.

A cursory reading of the recent law articles cited in this review confirms that some of the suggestions for procedural improvement made here appear to be in line with much of the recent civil litigation in federal district courts. The judge's role appears to be changing from the traditional one, of a neutral arbiter between disputing parties, to a more participatory one -- an emerging model of federal litigation which has been called "public law litigation":

(Ref. 53, p. 1,284):

> "The characteristic features of the public law model are very different from those of the traditional model. The party structure is sprawling and amorphous, subject to change over the course of the litigation. The traditional adversary

relationship is suffused and intermixed with negotiating and mediating processes at every point. The judge is the dominant figure in organizing and guiding the case, and he draws for support not only on the parties and their counsel, but on a wide range of outsiders -- masters, experts and oversight personnel. Most important, the trial judge has increasingly become the creator and manager of complex forms of ongoing relief, which have widespread effects on persons not before the court and require the judge's continuing involvement in administration and implementation."

(Ref. 53, pp. 1,300-01; references omitted):

"For these reasons, the judge will often find himself a personal participant in the negotiations on relief. But this course has obvious disadvantages, not least in its inroads on the judge's time and his pretentions to disinterestedness. To avoid these problems, judges have increasingly resorted to outside help -- for information and evaluation of proposals for relief. These outside sources commonly find themselves exercising mediating and even adjudicatory functions among the parties. They may put forward their own remedial suggstions, whether at the request of the judge or otherwise.

"Once an ongoing remedial regime is established, the same procedure may be repeated in connection with the implementation and enforcement of the decree. Compliance problems may be brought to the court for resolution and, if necessary, further remediation. Again, the court will often have no alternative but to resort to its own sources of information and evaluation" (emphasis added).

8.5 Concluding Reflections on the Illinois v. Milwaukee Case

My specific comments on the limnological aspects of this case are found in sections 2.5, 3.4, 4.3, 4.7, 5.4 and 6.3. My more general comments have been aired earlier in this chapter. This section presents a summary of my personal assessment of the deciding issues and wide significance of the Illinois v. Milwaukee pollution case. To me, the seven salient points of this case appear to be as follows.

(1) The Illinois v. Milwaukee and the U.S. v. Reserve Mining cases are both examples of water pollution conflicts that extended beyond the boundaries of a single jurisdiction and beyond the boundaries of a single state. Furthermore, both cases were tried not under provisions of the Clean Water Act, but under federal common law of nuisance, and anticipatory relief was granted in both cases against a perceived, but not quantified, hazard. In Judge Grady's words (tr. p. 14,226), "There is some degree of hazard to the residents of Illinois from Milwaukee's sewage. It is the degree of hazard which is in dispute," and (tr. p. 14,228), "It is my view and my understanding of the law that what the plaintiffs must show by clear and convincing evidence is the existence of a hazard, whether or not that hazard has in fact eventuated in an injury. The hazard itself is the injury justifying injunctive relief in this kind of case" (emphasis added).

(2) The principal perceived hazard was that posed by waterborne viruses to which Illinois citizens might be exposed through swimming in Lake Michigan or through their lake-derived water supply. This turned out to be the decisive issue. But distributions of viruses (or of other potential pathogens) in Lake Michigan, on its beaches or in water intakes (before and after treatment) were not explored; case histories of disease were not introduced, and no epidemiological evidence was presented by the plaintiffs. It seems to me, therefore, that the verdict on health risk should have been the Scottish "nonproven," and it should have initiated a short-term, full-year investigation* designed to determine how many pathogens and viruses in fact get into and get through the filters of all the major water treatment plants from Milwaukee to Chicago. At the same time, the Lake Michigan "bathing effect" should have been investigated (both in Milwaukee and Illinois) along the lines proposed by Cliver (see Section 6.3). Unless a significant risk can be defined and demonstrated, the argument for requiring Milwaukee to do better than other Great Lakes cities is weak.

(3) Eutrophication turned out to be a secondary issue, but serious enough in Judge Grady's view to be "an enjoinable nuisance" (tr. p. 14,243). While Milwaukee's treatment plant effluents and CSO make significant contributions to the nutrient enrichment of Milwaukee Harbor and Lake Michigan, the contributions from other point and nonpoint sources not under the defendants' control are substantially greater (Ref. 54; see also Ref. 38 and Section 5.4). The evidence presented in court for accelerating eutrophication in Lake Michigan, pointing to Milwaukee as the prime contributor, seems to me to be tenuous at best. The important fact to bear in mind is that eutrophication is primarily phosphorus-controlled, and in this respect Judge Grady's ruling failed to strike an effective blow for Lake Michigan because it did not go beyond the DNR/federal requirement for an upper limit of 1 mg/L phosphorus in effluent. Indeed, it can be argued that the judge's order for retention and treatment of all CSO will increase Milwaukee's total output of "available" phosphorus to Lake Michigan, even when the effluent conforms to the 1 mg/L limit.

Therefore, in my view, the goal should be a Great Lakes-wide limit of 0.5 mg/L phosphorus, which the experts (Ref. 34) see as achievable at reasonable cost, particularly if phosphate is removed from laundry detergents. For Lake Michigan, the additional dollars required to meet Judge Grady's stipulations could be better spent here and in regional control of toxic chemical inputs (this is discussed further in the last point of this section).

(4) I believe this case will be found to be unusual among environmental protection cases in that the judge publicly recorded his assessment of the "reliability" of the witnesses and candidly referred to his reliance on those assessments in coming to the judgement (see Section 7). One may wish to query particular points. For example, what persuaded the judge to

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*This would not remove the obvious need for long-term, more extensive studies of the role of viruses in water and the correlation of their numbers with the FCC.

accept one speculative eutrophication hypothesis (from a witness with whom he felt "comfortable") and not another? Why did a Cladophora expert's lifetime of experience carry no weight against the evidence of a single Cladophora sample picked up by a law clerk and dramatically produced during rebuttal? And why was no weight at all given to the admittedly limited factual content of Lake Michigan surveys presented by a witness characterized as "unreliable?" But the important question raised by the methodology revealed by Judge Grady is a more fundmental one: How can legal procedures and adversarial tactics be best combined with uninhibited and impartial scientific and technical debate to arrive at the facts, the probabilities and well-founded risk assessments? (Some aspects of this question were discussed in sections 8.1 and 8.2.)

(5) Despite some relaxation of the standards later granted in another federal court, Judge Grady's order (outlined in Section 1.3) requires the Milwaukee community to upgrade its sewage collection and treatment system more rapidly and to a higher level than that required by federal and state regulations. If not reversed by the U.S. Supreme Court, this accelerated timetable may increase the total improvements cost by as much as one-third and has already generated large additional costs just in planning for compliance with the order. This raises two questions: What benefits will the Milwaukee taxpayers and other users of Lake Michigan reap from the additional expenditures, and could that money have been more effectively used for water quality improvement under a regionally based technical and financial plan?

The accelerated timetable and the related question of cost-effectiveness make financing more difficult. For example (as pointed out in Ref. 55), the highest level of federal assistance (75%) under the somewhat complex provisions of the Clean Water Act is only applied to the most cost-effective solutions within a framework of priorities determined by the state according to clear and consistent regional criteria. Therefore, the Milwaukee community may be faced not only with meeting the additional costs generated by Judge Grady's timetable, but also with less than maximum federal support for the whole $1.6 billion project. The question of cost-effectiveness and the availability of federal funding was not assessed in the judgement, and apparently the existence of the order does not increase the priority of the project for such funding. If the cost-effectiveness of the project is judged to be submaximal, then full federal support may be in doubt.

(6) The order has even wider, potentially disturbing implications in that it transfers control of the project from local and state hands to the court. The plaintiffs (or their agents) are to be allowed to conduct and to be paid for "continuous engineering audits of the defendants' progress in complying with this order," and they are to be given "complete access to all planning, testing, design and construction or operational work or materials prepared by defendants or their consultants" (App. VI, pp. 7-8). There is, therefore, a risk that court-directed control in this and similar cases may distort state plans for regionally optimal water quality planning as envisaged under the Clean Water Act (Ref. 55), and this may lead to suboptimal use of available financial resources and engineering effort. Other Great Lakes cities with CSO and other sewage disposal

problems like Milwaukee's must view Judge Grady's judgement with deep concern -- Milwaukee has 72 km^2 of CSO-affected area, but Detroit has 790 km^2; Buffalo, 138 km^2; Cleveland, 190 km^2, and Gary 300 km^2 (Ref. 56). Chicago has a CSO-affected area of 940 km^2 but only discharges into Lake Michigan during rare emergencies.

(7) My final impression of this trial is that of a conspicuous omission. The long testimonies on sewage treatment defects and eutrophication left one demonstrable hazard almost unmentioned -- namely, the bioaccumulation of persistent toxic chemicals, of which PCBs are a notable example. Though the effect of PCBs and other potential toxins on the Lake Michigan ecosystem remains unclear, the effects on mammals have been well documented, and the danger signals seen in Lake Michigan played a part in the passage of the Toxic Substances Act. The threat to Lake Michigan as a resource is all too clear when a thriving fishery yields a product that is banned from interstate commerce, when dangerously high concentrations of toxins are encountered in the sediments of the Sheboygan River and Waukegan Harbor, and when it is discovered that a substantial portion of the load of hazardous substances enters the lake from the atmosphere.

In looking at the price tag attached to Judge Grady's order and the imperative to protect Lake Michigan as a resource, I am firmly convinced that the money could be much more effectively spent in keeping toxic chemicals out of the waterways, out of the municipal sewer (where they disrupt the biological process of sewage treatment) and out of the air. Needed are a stronger regulatory arm and more approved disposal sites and incinerators, which should be as common in every industrialized area as sewage treatment plants. These are national problems to be solved by national and local cost-effective efforts through federal and local taxes and federal laws that apply equally to all cities.

We should not ask, "Is Milwaukee doing harm to Illinois?" Our question should be, "How can we halt the harm that we all, as industrialized communities, are doing to our common precious resource, Lake Michigan."

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Appendices

APPENDIX I: Court Documents Reviewed for this Report

Illinois et al. v. Milwaukee et al. 1977, Case No. 72-C-1253

List of document boxes loaned to C.H. Mortimer, Center for Great Lakes Studies, University of Wisconsin-Milwaukee, by Ewald Moerke of Schroeder, Gedlen, Riester and Moerke (S. G. R. & M.) law firm, Milwaukee.

BOX NO.	BOX CONTENTS
D-1	Defendant's Exhibits #1-350(A)
D-2	Defendant's Exhibits #351-1059
D-3	Defendant's Exhibits #1060-1139
D-4	Defendant's Exhibits #1140-1406
D-5	Defendant's Exhibits Over-sized exhibits
P-1	Plaintiff's Exhibits 1-74 and 89-94
P-2	Plaintiff's Exhibits 95-159
P-3	Plaintiff's Exhibits 160-275 and Group #1
T-1	Daily Transcripts Pages 1-2705
T-2	Daily Transcripts Pages 2706-5903
T-3	Daily Transcripts Pages 5904-9024
T-4	Daily Transcripts Pages 9025-12,109
T-5	Daily Transcripts Pages 12,110-end
2*	S. G. R. & M. Set of Pleadings, Motion, Briefs Orders, etc.
3	S. G. R. & M. Notes & Memos Before & During Trial (Research Material)
4	S. G. R. & M. Copies of Deposition Transcripts (A)
5	S. G. R. & M. Copies of Deposition Transcripts (B)
6	Extra Copies of Deposition Transripts
7	Extra Copies of Exhibits -- Misc. Order
8	Extra Copies of Exhibits -- Misc. Order
9	Extra Copies of Exhibits -- Misc. Order
10	Reports, Documents & Background Materials, Not Exhibits (A)
11	Reports, Documents & Background Materials, Not Exhibits (B)
12*	Extra Copies -- Pleadings, Motions, Briefs, Orders, Etc.
13	Extra Daily Transcripts
14	Extra Daily Transcripts
15	Extra Daily Transcripts
16	Extra Daily Transcripts

*Returned to Mr. Moerke at his request, 3/2/80.

IN THE UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

PEOPLE OF THE STATE OF ILLINOIS, ex rel. WILLIAM J. SCOTT, Attorney General of the State of Illinois, et al.,	)	
Plaintiffs,	)	
vs.	)	No. 72 C 1253
CITY OF MILWAUKEE, etc., et al.,	)	
Defendants	)	

TRANSCRIPT OF PROCEEDINGS

had at the trial of the above-entitled cause before the Honorable JOHN F. GRADY, one of the Judges of said court, in his courtroom in the United States District Courthouse, Chicago, Illinois, on Tuesday, January 11, 1977, commencing at 10:50 a.m

PRESENT:

HON. WILLIAM J. SCOTT, Attorney General, by
MR. JOSEPH V. KARAGANIS, Special Assistant Attorney General, and
MR. SANFORD N. GAIL
(180 North LaSalle Street, Suite 3115
Chicago, Illinois 60601)

appeared on behalf of plaintiff State of Illinois;

PEOPLE OF THE STATE OF MICHIGAN, ex rel.
HON. FRANK J. KELLEY, Attorney General, by
MR. THOMAS J. EMERY, Assistant Attorney General
(Attorney General Department
Lansing, Michigan 48913)

appeared on behalf of plaintiff State of Michigan;

MESSRS. SCHROEDER, GEDLIN, REISTER & MOERKE
(212 West Wisconsin Avenue
Milwaukee, Wisconsin 53203) by
MR. EWALD MOERKE JR.
MR. ROBERT MELIN
MR. RICHARD D. MOAKE
MR. FREDERICK M. VAN HECKE
MR. HENRY PITTS

appeared on behalf of defendants Metropolitan Sewerage Commission of the County of Milwaukee and Sewerage Commission of the City of Milwaukee;

MR. JAMES B. BRENNAN, City Attorney, by
MR. MICHAEL J. MC CABE, Assistant City Attorney and
MR. ORVILLE E. PITTS, Assistant City Attorney
(City Hall - Room 800
200 East Wells Street
Milwaukee, Wisconsin 53202)

appeared on behalf of defendant City of Milwaukee;

MR. FRANCIS W. CATHLINA, City Attorney
(P.O. Box 367
South Milwaukee, Wisconsin 53172)

appeared on behalf of defendant City of South Milwaukee.

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APPENDIX III: Index to Court Transcripts

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*Pages were number to 1899 and then continued from 1800-1899 in error. The first 1800-1899 set is labelled (A), the second set (B).

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60	March 24	6911-7057
61 & 62	March 25	7058-7144; 7145-7202
63 & 64	March 28	7203-7292; 7293-7453
65 & 66	March 19	7454-7534; 7535-7649
67	(not assigned)	
68	(not assigned)	
69 & 70	March 31	7650-7736; 7737-7897
71 & 72	April 1	7898-7974; 7975-8125

Vol. No.	Date	Pages of Transcript
73	May 23	8126-8382
74	May 24	8383-8565
75	May 26	8566-8774
75a	May 27	8775-9024
76	May 31	9025-9300
77	June 1	9301-9427
78	June 2	9428-9701
79 & 79a	June 28	9702-9855; 9856-10020
80	June 29	10021-10141
81 & 81a	June 30	10142-10223; 10224-10380
82 & 83	July 1	10381-10498; 10499-10667
84 & 85	July 5	10670-10801; 10802-10940
85a	July 6	10941-11122
86 & 87	July 7	11126-11280; 11281-11489
88 & 89	July 8	11490-11634; 11635-11797
90 & 91	July 11	11798-11915; 11916-12109
92 & 93	July 12	12110-12191; 12192-12408
94 & 95	July 14	12409-12548; 12549-12770
96 & 97	July 15	12771-12955; 12956-13177
98 & 99	July 18	13178-13354; 13355-13560
100	July 20	13561-13580
101	July 21	13581-13669
102 & 103	July 25	13670-13835 (Karaganis Closing) 13836-13968 (Karaganis/Moerke Closing)
104 & 105	July 26	13969-14089 (McCabe Closing) 14090-13204 (Karaganis Closing)
106	July 29	14206-14257 (Findings of Fact)

1

I. Adverse Witnesses

Witness	Topic	Transcript Page Numbers: Direct Exam.	Cross Exam.	Redirect Exam.	Recross Exam.
Dedinsky, Henry	SSSTP	993-1426	1427-1432		
Ernest, Lawrence	JISTP	1436-(A)1892	(A)1893-(B)1823	(B)1823-(B)1851	
Kupfer, George	Milwaukee beaches	3473-3528	3528-3557	3558-3577	3577
Laszewski, Edward	Milw. sewage system	422-582			
Lundy, Thomas (Alvord, Burdick, Howson)	Advice to MMSD Commission	585-769	769-873	874-958	959-992
Manske, William	JISTP engineer	3672-3686	3686-3693	3693-3694	
Manthe, Richard	JISTP laboratory	(B)1852-(B)1917	(B)1917-(B)1920		
Munsey, Franklin	JISTP laboratory	3585-3623	3624-3638	3638-3672	
Wieland, Donald	Collection system	109-362			

II. Plaintiffs' Witnesses and Rebuttal Witnesses

Witness	Topic	Direct Exam.	Cross Exam.	Redirect Exam.	Recross Exam.
Allison, Melvin (rebuttal)	Hydrology	12410-12444	12444-12468	12468-12470	12470
Beeton, Alfred (rebuttal)	Limnology	12471-12693	12693-12850	12851-12867	12868-12869
Berg, Gerald (rebuttal)	Virology	11985-12124	12125-12246	12247-12284	12284-12287
Csanady, Gabriel	Dispersion and diffusion	(B)1921-2064	2064-2757	2757-2798	2798-2801
Rebuttal					
Culp, Gordon (rebuttal)	Technology/costs	13462-12471	13472-13474		

Witness	Topic	Direct Exam.	Cross Exam.	Redirect Exam.	Recross Exam.
Geldreich, Edwin	Bacteriology	3048-3119	3120-3234	3234-3239	3240
Goodin, Robert (rebuttal)	Glencoe Water Plant	13517-13533	13533-13538		
Mack, Walter	Virology	13475-13487	13488-13516		
Megregian, Stephen	Evidentiary foundation	3745-3750	3750-3754	3754-3756 3759	3756-3759
Melnick, Joseph	Virology	2115-2221	2221-2325	2325-2340	2341-2344
Renz, Jeffrey (rebuttal)	*Cladophora* sample	13155-13177			
Riddell, Matthew	N. Shore Sanitary District	13433-13444	13444-13461	13462-13463	
Schelske, Claire	Limnology	2810-2927	2927-3045		
Rebuttal		12869a-12954			
Tierney, Dennis	Limnology (actinomycetes)	3243-3388	3388-3458	3458-3461	3461-3462
Verber, James L.	Lake currents	2350-2401	2402-2564		
Wellings, Flora Mae (rebuttal)	Virology	12288-13272	13272-13427	13427-13430	13430-13431

APPENDIX V: Defendant Witnesses

Witness	Topic	Direct Exam.	Cross Exam.	Redirect Exam.	Recross Exam.
Benarde, Melvin	Epidemiology	9027-9161	9161-9223	9223-9242	9242-9247
Borchardt, Robert	MMSD/DNR stipulation	9247-9563	9563-9690	9690-9700	
Carter, Harry	Currents, dispersion	8568-8726	8727-8953	8954-9016	9016-9018
Cliver, Dean	Virology	10143-10274	10274-10351	10351-10367 10377	10367-10376
Fitzgerald, George	Cladophora	7991-8173	8174-8329		
Gruber, David	Foundation Run-off	5059-5095 7652-7713	5095-5170 7713-7791	5172-5182 7791-7821	5182-5188 7821-7844
Gupta, Mahendra	Technology/costs	8524-8565 9720-9823	9823-10003	10004-10015	10015-10019
Harper, Martin	Modelling CSO	5905-6245 8372-8485	8486-8512	8513-8520	8520-8522
Heaps, Richard	Cost impact	10838-10947	10948-11100	11100-11106	11107-11110
Katz, Richard	Compliance, EPA funding	11112-11382	11383-11472	11473-11488	
Kupfer, George	Dye tests	7587-7629	7629-7649 7900-7965	7965-7991	
Laszewski, Edward	Remedy	7442-7527	7527-7579	7580-7586	
Meinholz, Thomas	STORM and SWMM models	7845-7897	10729-10825	10825-10833	10833-10837
Otto, Robert	Plankton, bottom fauna	10040-10141 11491-11546	11567-11726	11727-11741	11748
Pritchard, Donald	Currents, dispersion	6247-6576	6576-6910	6913-7042	7043-7194
Sawyer, Claire	Effect on harbor discharge	7204-7331	7332-7438	7438-7441	
Shapiro, Joseph	Limnology	11753-11881	11881-11971	11972-11973	11973-11976
Sproul, Otis	Virology	10382-10517	10518-10667		
Zanoni, Alphonse	Envirex surveys	3780-5059	5190-5669	5671-5760 5883-5893	5760-5882 5893-5901

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

PEOPLE OF THE STATE OF ILLINOIS, ex rel., WILLIAM J. SCOTT, Attorney General of the State of Illinois,

Plaintiff,

PEOPLE OF THE STATE OF MICHIGAN,

v.

Case No. 72-C-1253

CITY OF MILWAUKEE, WISCONSIN; CITY OF KENOSHA, WISCONSIN; CITY OF RACINE, WISCONSIN: CITY OF SOUTH MILWAUKEE, WISCONSIN; THE SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE, and THE METROPOLITAN SEWERAGE COMMISSION OF THE COUNTY OF MILWAUKEE,

Defendants.

JUDGMENT ORDER

This cause having come on trial before this Court, and the Court having heard the witnesses and having examined the exhibits admitted into evidence, and the Court having heard the legal arguments for the parties, and the Court, on July 29, 1977, from the bench having announced its "FINDINGS OF FACT AND CONCLUSIONS OF LAW."

NOW, THEREFORE, IT IS HEREBY ORDERED, ADJUDGED AND DECREED that the defendants CITY OF MILWAUKEE, SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE AND THE METROPOLITAN SEWERAGE COMMISSION OF THE COUNTY OF MILWAUKEE and each of them and their agents, employees or successors in interest are hereby permanently en-

joined from emitting sewage discharges, from the respective sewer pipes or structures owned or maintained by the defendants, into Lake Michigan or any of its tributary waters, except as hereinafter permitted in this order and said defendants are hereby ordered to:

(1) The respective defendants shall in their respective jurisdictions eliminate all sewage overflows emanating from sewer pipes or structures owned, operated or maintained by the defendants located outside of the area which was designated by the defendants at trial as the Combined Sewer System Area hereinafter ("CSO"). Elimination of such overflows shall be completed on or before July 1, 1986. For purposes of this order, an overflow is defined as a crossover, bypass, diversion structure, relief structure, pump station or any other device or mechanism by which human fecal waste is discharged directly or indirectly to public streams,.rivers or lakes without collection and treatment according to the treatment methods and effluent limits set forth in paragraph (3) below. If, in defendants' opinion completion by such date becomes impossible due to circumstances beyond defendants' control, then defendant(s) may apply to the Court for an extension of time for completion. Any such application, if opposed by either plaintiff, must be predicated on an evidentiary hearing preceeded by adequate opportunity

for discovery by plaintiffs. Defendant shall be required to prove the basis for and the necessity for such extension which extension shall be granted or denied in the sound discretion of the Court. Defendants shall pay plaintiff(s)' entire costs of any such application including reasonable attorneys' and experts' fees, and the costs of discovery, preparation and presentation of their position.

(2) The Commission defendants shall in three stages, the first to be completed on or before December 31, 1985; the second on or before December 31, 1987; and the third on or before December 31, 1989, put into operation a collection, and conveyance system in the combined sewer system area ("CSO") which shall collect and convey all human fecal waste entering the sewers in the combined sewer system area. The first stage of such system shall have storage capacity of not less than 700 acre feet, the second not less than an additional 1290 acre feet, and at the completion of the third stage (December 31, 1989) the entire system shall have storage capacity of not less than 2605 acre feet and shall be designed and operated within such storage capacity so as to collect, convey and store the volume of flow and all human fecal waste capable of transmission by the combined sewer system. Defendants have analyzed rainfall events ex-

perienced during the period 1940 through the date hereof (which is the period for which detailed hourly rainfall data is available) and have represented to this Court that their analysis demonstrates that at a storage capacity of 2605 acre feet, there would have been no overflows from such a system. All fecal wastes and flows collected and conveyed from the combined sewer area shall be treated according to the treatment methods and to the effluent limits set forth in paragraph (3) below.

Overflows, if any, which do occur shall constitute a violation of this order unless defendants can prove as a defense to a charge of violation either:

1. that the overflow resulted from runoff conditions which exceeded the capacity of the 2605 acre feet of storage at a pump out rate to advanced treatment of 110 CFS; and

that the runoff events which resulted in the overflow would have caused an overflow in excess of the design capacity of the 2605 acre feet storage system at 110 CFS under the identical scientific premises and calculations used by the defendants prior to the date of this Order to design the size of such storage systems; or in the case of overflows resulting from causes other than excess runoff events,

2. that the overflow was wholly caused by actions or occurrences wholly outside the control

of the defendants and was in no way caused or contributed to by the negligence of the defendants.

Any defense to an overflow violation shall be predicated on an evidentiary hearing preceded by an adequate opportunity for discovery by plaintiffs. Defendants shall bear the evidentiary burden of proof of establishing the defenses listed above, and if the Court finds that the defense has not been proven, shall pay plaintiff(s)' entire costs of opposing any such defense including reasonable attorneys' and experts' fees and the costs of discovery, preparation, and presentation of plaintiffs' position. In any event, any overflows which may conceivably occur shall be subjected to treatment by bar screens, followed by drum screens, followed by chlorination prior to discharge. Should defendants develop information which establishes in defendants' opinion that separation of all or part of the system is a preferred alternative, which will provide a collection and treatment level equal to or better than that required herein then defendants may apply to the Court for modification of this paragraph to provide therefor. Any such modification, if opposed by either plaintiff, must be predicated on an evidentiary hearing preceded by adequate opportunity for discovery by plaintiffs. Defendants shall bear the evidentiary burden of proof of establishing that such modification equals or exceeds the level of protection provided herein. Defen-

dants shall pay plaintiff(s)' entire costs of any such application including reasonable attorneys' and experts' fees, and the costs of discovery, preparation and presentation of their position.

(3) The Commission defendants or their successors in interest shall from and after December 31, 1985 treat all human fecal wastes which reach existing, expanded, or newly constructed treatment plants owned, operated or maintained by the defendants by means of appropriate secondary treatment facilities to be followed by treatment with chemical coagulation, sedimentation, and sand or multi-media filtration which facilities shall as of December 31, 1986 and thereafter produce an effluent which does not exceed five (5) milligrams per liter (mg/l) suspended solids and five (5) milligrams per liter of five (5)-day carbonaceous biochemical oxygen demand (BOD_5). From and after December 31, 1986, there shall be no by-pass at any existing, expanded or newly constructed treatment plant. The effluent requirements shall be calculated on the basis of daily composite samples averaged on a 30 day consecutive basis, provided that the maximum effluent concentration discharged on any given day shall not exceed ten (10) milligrams per liter suspended solids and ten (10) milligrams per liter carbonaceous BOD_5. The effluent shall be treated with chlorine, so as to achieve a free

chlorine residual as measured by the amperometric test after 15 minutes residence time. If defendants conclude that some other disinfectant chemical or procedure will provide a level of protection equivalent to such chlorine treatment and is preferable, defendants may apply to the Court for a modification of this paragraph (3) to permit the use of such other disinfectant chemical or procedure. Any such modification, if opposed by either plaintiff, must be predicated on an evidentiary hearing preceded by adequate opportunity for discovery by plaintiffs. Defendants shall bear the evidentiary burden of proof of establishing that the proposed modification will provide a level of protection equivalant to such chlorine treatment.

Maximum fecal coliform counts on any one grab sample shall not exceed 40 fecal coliform per one hundred (100) milliliters. Phosphorous (P) concentrations shall be no more than one (1) miligram per liter based on a monthly average.

(4) Plaintiffs have emphasized their concern to maintain a detailed understanding of defendants' progress in designing and constructing the facilities ordered by the Court. Defendants have agreed to and shall allow plaintiffs, during working hours and upon reasonable notice, to conduct a continuing engineering audit of defendants' progress in complying with this

order and have agreed to permit plaintiffs (and persons designated by plaintiffs) complete access to all planning, testing, design and construction or operational work or materials prepared by defendants or their consultants. Defendants have also agreed to and shall promptly pay the reasonable charges or fees of persons designated by plaintiffs to conduct such continuing engineering audit provided that such engineering audit activities to be paid by defendants shall not exceed 50 man days per calendar year; and any of such required payments accrued or made during the course of appeal shall be and remain the obligation of defendants regardless of the outcome of any appeal.

(5) During the periods necessary to complete the facilities required for compliance with the provisions of this order, as set forth above, the defendants shall be permitted, on the basis of using the best engineering practices available within the limits of the capabilities of those facilities, to continue the operations of their respective sewage collection, treatment and discharge facilities as the same may be modified from time to time to comply with the requirements of this order. Existing disinfectant systems shall be maintained and operated in such periods and no new by-passes or overflows shall be installed or operated during such periods except that prior to December 31,

1986 and not thereafter a by-pass may be installed and operated if required as a protective device to protect the South Shore Plant and then only if triggered at and operated during the existence of a flow rate equal to or greater than the plant flow capacity (260 to 316 mgd) for flow in excess of such capacity. In the event that plaintiff(s) challenge any overflow as being in violation of the provisions of this order for the reason that such overflow was not triggered by and limited to flows in excess of plant capacity, it shall be the burden of the defendants to prove in an evidentiary hearing preceded by adequate discovery by plaintiff(s) that such overflow was triggered by and limited to flows in excess of plant capacity. If the Court finds that the defense has not been proven, defendant(s) shall pay plaintiff(s)' entire costs of opposing any such defense including reasonable attorneys' and experts' fees and the costs of discovery, preparation, and presentation of plaintiffs' position.

As set forth in paragraph (3) above, all by-passes shall be eliminated by December 31, 1986. If one or more additional temporary overflows become necessary in defendants' opinion in the defendant City of Milwaukee's system for operation to protect the public health prior to December 31, 1986, then defendants may apply to the Court for a modification of this paragraph 6 to permit

operation of such additional overflows up to but not after December 31, 1986. All such overflows shall be eliminated by December 31, 1986. Any such modification, if opposed by plaintiffs, must be predicated on an evidentiary hearing preceded by adequate opportunity for discovery by plaintiff(s). Defendants shall bear the evidentiary burden of proof establishing the public health requirements for such modification which shall be founded in such public health requirements as, but not limited only to, preventing the backing-up of sewage in basements. Defendants shall pay plaintiff(s)' entire costs of any such application including reasonable attorneys' and experts' fees and the costs of discovery, preparation and presentaton of their position. Nothing herein shall relieve defendants or any of them from compliance with other applicable discharge standards.

(6) As a joint and several responsibility, defendants shall pay immediately to plaintiffs the amount of $230,000.00, in the manner directed by plaintiffs, as costs of these proceedings, in lieu of following normal procedures to tax costs by the Clerk of this Court. Such sum in total shall be returned to defendants in the event judgment is reversed in toto; in no event shall defendants question the individual items or dollar amounts within such total.

(7) All burdens of proof set forth as requirements of this Judgment Order shall be met by a standard of a preponderance of the evidence.

(8) The Court hereby approves and orders the defendants to adhere to the schedules set forth in Exhibits 1 and 2 attached hereto for compliance with this Judgment Order. If defendants apply to the Court for modification of any component of the time schedules herein, such modification, if opposed by plaintiffs or either of them, must be predicated on an evidentiary hearing preceeded by adequate opportunity for discovery by plaintiffs. Defendants shall bear the burden of proof that such modification is required by causes wholly outside the control of the defendants or their agents, consultants or employees, and was in no way caused or contributed to by the negligence of the defendants or their agents, consultants or employees. The granting or denial of any such application shall be in the sound discretion of the Court.

(9) The Court hereby expressly reserves jurisdiction over the parties hereto and over the subject matter hereof to enforce the provisions of this Judgment Order.

Entered: ____________________ ______________________________
United States District Judge

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

PEOPLE OF THE STATE OF ILLINOIS, ex rel. WILLIAM J. SCOTT,

Plaintiff,

PEOPLE OF THE STATE OF MICHIGAN,

Intervening Plaintiff,

NO. 72 C 1253

CITY OF MILWAUKEE, WISCONSIN; THE SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE; and THE METROPOLITAN SEWERAGE COMMISSION OF THE COUNTY OF MILWAUKEE,

Defendants.

MEMORANDUM OPINION

This is an injunction suit brought by the State of Illinois against the City of Milwaukee, Wisconsin, and the two commissions which own and operate the sewage facilities serving the City and most of Milwaukee County.[1/] The gravaman of the three-count complaint is that the sewage discharged by the defendants into Lake Michigan adversely affects the residents of Illinois and Michigan. Count I

1/ The Wisconsin cities of Kenosha, Racine and South Milwaukee were additional defendants, but they entered into a settlement with plaintiffs and were dismissed prior to trial.

alleges that the conduct of the defendants constitutes pollution of an interstate waterway and is actionable under the federal common law of nuisance. This count is therefore based upon federal question jurisdiction. Counts II and III of the complaint set forth substantially the same allegations and are predicated upon the Illinois common law of nuisance and specific violations of the Illinois Environmental Protection Act respectively.[2/] All three counts pray for injunctive relief. Service on the defendants was had pursuant to the Illinois Long-Arm statute.[3/]

The case was initially filed by Illinois in the United States Supreme Court, invoking the original jurisdiction of that Court on the theory that it is an action between states. The Supreme Court held that these defendants are not a "state" for jurisdictional purposes, and denied Illinois' motion for leave to file an original bill. The Court then remitted the case to this court for trial. Illinois v. Milwaukee, 406 U.S. 91, 98, 108 (1972). The Court stated that the case should be tried under the federal common law of nuisance and did not indicate whether Counts II and III should be tried as pendent claims. The defendants took the position in this court that only Count I should be tried, but I felt it was proper to take the case on all three counts, especially since I see no difference in the elements of proof required to support each of them.

2/ Ill. Rev. Stat. ch. 111 1/2, §§ 1001 et seq.

3/ Ill. Rev. Stat. ch. 110, § 17.

The question of whether this is a suit between states was thought by the parties to have some importance in this court, since it has been held that principles of comity require clear and convincing evidence before the activities of one sovereign state can be circumscribed at the instance of another. New York v. New Jersey, 256 U.S. 296 (1921); Missouri v. Illinois, 200 U.S. 496 (1906). Defendants continue to assert that this is a suit between states, even though that question seems to have been disposed of by the Supreme Court. I have difficulty perceiving an identity between these defendants and the State of Wisconsin in this context, especially in view of the fact that the State has filed a suit against these defendants in the Wisconsin courts to restrain the very kinds of activities involved here. In any event, the question has become academic because I found the evidence in favor of plaintiffs to be clear and convincing.

The bench trial of the case took four months, and at the conclusion, I gave oral findings of fact and conclusions of law from the bench. The transcript of those remarks has been filed as my findings of fact and conclusions of law under F.R.C.P. 52. I found against the defendants on all three counts and ruled that they will be required to make extensive changes in their sewage collection and treatment methods.4/ The case was continued for a further evidentiary hearing on the timetable for these remedial measures. The parties

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4/ See note 5, infra.

then conducted additional discovery on this issue, and, on the date set for the hearing, submitted an agreed timetable, with the defendants reserving their rights to appeal on the merits. A final judgment order was then entered, incorporating the timetable.

My findings and conclusions were probably too detailed and specific to this case to be of general interest. However, several of the legal points involved do seem to be of sufficient interest to warrant a published discussion.5/ As background, a brief reference to the facts will be helpful.

The Milwaukee metropolitan area, with a population of about one million people, takes its water supply from Lake Michigan and, after sewage treatment, discharges the water back into the lake. Sewage – the used water, contaminated by solids – is collected by a network of pipes which, through gravity or with the aid of pumping, carries the sewage to one of two treatment plants. At the plants, a sequence of treatment processes occurs: The sewage is run through a series of grates and screens, to remove gross solids such as paper. The material removed in this manner is incinerated or hauled away to landfills. After screening, the water is conveyed to "primary settling basins," where it is held for a period of time to allow additional solids to settle out through gravity. Everything up to this point is known as "primary treatment."

5/ Everything said here was contained in the oral decision at the end of the trial, and publication of this opinion is not intended to supplement the record in the case.

The sewage is then given a form of "secondary" treatment known as the activated sludge process. The water which has received primary treatment is conveyed to "aeration basins" containing large numbers of microorganisms which feed on the contaminants in sewage. The metabolic processes of these organisms are enhanced by the presence of oxygen, which is fed into the basins under pressure.

From the aeration tanks, the water is drained into "final" settling basins and allowed to stand, so that more solids, including the organisms which have fed on the contaminants, can settle to the bottom.[6/] The relatively clear water at the top of these basins, called "secondary effluent," is then treated with chlorine and discharged to the lake. The purpose of the chlorine is to kill any live infectious organisms which have not already been removed from the effluent.

The treatment process, then, is basically a series of steps designed to take solid material out of the water. Aside from the initial screening, all of these procedures are designed to make the material settle. This takes time, and, particularly in the case of the final settling basins, it requires that the water not be agitated. If the sewage is taken through the plant so rapidly that there is

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6/ These solids are then drawn off the bottom of the tanks. Additional phases of a sewage treatment plant involve disposal of the solids, but for purposes of this opinion it is not necessary to discuss them.

inadequate primary settling time, inadequate aeration time, or inadequate detention time in the final settling basins, the solids simply will not be removed from the effluent to the desired degree before it is discharged to the lake.

Discharge of excessive solids to the lake is harmful from two standpoints. First, solids contain large numbers of bacteria and viruses which can cause disease if ingested by humans. These organisms, or pathogens, are contained primarily in the human fecal matter which is a part of the sewage. A small particle of fecal matter can contain literally millions of these microorganisms capable of causing disease. Chlorine will not penetrate to the pathogens imbedded in solids, so that, to the extent a final effluent contains significant quantities of solids, the chlorination process is ineffective.

The other undesirable feature of solids in sewage is that they are rich in nutrients such as phosphorus and nitgrogen which affect the quality of the water in the receiving lake by a process known as "eutrophication."

The basic problem with the Milwaukee area sewage facilities is that they are physically inadequate to treat the amount of sewage generated by the population of one million. The population has grown rapidly in recent years, but construction of sewage collection and treatment facilities has not kept pace. The result is that the sewage commissions have been faced for years with a continuing dilemma.

If all of the sewage produced by the population is accepted at the two treatment plants, it cannot be adequately treated. To have adequate treatment, the flow to the plant must be shut off when capacity is reached; this would result in sewage backing up into basements unless some other expedient is found. The problem is aggravated in wet weather due to the fact that much of the Milwaukee area is served by "combined sewers." This means that storm water goes into the same pipes as sanitary sewage, greatly diluting and thereby increasing the amount of contaminated water needing treatment before discharge to the lake.

The defendants have dealt with the problem of inadequate capacity in three ways. First, they send sewage to the treatment plants in amounts which often exceed the capacity of the plants to render effective treatment. This is true in both dry weather and wet weather, although the problem is much worse in wet weather. Second, they discharge raw, untreated sewage in immense volume directly into the lake in wet weather. This practice is made possible by the existence of hundreds of "overflow devices" on their sewers which, when opened, will allow raw sewage to flow into drainage ditches, creeks and rivers, which, in turn, empty into Lake Michigan. The third thing the defendants have done is construct additional sewers and treatment facilities. This work represents but a small fraction of what will need to be done to bring about effective sewage treatment in the

Milwaukee area. Before the decision in this case, the defendants' long range plans contemplated an ultimate treatment level which I have found to be inadequate to abate the nuisance. 7/

It was incumbent upon the plaintiffs, of course, to prove not simply that Milwaukee is contaminating its own drinking water but that the Milwaukee discharges have an effect upon the residents of Illinois and Michigan. I have found from clear and convincing evidence that the Milwaukee discharges do adversely affect the residents of these other states, and I will explain briefly what the evidence has shown. There are two aspects of this, first, the public health problem and second the problem of eutrophication.

As far as public health is concerned, the evidence demonstrated that raw sewage and insufficiently treated sewage contain great numbers of viruses and bacteria which, when discharged into the lake, can live long enough to be transported to Illinois waters by the lake currents. The distance from Milwaukee south to the Illinois line is 39 miles, and the experts on both sides agreed that, at least on <u>some</u> occasions during the year, parcels of water from Milwaukee will be transported by the currents southward to Illinois. They disagreed as to how often this might occur, but I have concluded on the basis of this testimony that it probably happens at least six times a year.

7/ I have found from the evidence in this case that effective chlorination requires a final effluent containing no more than 5 parts per million of suspended solids and 5 parts per million of BOD (biochemical oxygen demand). This will require "tertiary" level

This contaminated water can cause infection in Illinois residents in two ways. It can be ingested by persons who are using the bathing beaches,[8/] and it can be ingested by persons who use contaminated drinking water.[9/] (All of the residents of the Illinois shore use Lake Michigan as their source of drinking water). The illnesses caused by these water-borne pathogens are mostly non-fatal, but they are sufficiently disabling to be a matter of serious public health concern. They include such diseases as shigellosis, salmonellosis, hepatitis and encephalitis, all of which are transmitted by pathogens contained in human fecal matter.

The other problem is eutrophication. Briefly, this is a process by which the plant and fish life of the lake undergo changes due to an increase in the amount of the available nutrients. For example, there is a direct relationship between the amount of phosphorous in the water and the amount and kind of algae found in the water. Human fecal matter is rich in phosphorous as well as nitrogen, vitamins and minerals which encourage the growth of algae. Some

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treatment, involving the use of chemicals and filtration of the secondary effluent prior to chlorination. The defendants' goal was an eventual standard of 30 parts per million of suspended solids and 30 parts per million of BOD, standards attainable by efficient secondary treatment.

8/ A swimmer will swallow about 10 milliliters of water during a session of swimming. Therefore, if there are viruses in the water, he can ingest them.

9/ Water treatment plants do not always remove all viruses from the water even when operating at maximum efficiency. Viruses, which measure one millionth of an inch in diameter, are found in treated drink-

of this plant life appears as a green scum on the surface of the water near shore. It can interfere with the recreational use of the water and also affect the taste and odor of drinking water. Most of the plant life is microscopic and is not recognizable to a layman as plant life at all; rather, it forms a mass of microscopic particles which result in a murky or turbid appearance of the water.

I have found from the evidence that the western shore of Lake Michigan is undergoing a process of accelerated eutrophication, evidenced by changes in the volume and species of algae, increased turbidity of the water and taste and odor problems in drinking water. Because there is an interchange of water along the western shore and between the inshore and offshore zones, the lake as a whole is affected, including the waters within the territorial boundaries of the States of Illinois and Michigan.

The situation in the inshore zone is not critical yet, and it is even less so in the lake at large. So far, there is no evidence that eutrophication has caused any changes in the fish life.[10/] However, history teaches that there is no "critical point" at which one must start to worry. Eutrophication is a gradual process in which

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ing water. Moreover, water treatment plants are not always operated at maximum efficiency.

10/ There have been substantial changes in fish species in recent years - for instance, the disappearance of lake trout and the enormous increase in alewives - but plaintiffs did not attempt to attribute this to eutrophication. The phenomenon appears to be related to the introduction of new predators such as the sea lamprey which entered the lake through the St. Lawrence Seaway.

the changes from year to year are imperceptible. One must measure in terms of decades if not longer intervals to see the difference. Viewed in these terms, the evidence leaves no doubt that Lake Michigan is undergoing increased and accelerated eutrophication, especially in the inshore zone of the western shore. The situation is most dramatically illustrated by Green Bay, Wisconsin, north of Milwaukee, which, instead of obtaining its drinking water from the turbid bay on which it is located, has chosen to reach out across the Door pennisula to obtain its drinking water from Lake Michigan, 50 miles away. Green Bay is a cul de sac which exchanges its waters with the larger lake on a long term basis, and the nutrients put into the bay tend to stay there and promote the growth of algae on a more rapid basis than occurs in the larger lake. Unfortunately, Lake Michigan is itself a cul de sac, taking 100 years to empty into Lake Huron. Defendants' argument that the lake is simply too large to experience the dramatic impact seen in Green Bay loses force when one recalls that the same argument was made in regard to Lake Erie decades ago, when the alarms were beginning to sound. Experts of all varieties confidently predicted that the eutrophication seen in the inshore zones of Lake Erie would stay there and not extend to the lake at large. They were wrong, and Lake Erie, at least in its western basin, is a eutrophic lake, with all the problems that involves. While Lake Michigan is not in the sad condition of Lake Erie, neither is it in the relatively pristine condition of Lake

Superior, where nutrient inputs from the smaller population inhabiting its basin are minor compared to those experienced by Lake Michigan. A secchi disc, a device to measure turbidity, dropped into the water of Lake Superior can be seen at a depth of 60 feet. In Lake Michigan, the disc typically cannot be seen past a depth of 10 or 15 feet.

Nutrients are discharged into the lake by "point sources, such as paper mills and sewage treatment plants, and by "non-point sources," such as tributary creeks and rivers carrying the runoff from farm lands, and even the air, which conveys significant quantities of phosphorous and other chemicals into the lake. There is no means of identifying any particular molecule of phosphorous or nitrogen or any other chemical as having come from a particular source, either point or non-point. More than that, no one knows how much phosphorous there is in the lake or how much is being added each year. The ratio of point loadings to non-point loadings is unclear. It is only in recent years that any measurements have been made and any records kept. What is clear, however, is that Milwaukee is the largest point source on the lake and the only one of major significance on the western shore. (The Illinois communities on Lake Michigan do not discharge their sewage effluent into the lake, but, rather, into a system of water courses connecting to the Illinois River.) There are no communities on the Michigan side of the lake which compare in size to Milwaukee. By their own measurements, the Milwaukee sewage plants discharge one million pounds of phosphorous into the lake each year. This is simply the amount contained in the treated effluent and does not include additional phosphorous contained in the raw sewage discharged directly to the lake during wet weather. By any analysis, the Milwaukee contribution of nutrients to the lake is substantial.

The foregoing should be a sufficient factual predicate for a discussion of the significant legal issues argued by the parties.

In regard to the public health aspect of the case, the defendants argue that there is no evidence of any actual outbreak of disease in Illinois caused by Milwaukee sewage. Therefore, they reason, there is no proof of any actual injury to the residents of Illinois and injunctive relief is not appropriate.

It is impossible to demonstrate that any Illinois resident has been infected by pathogens originating in Milwaukee sewage. Viruses and bacteria do not bear labels, and there is usually no way of knowing where they come from, except that the type of viruses and bacteria we are concerned with here are always water borne, they all originate in the human intestine and are contained in the fecal matter of infected persons. Evidence shows that most of the diseases caused by such pathogens are unlikely to be reported, and, if reported, are likely to be misdiagnosed. The typical symptoms are diarrhea, nausea and headaches - the kind of thing usually attributed to "the flu" or "a cold." The time and expense involved in isolating and identifying

a virus is so great that the effort is rarely undertaken.

What Illinois has shown, and, as a practical matter, all it can show, is that its residents are subjected to a substantial risk of infection by Milwaukee sewage. I believe this is a sufficient showing to warrant relief. In Missouri v. Illinois, 180 U.S. 208, 242, 244 (1901), the State of Missouri was complaining about pollution of the Mississippi River allegedly caused by sewage discharges from the City of Chicago. The State of Illinois protested that there had as yet been no showing of any harm to residents in Missouri. The Supreme Court rejected this argument:

> In the first place, it is urged that the drawing by artificial means, of the sewage of the City of Chicago into the Mississippi River may or may not become a nuisance to the inhabitants, cities and towns of Missouri; that the injuries apprehended are merely eventual or contingent, and may, in fact, never be inflicted. Can it be gravely contended that there are no preventative remedies, by way of injunction or otherwise, against injuries not inflicted or experienced, but which would appear to be the natural result of acts of the defendant, which he admits or avows it to be his intention to commit?
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> The nature of equitable remedy in the case of public nuisances was well described by Mr. Justice Harlan speaking for the court in the case of Mugler v. Kansas, 123 U.S. 623, 673: "The grounds of this jurisdiction in cases of purpresture, as well as of public nuisances, is the ability of courts of equity to give a more speedy, effectual and permanent remedy than can be had at law. They can not only prevent nuisances that are threatened, and before irreparable mischief ensues, but arrest or

> abate those in progress and by perpetual injunction protect the public against them in the future; whereas courts of law can only reach existing nuisances, leaving future acts to be the subject of new prosecutions or proceedings. This is a salutary jurisdiction, especially where a nuisance affects the health, morals, or safety of the community.

Another case which is pertinent to this point is Harris Stanley Coal and Land Company v. Chesapeake and Ohio Railway Company, 154 F.2d 450, 454 (6th Cir. 1946):

> Though no injury had yet been shown to have been incurred by the railroad, possible future injuries may be enjoined. . .(citations omitted) and suits are not premature because the plaintiff does not await an actual test of the results of a proposed or threatened act."

In their argument on this question, the defendants seem to me to have confused two questions. One question is what elements the plaintiffs must prove to make out their cause of action, and the other is the standard of proof by which those elements must be established. The defendants contend that the evidence must be clear and convincing. I have adopted that view for purposes of this case. The defendants further reason that because the evidence must be clear and convincing, it must show an actual injury. Otherwise, they say, it is not clear and convincing. I believe that what plaintiffs must show by clear and convincing evidence is the existence of a hazard, whether or not that hazard has in fact eventuated in disease. It is the exposure to the hazard which is the injury justifying injunctive relief in this kind of case.

The second major argument of the defendants concerns the matter of eutrophication. Defendants argue that they cannot be held liable for their nutrient discharges into the lake in the absence of a showing that the elimination or reduction of those discharges would, of itself, "measurably" improve the condition of the lake. Many of the defendants' expert witnesses testified that a reduction or elimination of Milwaukee discharges would not have any "measurable effect" on the lake. Plaintiffs' witnesses testified that Milwaukee does make a substantial difference, but they had to admit that the difference cannot be stated in terms of any specific measure or quantity. Again, this is because no one knows the existing nutrient content of the lake nor what quantities are being added by each of the many point and non-point sources.

Defendants argue that on this state of the record there is no satisfactory proof of a causal relationship between their conduct and the problem of eutrophication of the lake. Moreover, they argue that, as an equitable matter, it would be unfair to require them to incur the great expense of improving their sewage treatment facilities when it is not demonstrable that there will be any corresponding benefit to the lake. In this connection, they point out that, whatever controls are imposed upon point sources, there will still be large inputs of nutrients from non-point sources which are not subject to control.

If defendants' argument were to be adopted, it would be impossible to impose liability on any polluter. If any one point source can defend successfully on the ground that its discharge alone is not causing the problem and that, without its discharge, the problem would still exist, then that defense would have to be equally available to all point sources. What is a good defense for Milwaukee would have to be a good defense for any other point discharger, especially since Milwaukee is the largest point discharger.

I believe it is sufficient for plaintiffs to show that defendants' nutrient discharges constitute a significant portion of the total nutrient input to the lake. The correct rule would seem to be that any discharger who contributes an aliquot of a total combined discharge which causes a nuisance may be enjoined from continuing his discharge. Either that is true or it is impossible to enjoin point dischargers.

The situation is somewhat analogous to that of joint tort feasors: Anyone who contributes to the injury is liable, even though his conduct, standing alone, might not have been sufficient to cause the injury. Here, it may be that Milwaukee's one million pounds of phosphorous a year would not cause a problem in the lake if there were no other phosphorous being added. But there is other phosphorous being added, and it is clear that the total amount of phosphorous being put into the lake is causing a problem.

There may be a discharge so small that, as a practical matter, it can be regarded as de minimis, even though as a logical matter it is still part of the whole. But clearly that is not this case. We are dealing here with the most significant point source on the lake.

There is not much authority squarely on point. The closest case I have found is the early decision of the Illinois Supreme Court in Barrett v. Mt. Greenwood Cemetery Assn., 159 Ill. 385, 390, 42 N.E. 891 (1896). The court rejected the argument that the existence of non-point sources is a defense to point sources:

> [W]e know of no rule of law that sanctions one wrong because another has preceded it. It is doubtless true that streams of water cannot be kept as pure when flowing through lands occupied by populous communities as when flowing through sparsely settled lands, but these effects that unavoidably arise from the occupation and cultivation of the soil by man do not justify the deliberate pollution of the stream of water flowing through another private property, in order that the interests of private persons, or even the public, may be enhanced thereby. (emphasis added)

See also Wickard v. Filburn, 317 U.S. 111, 127-128 (1942); U.S. v. Ashland Oil & Transportation Co., 501 F.2d 1317, 1329 (6th Cir. 1974).

The last point deserving of discussion is defendants' argument that discharges by point sources in Illinois and Michigan are a defense. The evidence shows that a number of small municipalities on the Michigan shoreline discharge inadequately treated sewage effluent to the lake. The only Illinois community still regularly discharging into the lake is Waukegan, with a plant capacity of ten million gallons per day. (The combined capacity of the two Milwaukee plants is 320 million gallons per day.) Within the next few months, it is expected that Waukegan will no longer be discharging to the lake except on rare occasions when overflows will occur. There are instances of wet weather overflows in Chicago when raw sewage is discharged to Lake Michigan. These are exceptional situations, however, and Chicago is in the process of planning large underground reservoirs to contain the excess storm water and prevent these overflows.

In short, there are point sources in both Illinois and Michigan which discharge pollutants to the lake. These sources are diminishing in Illinois, but it cannot be denied that they exist and that their existence is undesirable. The question is, does this somehow excuse the conduct of the defendants. The defendants cite Missouri v. Illinois, 200 U.S. 496 (1906), and New York v. New Jersey, 256 U.S. 296 (1921), both cases in which plaintiffs were denied relief because they had already polluted the waters in question to an extent that the results of further pollution contributed by the defendants were virtually imperceptible. Nothing like that exists in the instant case.[11/] Despite the accelerated eutrophication going

11/ This is not a negligence case and "contributory negligence" on the part of some Illinois and Michigan communities is not a defense, even assuming that the conduct of those communities can be imputed to the plaintiff states.

on in Lake Michigan, it is still a relatively clean body of water. Further degradation is not only a possibility, it is a certainty unless the defendants' conduct is enjoined. The cases cited by defendants are distinguishable on this ground, and I conclude that the existence of Illinois and Michigan point sources is no basis for denying relief in this case.

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