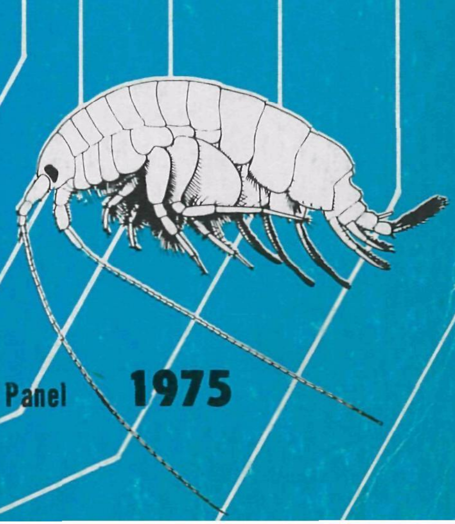
STATEMENT OF CONCERNS
AND SUGGESTED ECOLOGICAL RESEARCH



Report Number 1 of the Lake Michigan Cooling Water Studies Panel **1975**

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A STATEMENT OF CONCERNS AND SUGGESTED ECOLOGICAL RESEARCH

REPORT NO. 1

OF THE

LAKE MICHIGAN COOLING WATER STUDIES PANEL

THE PANEL IS SUPPORTED BY THE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION V, CHICAGO, AND THE
POLLUTION CONTROL AGENCIES OF
ILLINOIS, INDIANA, MICHIGAN, AND WISCONSIN

EDITED BY
CALDWELL D. MEYERS
AND
KARL E. BREMER

QUALIFYING STATEMENT

The Panel does not unanimously recognize nor endorse all concepts and recommendations in each section of this report.

This report is the result of many months of thought, discussion and work by the Section authors. Their objective has been to produce a statement of concerns which would assist in development of investigations of the effects of cooling water use on Lake Michigan. The priority lists are an attempt to focus further on key gaps in understanding. It is hoped that this report will spark research, help realize goals, and provoke discussion leading to continuing modification of its content. Such modification is anticipated and is a desirable result of its production. It is a working document.

The Panel fully recognizes the many implications this report carries to cooling water users and to those responsible for regulation. However, this report is not intended to be a regulatory document.

SECTION AUTHORS

Section I — Introductory Considerations of Lake Michigan

Caldwell D. Meyers

Section II — Data Requirements Related to Lake Michigan Studies

Caldwell D. Meyers
Jerrold H. Zar
Andrew J. McErlean

Section III — Measurement of the Effects of Cooling Water Use on Physical Parameters

John Z. Reynolds
Wesley O. Pipes
Howard Zar
Clifford H. Mortimer
Barton M. Hoglund

Section IV — Measurement of the Effects of Cooling Water Use on Chemical Parameters

Wesley O. Pipes
Carl T. Blomgren
John L. Winters

Section V — Measurement of the Effects of Cooling Water Use on Primary Producer and Consumer Communities

Eugene F. Stoermer
John Neess

Section VI — Measurement of the Effects of Cooling Water Use on Macrozoobenthos

Carlos M. Fetterolf, Jr.
Merle H. Maass
Andrew J. McErlean
Alfred M. Beeton
Wesley O. Pipes

SECTION AUTHORS
(continued)

Section VII Measurement of the Effects of Cooling Water Use on the Fishery

Thomas A. Edsall
Thomas G. Yocom

Section VIII Measurement of the Effects of Cooling Water Use on Entrapped and Entrained Organisms

Arthur S. Brooks
James G. Truchan
John Z. Reynolds
James R. Gammon
Thomas A. Edsall

Section IX Radioecological Considerations Related to Cooling Water Use

Phillip F. Gustafson

ACKNOWLEDGEMENTS

This report would not have been possible without the strength and combined effort of the members and participants of the Lake Michigan Cooling Water Studies Panel.

It is appropriate to recognize the wise counsel and thoughtful help afforded the editors by Wes Pipes, Carlos Fetterolf, Dick Herbst, Jerry Zar and Bob Otto toward this ultimate version of Report No. 1. The Panel extends special appreciation to Delores C. Sieja for secretarial assistance in final preparation of the Report.

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GENERAL INTRODUCTION

Purpose of the Report

This report outlines scientific questions and some methods that might be used to obtain answers regarding the ecological effects of the intake and entrainment of water, the introduction of waste heat, the introduction of specific chemicals, and the release of radionuclides associated with condenser cooling. It is anticipated that the report will produce improvements in research design and a trend toward standardization of results. It may also provide the basis for the selection of appropriate locations for more intensive research and for the possible generalization of the results at those locations to wider areas of the Lake. The Panel recommends priority research studies leading toward an understanding of the whole Lake and designates specific studies and their appropriate priorities.

Description and Objectives of the Panel

The Lake Michigan Cooling Water Studies Panel is a technically oriented group formed at the suggestion of representatives to the joint public sessions of the Lake Michigan States and the U.S. Environmental Protection Agency. In a message to the joint Federal-State Conference of November 1972, the Regional Administrator of EPA, Mr. Francis T. Mayo, cited the need for development of 1) monitoring programs to assess possible damage to the aquatic environment of Lake Michigan attributable to existing and planned cooling water use, 2) criteria to trigger employment of appropriate corrective measures should damage become evident, and 3) mechanisms with which to make an overall assessment of the damage that may occur to the Lake's ecosystem from waste discharges scattered at various points around the Lake. He then suggested formation of a group to review these propositions and charged them to:

-- review background information dealing with past, present and future studies relating to thermal discharges to Lake Michigan;

-- make assessments as to whether the individual studies concerning thermal discharges will adequately assess damages attributable to that cooling water use;

-- assess the pertinence of individual localized studies to monitor changes in the overall lake ecosystem;

-- recommend, as necessary, additional efforts that should be expended to assess environmental effects of the use of Lake Michigan water for cooling.

This enjoinder and these charges have been accepted by the Panel as objectives for its deliberations beyond production of this report.

Actual formation of the Panel was put in motion by Mr. Mayo in December 1972. The Panel consists of the following members, alternates and contributors:

Members and Alternates

State	Name	Affiliation
ILLINOIS		
Members:	Mr. David D. Comey	Businessmen for the Public Interest, Chicago, Illinois
	Dr. Wesley O. Pipes (Until January 17,1975)	Northwestern University, Evanston, Illinois
	Mr. William V. Pye (Until May 9,1974)	Illinois Environmental Protection Agency, Springfield, Illinois
	Mr. Thomas McSwiggin	Illinois Environmental Protection Agency, Springfield, Illinois
	Dr. Jacob Verduin	Southern Illinois University Carbondale, Illinois
Alternates:	Mr. Carl T. Blomgren	Illinois Environmental Protection Agency, Chicago, Illinois
	Dr. John Neess	University of Wisconsin, Madison, Wisconsin
INDIANA		
Members:	Mr. Gary Doxtater	Aquatic Controls Inc., Seymour, Indiana
	Dr. James R. Gammon	DePauw University, Greencastle, Indiana
	Mr. John L. Winters	Indiana Stream Pollution Control Board, Indianapolis, Indiana
Alternate:	Mr. Harold L. BonHomme	Indiana Stream Pollution Control Board, Indianapolis, Indiana

State	Name	Affiliation
MICHIGAN		
Members:	Mr. Carlos M. Fetterolf,Jr.	Michigan Department of Natural Resources, Lansing, Michigan
	Dr. John Z. Reynolds	Consumers Power Company, Jackson, Michigan
	Dr. E. F. Stoermer	University of Michigan, Ann Arbor, Michigan
Alternates:	Dr. Claire L. Schelske	University of Michigan, Ann Arbor, Michigan
	Dr. James G. Truchan	Michigan Department of Natural Resources, Lansing, Michigan
WISCONSIN		
Members:	Dr. Alfred M. Beeton	University of Wisconsin, Milwaukee, Wisconsin
	Mr. Nicholas A. Ricci (Until January 8, 1974)	Wisconsin Electric Power Co., Milwaukee, Wisconsin
	Dr. Frank Boucher	Wisconsin Electric Power Co., Milwaukee, Wisconsin
	Dr. Clifford H. Mortimer	University of Wisconsin, Milwaukee, Wisconsin
Alternates:	Dr. Arthur S. Brooks	University of Wisconsin, Milwaukee, Wisconsin
	Mr. Kenneth Lehner (Until September 1, 1974)	Wisconsin Electric Power Co., Milwaukee, Wisconsin
	Mr.Merle H. Maass	Limnetics Inc., Milwaukee, Wisconsin
	Dr. John Ney	Wisconsin Electric Power Co., Milwaukee, Wisconsin
FEDERAL		
Members:	Mr. Yates M. Barber (Until August 30, 1973)	NOAA, National Marine Fisheries Service, Washington, D. C.

State	Name	Affiliation
FEDERAL (continued)		
Members:	Dr. Thomas A. Edsall	U. S. Bureau Sports Fisheries and Wildlife, Ann Arbor, Michigan
	Dr. Philip F. Gustafson	Argonne National Laboratory Argonne, Illinois
	Dr. Andrew J. McErlean	U. S. Environmental Protection Agency, Washington, D. C.
Alternates:	Dr. Donald L. McGregor	Argonne National Laboratory Argonne, Illinois
	Mr. Barton M. Hoglund (Until January 1, 1975)	Environmental Technology Assessment, Oak Brook, Illinois
Chairman:	Mr. Karl E. Bremer	U. S. Environmental Protection Agency Chicago, Illinois
	Mr. Caldwell D. Meyers (Until October 1,1974)	U. S. Environmental Protection Agency Chicago, Illinois
Technical Secretary	Howard Zar (Until June 1, 1974)	U. S. Environmental Protection Agency Chicago, Illinois
Recording Secretary	Ms. Marion Young	U. S. Environmental Protection Agency Chicago, Illinois

Contributors

Dr. Wayne P. Alley	California State University Los Angeles, California
Mr. Jarl Hiltunen	U. S. Fish and Wildlife Service, Ann Arbor,Michigan
Mr. Peter Howe	Commonwealth Edison Co., Chicago, Illinois
Mr. John H. Hughes	Commonwealth Edison Co., Chicago, Illinois
Mr. Gary Milburn	U. S. Environmental Protection Agency Chicago, Illinois

Contributors
(continued)

Dr. Samuel C. Mozley	University of Michigan, Ann Arbor, Michigan
Dr. Robert G. Otto	Industrial Bio-Test Laboratories, Inc. Northbrook, Illinois
Mr. Pete Redmon	U. S. Environmental Protection Agency, Chicago, Illinois
Dr. James J. Reisa	Council for Environmental Quality, Washington, D. C.
Dr. Steven Spigarelli	Argonne National Laboratory Argonne, Illinois
Mr. Thomas Yocom	U. S. Fish and Wildlife Service Ann Arbor, Michigan
Dr. Jerrold H. Zar	Northern Illinois University DeKalb, Illinois

The Chairman, Technical Secretary, staff support, and financial support for the Committee are contributed by Region V, EPA.

At the date of this writing, the Panel has had twenty-five monthly meetings.

At the second Panel meeting on January 30,1973, the following standing subcommittees were formed from the appointed Panel members and alternates; Fisheries, Microbiology, Chemistry, Physical, Benthos, Data Handling and Evaluation, Radioecology, and Entrainment and Entrapment. Each of these Panel subcommittees consist of one to six members permitting full use of the expertise of the individual members to consider subdisciplinary problems, and for preparation of this report. Alternates, observers, professional colleagues and others interested in the future of the Lake also made substantial contributions to the subcommittees, to the Report, and by extension, to the effectiveness of the Panel.

Priority Research

Most issues of water pollution resolve into conflict between competing demands for use of a particular water resource. The issue of thermal discharges to Lake Michigan reduces to an attempt to ascertain the extent to which use of the Lake for cooling large stream electric generating stations is compatible with the protection and propagation of a desirable community of aquatic organisms and with recreational use of the Lake. There is no doubt that Lake Michigan will continue to be used for cooling, for aquatic life, and for recreation; there is doubt that these uses are compatible at various levels.

The Lake Michigan Cooling Water Studies Panel was formed as a technical and scientific group to examine evidence relating to the effects of cooling water use. As such, the Panel is not attempting to determine the relative values of cooling use, aquatic life use, and recreational use. These value judgments must perforce be made by the citizens of the several states and their elected and appointed representatives. The task of the Panel is to make recommendations as to the types and value of scientific information available as an input to the political, decision-making process.

Studies of the effects of cooling water use on Lake Michigan have been in progress for over seven years. With few exceptions these studies have been oriented toward the local effects of individual power plants. Studies commissioned and supported by individual utility companies will, no doubt, continue to focus on local effects. The needs recognized by the Panel provide a mechanism for coordinating individual studies to develop information on lakewide effects and to eliminate from individual studies those elements either adequately explored or obviously unfruitful.

Since its inception, it was the intention of this Panel to identify areas of ignorance which seem to be the most formidable barriers to an adequate understanding of the effects of cooling water use on the biota of Lake Michigan. Stated conversely, the Panel focused on additional steps or research which, when accomplished, would most rapidly increase our understanding of the effects of cooling water use. Since it was difficult to isolate these areas of research, the Panel used the following methodical approach:

1. Recognition of primary areas of ecological concern by division of the Panel, and of its deliberations, into eight subcommittees; e.g., Fisheries, Physical, Chemical, etc.

2. Development of a research program to elucidate the effects of cooling water use within those subcommittees by discussion and deliberation based on

knowledge, experience, published literature, and consultation.

3. Development of priority lists, with appropriate numerical values based on the availability of relevant data, for those areas of knowledge which are barriers to an adequate understanding of the effects of cooling water use. (These lists have been placed at the end of the appropriate sections)

The next step was to examine the priorities to which the Panel has ascribed the highest degree of urgency and to attempt to select several key issues. The criteria for selection of key issues were that they be recognized (1) as steps facilitating the orderly use of data for well documented answers to the remaining questions about cooling water use or (2) as statements embodying the ultimate goals of the Panel. The key issues identified are important to all studies of cooling water use on Lake Michigan as a group but all issues are not pertinent to any individual study. For instance, the subcommittees on macrozoobenthos, plankton, and fisheries observe that although methods of identification of species and their distribution in a local study area may be well-known, the absence of such basic data for the Lake as a whole is recognized as a very real barrier to the understanding of possible lakewide effects.

The ultimate step was to obtain concurrence of the Panel in selection of issues of highest priority and this has resulted in the following, not necessarily in order of importance:

1. To determine the periods of time, and extremes and average temperatures to which aquatic organisms are exposed when they meet elevated temperatures in discharge plumes and to evaluate available data to determine the feasibility of detecting ecological effects attributable to cooling water use.

2. To standardize units of measurement for each parameter for which environmental data are collected, by agreement between Lake Michigan investigators and institutions, so that information from the large number of local studies can be expeditiously integrated for consideration of lakewide effects.

3. To develop a taxonomic and zoogeographic characterization of the Lake Michigan biota.

4. To facilitate organization of Lake Michigan data to determine location and design of discharge and intake structures to minimize important biological effects.

These are clearly issues which must be resolved before questions of lakewide effects can be answered. This does not imply that each utility company and governmental agency provide answers for each of these questions, for that would be redundant and wasteful. Just as individual sections of this Report describe studies for local and lakewide effects, these priorities refer to broadly applicable studies useful to all interested parties. An organizational effort is clearly needed to focus resources toward cooperative efforts which will advance the overall understanding of the effects of cooling water use.

PROPOSED DEFINITIONS
WITH APPLICATION TO LAKE MICHIGAN

In an attempt to provide a common terminology from which to address Lake problems, the Panel stipulates the following definitions of the water zones:

Profundal Area

(Approximately 45 meters and deeper) - that area of the lake in which the lake bed is in the hypolimnion in the summer and in which the temperature of the whole water column does not generally fall below 2C in the winter and over which a continuous ice sheet forms only for brief intervals in exceptional years.

Sublittoral Area

(Approximately 10 to 45 meters deep) - that area of the lake in which the lake bed in the summer is sometimes in the hypolimnion and sometimes in the epilimnion depending upon the occurrence of internal waves and upwellings.

Littoral Area

(Less than approximately 10 meters depth) - that area in which (1) most of the surface wave energy is dissipated, in which sediments (if present) are frequently resuspended by wave action and where the physical conditions are often suitable for growth of attached algae and sometimes macrophytes, (2) where epilimnetic water is the dominant medium, but, where hypolimnetic water may occasionally intrude via upwellings or internal waves, (3) containing the beach zone. The outer limits of the beach zone may be defined as the outer limits of breaking waves in severe storms. This limit is determined by water depth, wind fetch and exposure. Only in the beach zone, so defined, are wave-induced, longshore and rip currents found.

SECTION I

INTRODUCTORY CONSIDERATIONS OF LAKE MICHIGAN

Section I. INTRODUCTORY CONSIDERATIONS OF LAKE MICHIGAN

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Section I. INTRODUCTORY CONSIDERATIONS OF LAKE MICHIGAN

CHARACTERISTICS OF LAKE MICHIGAN

The material in this section of the Report is drawn largely from data presented in the Great Lakes Basin Framework Study, 1972.

Location and Dimensions

Lake Michigan is the third largest of the Laurentian Great Lakes (Table I-1) and the sixth largest freshwater lake in the world. It is bordered by the states of Wisconsin, Illinois, Indiana, and Michigan and is the only lake in the group entirely within the borders of the United States.

The maximum length of the Lake is 307 (494 km) miles. The maximum width of the northern basin (from Little Traverse Bay to Little Bay de Noc) is 118 miles (190 km); the southern basin (from Grand Haven to Milwaukee) is 75 miles (121 km) wide.

Lake Michigan is a relatively deep lake with a maximum depth of 923 feet (281 m) and a mean depth of 276 feet (84 m). The volume is estimated to be 173 trillion cubic feet or 1,181 cubic miles (4,919 km^3) at average lake level, with an areal surface of 22,400 square miles (57,991 km^2), and a land drainage basin in excess of 45,400 square miles (117,535 km^2).

The shoreline of the Lake is regular in the southern two-thirds of the basin but less so in the northern one-third. The total shoreline extends 1,660 miles (2,671 km). Shoreline and shallow areas of Lake Michigan are important to the effectiveness of the Lake as a productive unit since a large portion of the biota depends upon shallows for reproduction, feeding, and as nursery grounds for immature organisms.

Table I-1. Dimensions of the Great Lakes.

Lake[1]	Length (mi)	Breadth (mi)	Water surface (mi)	Drainage Basin (mi)	Avg. surf. Elev. above mean sea level since 1860 (ft)	Mean discharge (cfs)	Max. depth (ft)	Mean depth (ft)
Superior	350	160	31,820	80,000	602.20	73,300	1,333	487
Michigan	307	118	22,400	67,860	580.54	55,000	923	276
Huron	206	183	23,010	72,620	580.54	177,900	750	195
St. Clair	26	24	490	7,430	574.88	178,000	21	10
Erie	241	57	9,930	32,490	572.34	195,800	210	58
Ontario	193	53	7,520	34,800	246.03	233,900	802	283

[1]Data from Beeton, A.M. and D.C. Chandler (1966).

GEOLOGIC DESCRIPTION

The stratigraphy of the Great Lakes basin has determined both land form development and the mineralogical composition of ground and surface waters. Lithologic units range from Precambrian to Recent and can be grouped into three time-stratigraphic divisions with unique origins and impacts: Precambrian, Paleozoic, and Cenozoic.

Precambrian units consist of complex folded and faulted igneous, metamorphic and sedimentary aspects; Paleozoic are largely of marine or strand-line origin; and Cenozic are largely consolidated sediment deposited from Precambrian and Paleozic strata from within, and north of, the basin. Paleozoic and Cenozoic depositions, as well as major erosional and depositional land forms, were a result of Pleistocene glaciation during the four glacial periods (Nebraskan, Kansan, Illinoisian, and Wisconsin). These sedimentary strata were also subjected to regional folding resulting in outcrops such as the Wisconsin Dome and the Findlay - Algonquin Arch, which effectively determine the size and direction of the drainage of Lake Michigan. The Michigan Basin has a saucer-shaped cross-section with Precambrian strata sloping to their greatest depth under the approximate center of the lower Michigan peninsula. Due to this alone, and to tectonic outcrops previously mentioned, the strata of the Eastern shore are Mississippian-Pennsylvanian with the center of the Lake underlain largely by a Silurian-Devonian series. Lake Huron has a similar stratigraphic profile on the eastern side of this depositional saucer.

Physiographic Description

Lake Michigan is located in the Interior Lowlands Province which is characterized by better drainage than areas to the North, by glacial moraines, and by outcrops of resistant, dipping, Pre-Pleistocene strata. An example of the latter is the Niagara Escarpment to the north and the west of Lake Michigan. Glacial sediments are either morainal or non-morainal debris with the latter glacio-lacustrine, glacio-fluvial and eolian sediment. Due to glaciation, the drainage basin of Lake Michigan (along with Superior and Huron) is poorly developed and the residence time of water in the basin is extended.

Physical and Chemical Description

The physical and chemical properties of the Lake are of great significance to its possible use as a resource, but, in light of the number of documents on the subject, and since the purpose of this section is introductory, the treatment here will not be exhaustive.

General Physical

Important properties of the waters of Lake Michigan such as circulations, viscosity, ice formation, sedimentation, distribution of suspended and dissolved solids, chemical reaction and interaction, biological productivity, waste assimilative capacity, rate of eutrophication and many others, depend in a large part on the temperature, pressure and density of the water. The most significant thermal properties are: latent heats of fusion and vaporization, specific heat, coefficient of thermal conductivity and coefficient of eddy conductivity. Density is itself dependent on composition of the water and varies with temperatures as affected by solar radiation and to a much smaller extent on man-influenced introductions. Composition of the water, and especially dissolved and suspended solids, affect transparency which in turn affects incoming radiation, temperature, heat storage, loss of heat, photosynthetic rate, chemical reaction, evaporation, modification of the water and, ultimately, lake circulation. The dependence and interdependence of these factors on the lake waters can easily be recognized.

Thermal Characteristics

Since temperature and the heat balance of the Lake are primary subjects of this Report, these characteristics will be most thoroughly covered. The specific heat of water is very high; water stores large quantities of heat, does not give it up readily, and acts as a thermal mediator in the atmospheric and terrestrial environments. In general, the thermal conductivity of water is low, but since water is rarely motionless, heat transfer is effected through turbulence and is dependent upon mixing, circulation, stratification and climate. It should be observed that viscosity, which is temperature dependent as a non-linear function, also affects transport, stratification and other aspects of circulation.

Interfacial reactions are affected largely by the latent heats of fusion and vaporization which for water are among the highest of all substances.

Temperature

Lake temperatures vary with latitude and depth. Depths controls heat storage, absorption, and transfer, but the distribution is also strongly affected by wind driven mixing. Since winds in Lake Michigan are predominately westerlies, warmer waters generally appear on the eastern shore and cold water up-wellings occur in the west. Highest variation in mean water temperatures on the Great Lakes occurs during mid-summer, while the range of variation is reduced sharply in the fall during which hypolimnetic cooling is significant; lowest variation occurs in late winter.

Vertical variation is also affected by many of the mentioned parameters but winds are the basic mechanism of mixing. During the spring warming phase following ice break-up, deeper waters are colder than 4C and less than maximum density.

The following is a description of the development of the thermal bar by Dr. C.H. Mortimer of the Center for Great Lakes Studies, Milwaukee, Wisconsin:

"The spring warming phase first affects shallow nearshore waters, in which stratification develops, while the offshore water mass remains in its homo-thermal mixed winter condition, typically at temperatures well below 4C. Between the offshore water mass and the nearshore stratified water a very narrow transition zone forms, often marked by a nearly vertical 4C isotherm. This zone, known as the thermal bar, is interpreted as a convergence brought about by the mixing of the warm inshore and cold offshore masses at the convergence to produce a mixture which, being close to 4C, is denser than the parent water masses, and therefore sinks.

As the spring heat influx continues and strengthens, the volume of nearshore stratified water increases and the "bar" (4C isotherm) moves offshore. There are usually striking chemical and optical contrasts at this time, between inshore and offshore water, because inflows from rivers and municipal and industrial sources remain temporarily trapped inshore of the bar, and biological production is higher and starts earlier there than offshore. The offshore movement of the bar continues until thermal stratification is established in late June over the whole basin."

Continuing with a description of the overall seasonal stratification of the Lake, Dr. Mortimer states:

"The form which the thermal stratification takes is determined by the interplay of the buoyancy of the surface, heated water masses and the mechanical mixing energy of the wind. Typically the upper layer (the epilimnion) is mixed to near uniformity down to about 30 feet (10 m) by the end of June, at which time the lower water masses (the hypolimnion) has warmed up to approximately 4C. The epilimnion and hypolimnion are separated by a thermocline, a relatively narrow zone in which temperature falls and density increases sharply with depth. The mean level of the thermocline gradually descends during the summer but its actual level at any one time is strongly perturbed by down-tilting (downwelling) and up-tilting (upwelling) within 10 miles (16 km) of the shore and by large internal waves occupying the whole basin. When the net heat flux to the water surface becomes negative at the end of August, the epilimnion cools and the thermocline begins to descend more rapidly, culminating in a complete mixing of the water layers (the overturn) in December. Subsequent cooling of offshore water during winter occurs with a more or less homogeneous water column well mixed from top to bottom, falling in typical winters, to a temperature close to 2C by the end of March. Ice normally forms only in bays, e.g. Green Bay, and near the shore."

Water temperatures at or near the surface respond to daily insolation, diurnal heating, and cooling of surface layers. During the summer, longer days cause a net heat gain; during winter, longer nights cause a net heat loss. The temperature interaction at the air-water interface also causes climatic modification through overall temperature mediation and lake breezes.

As stated earlier, the winter minimum in offshore waters of Lake Michigan occurs in late March at temperatures near 2C. The shallow water near the shore is essentially freezing temperature for a period of approximately 3 months, January through March; however, solar insolation may warm the shallow water to 1C - 2C for a brief period of time on bright winter days. Surface water temperatures may reach highs of 18C to 21C in mid or late August. At any time during the year more than half of the water in Lake Michigan is at a temperature of 4C or less.

Transparency

In water, transparency is the ability to transmit solar, indirect, and artificial light. Its effects are felt on water chemistry, biological activity including phytosynthesis, circulation, stratification, and materials transport. It is affected by color, dissolved solids, and suspended solids, and the penetration is determined by intensity at the surface and angle of incidence with the water surface. In other words, the more turbid the waters the less the light penetration. Further, accumulations of suspended silt, organic materials and other particles around the periphery of Lake Michigan, particularly in the southern basin, would lead one to expect lower transparencies there. Short term variation might be caused by tributary inflows, storm activity, and plankton blooms.

Seasonal variation is influenced by basin physiography and cultural development. Mean transparency in late spring is highest in the deeper portions of Lake Michigan with lower transparencies near shore and in shallower northern portions.

General Chemical

The chemical qualities of Lake Michigan are influenced by the biota and sediment in the Lake in addition to contributions through natural and cultural loads from run-off and tributaries. Nutrient loads have the greatest effects along with more general pollutional loadings at the heavily industrialized southern portion of the Lake. Water quality is complicated by the uncertainties of circulation, by the great depths of the Lake and by relatively small out-flow from the Lake which might ordinarily lead to a displacement of chemical products.

Natural Contributions

These constituents are weathered products of soil and bedrock along with organics derived from the biota.

Cultural Contributions

Materials that result from man's activities are either associated with run-off or are directly discharged into the Lake. The major contributions include agricultural wastes, industrial and municipal wastes, and atmospheric fallout. Nutrients, toxic metals, hydrocarbons, pesticides, phenols and complex organics present problems of great concern in the management of Lake Michigan.

Dissolved Solids

A useful index of the total natural and cultural inputs to Lake Michigan is total dissolved content. Specific conductance is a common measure of the inorganic dissolved content, and surveys of conductance demonstrate major sources in the Chicago-Gary area and disclose maxima along the periphery of the southern basin.

Chlorides

This ion is conservative, i.e., does not readily enter into chemical and biological reactions and may therefore be used as an index of chemical loading and chemical build-up yielding useful comparisons with the behavior of non-conservative material. Chlorides originate from brines, road deicing, industrial compounds, cleaning compounds, and natural soil and rock weathering. Lake Michigan data indicate chloride increases from Chicago-Gary, to Green Bay and Milwaukee, and reaches from Benton Harbor to Muskegon and Little Sable Point to Frankfort. Major loading problems have also occurred at Manistee and Ludington from natural ground water concentrations there.

Carbonates

The interaction of water with carbon dioxide is significant to living systems of the Lake due to requirements for CO_2 for photosynthesis. A complex equilibrium of CO_2 in the carbonate system supplies this necessary ingredient. This equilibrium is controlled by temperature, atmospheric CO_2, pH and associations with calcium carbonate, $CaCO_3$. Some measurement for the capacity of the water to support life are pH, alkalinity and bicarbonate. The tendency for change is counteracted by the buffering capacity of the water and the most abundant mineral in the Great Lakes system which supplies this buffering capacity is $CaCO_3$.

So far, there are insufficient data to determine areal pH distribution in Lake Michigan. In addition, there is some evidence that rises in Ph can occur as a result of algal photosynthesis and may displace the CO_2/carbonate equilibrium to a point at which calcium carbonate precipitates.

Oxygen and Redox Potential

Oxygen is also essential for life support and its solution into the water depends upon pressure and temperature. Parameters which reflect oxygen and oxygen demand in the water are D.O. concentration, O_2 activity, percent saturation, Biological Oxygen Demand, and Chemical Oxygen Demand. Redox potential reflects the potential of the environment to oxidize or reduce material. Although oxygen supplies in the Great Lakes have been thoroughly studied, Lake Michigan has not experienced serious problems except at the southern end of Green Bay. Other data which reflect areal trends in oxygen or redox potential are insufficient for comparison.

Phosphorus

This nutrient is essential in living systems, is readily recycled and can be a factor limiting growth. It occurs in a number of forms, predominately as ortho and poly phosphates, and it is removed from lake water by organic sedimentation, by ion exchange on clays and through uptake by algae.

The assimilative capacity of the Great Lakes for phosphorus is high due to their water volumes but continued loading leads to local overproduction of algae. Phosphorus removal is difficult and control in Lake Michigan is by limitations on nutrient loading, particularly from the sewage treatment plants discharging to the Lake and its tributaries.

Nitrogen

This nutrient encourages eutrophication in excess, but many sources such as atmospheric and ground water inputs are not readily controllable. It occurs as free nitrogen, nitrate, nitrite and ammonia, as well as in most organic forms. The nitrogen cycle is complex but well understood. Nitrogen is also assimilated rapidly into the Great Lakes System but relatively high concentrations may develop in nearshore areas receiving high loadings.

Organic Compounds

These compounds have the principal effects as oxygen demanding compounds and as toxic substances. An attempt is made here to introduce the problems associated with those compounds as pollutants while recognizing that recent control measures have reduced their seriousness to the Lake.

Chlorinated hydrocarbons are persistent, rapidly distributed, and easily assimilated and magnified toxicants. In Lake Michigan, DDT accumulations in Coho Salmon were determined to be unsafe for human consumption by the Food and Drug Administration in 1969. Discontinued use of non-biodegradable pesticides is a practical control but physical-chemical interactions may tie up quantities of these compounds in the environment, particularly in sediments and degradation products. A serious problem area with respect to chlorinated hydrocarbons exists around Green Bay, Wisconsin, but DDT levels in many fishes from the open lake were 2 to 5 times higher than in other Great Lakes fishes according to surveys.

Polychlorinated biphenyls also persist, are biologically magnified, and are toxic in sufficient doses. They have been identified from industrial sources in the Great Lakes and may be found in fish at higher than acceptable concentrations.

Phenols and phenolics are benzene derivatives which impart undesirable tastes and odors to water and edible biota, and which are toxic in low concentrations. Since they are biodegradable and nonpersistent, they cause problems only near their sources.

Detergents add nutrients, usually in the form of phosphates. These compounds indirectly reduce light penetration, and may be toxic in quantity. Since the so called "soft detergents" containing linear alkylate sulfonates are biodegradable, their current use is less of a problem than the alkyl benzene sulfonate fractions formerly used.

Petroleum can be a problem in lake waters by exerting oxygen demand, by restricting gas exchange and by leaving unsightly slicks. Lighter fractions may also be toxic. A recurrence of oil spills from shore installations and loading docks has been noted on Lake Michigan in the Chicago-Gary area and has caused considerable concern and study.

Calcium and Magnesium

These are the main elements contributing to hardness and scale formation. Their presence in water results from leaching of limestone, dolomite and other minerals containing calcium and magnesium found in the watershed. Calcium and magnesium ions are major contributors to the total ionic strength in Lake Michigan. Calcite and dolomite are important components of the carbonate buffering system and Lake Michigan is essentially at steady-state condition with respect to calcium and magnesium.

Sulfur

Sulfur, important in protein synthesis and in hydrogen sulfide, sulfuric acid and its dissociation products, enters the system through precipitation, ground and surface waters, industrial wastes and domestic sewage. The sulfides add disagreeable tastes and odors and may be toxic to certain biota.

Concentrations of sulfur compounds in the Great Lakes have been rising in recent years. Concentrations in Lake Michigan are greatest in areas of limited circulation such as Green Bay and Traverse Bay.

Silicon

This constituent is important as a nutrient for diatomaceous phytoplankters, as an index of weathering of silica rocks and because of its reaction to form sedimentary silicate minerals. This "rate of reaction" depends upon residence time of water in the vicinity of the mineral, composition and crystal structure of the mineral, temperature and composition of the water.

It has been concluded that the silicate system is an active buffering mechanism in the Great Lakes. Depletion of silica levels in the photic zone in the summer is attributed to uptake by diatoms.

Iron and Manganese

These compounds are important in the Great Lakes because of their sensitivity to chemical changes, their buffering capacity, their function in nutrient removal, their toxicity to plant and animal growth under certain conditions, their role as micronutrients, the possible presence of mineable manganese nodules, and their contribution to taste and color of Great Lakes waters.

Trace Elements

When certain of the trace elements are present in sufficient quantities, they can be toxic; all can be used to identify sources of natural and cultural inflows. Increased concentrations have been measured within the upper few centimeters of the sediment - water interface. Trace metals inputs have been measured in major tributaries to Lake Michigan. Iron, copper, nickel, chromium, and zinc are found in detectible quantities. Cores from southern Lake Michigan have indicated high concentrations of arsenic near Benton Harbor and Grand Haven, Michigan and Waukegan, Illinois. These concentrations are supposedly derived from pesticides.

Barium, boron and bromine have not been found in Lake Michigan waters in sufficient quantities to present a serious problem. However, cadmium, chromium and copper have been measured in the sediments of southern Lake Michigan in a wide range of concentrations.

Iodine in Lake Michigan was measured in quantities lower than in any other Great Lake. Lead is concentrated in the upper sediment layer and is presumed to originate from airborne particulate compounds.

Mercury has been found in the Great Lakes in alarming quantities. Sources are clear-alkali plants, pulp and paper mills, electrical industries and other public and industrial uses. Metallic mercury was discharged indiscriminately to the environment prior to the middle 1960's under the assumption that it was relatively inert, but methylation has been shown to occur. These processes lead to concentrations in fish well above levels set by the USFDA and Lake Michigan sediment cores contained concentrations from 3 to 8 times that of the water over the sediment.

Little is known of the concentrations of silver, selenium and the uranyl ion in Lake Michigan. However, zinc was found in quantities in sediment cores from the southern part of the Lake.

Radionuclides

Technological control of radionuclides has received ample attention since the hazards of raioactivity have been recognized. Sources are limited, but small additions accrue from atmospheric fallout, reactor waste disposal, and accidental reactor, industrial, and research release.

Total alpha radioactivity is greatest on the Michigan side of Lake Michigan but this is attributed to natural radioactivity. Water from near Big Rock Point nuclear plant, at Charlevoix, Michigan, has shown counts slightly higher than counts west of the plant.

Biological Characteristics

Clearly, there is little hope that this section of the Report can adequately treat the wealth of information on the biology of Lake Michigan. It is hoped, however, that by addressing aspects salient to the introduction of thermal effluents, the more obvious gaps in understanding will be emphasized, and it will spur necessary biological investigations. Floral and faunal groups described here are the bacteria and fungi, invertebrates, algae and fish.

Bacteria and Fungi

Routine field studies on bacteria and fungi of natural waters such as Lake Michigan are relatively rare in comparison to studies of higher biotic groups. Problems in the biological and biochemical characterization of these natural populations have not been solved due to lack of adequate methodology. However, many of the chemical processes which comprise the major roles of these organisms in the functioning of the ecosystem have been studied extensively.

Bacteria and fungi are decomposers, converting organic material into simple inorganics which can be easily utilized by heterotrophs and autotrophs alike. Some bacteria are chemotrophs, producing energy as a result of oxidation of inorganic compounds; and yeasts often fill a vital consumer role. Seasonal variation in the nitrate concentration in Lake Michigan has been found to correlate with changes in the rate of nitrification as well as the uptake of nitrate by phytoplankton. Specific decomposers such as those with affinities for starch, chitin, or cellulose may be scarce in areas of Lake Michigan at certain times. Increases in these and other bacterial populations may be closely dependent upon the availability of surfaces (to which they may attach) in the Lake and the fact that Lake conditions are often unsuitable for the growth of aerobes from allochthonous origins. The variety of yeasts in Lake Michigan has been related to sediment type with evidence of only a slight relation to depth.

One of the more outstanding problems in analysis of bacterial and fungal populations from Lake Michigan is incubation temperature. Although these microorganisms are typified by culture at 35C, lake temperatures rarely approach those conditions and a false estimate of thermophils versus psychrophils may be obtained. Other bacterial increases may be closely linked with the availability of essential nutrients and with the compounding effect of light penetration.

Lake Michigan is lower than Lake Erie in total counts of bacteria used as indicators of sewage, with highest levels in the southern periphery and in the area of Green Bay. It has been found that Lake Michigan waters are toxic to patheogenic enteric bacteria such as *Shigella* and certain Salmonella organisms during certain times of the year. Toxins produced by *Clostridium botulinum* are presumed to have caused large waterfowl mortalities in the Lake in 1963-64.

Invertebrates

Knowledge of the invertebrate forms of Lake Michigan is behind that of Lake Erie and there are still major gaps in our understanding of this important component.

Although zooplankton are likely to integrate environmental conditions, their passive movements through large water masses make interpretation of both quality and quantity difficult. Early data indicated no qualitative difference in zooplankton of Lake Michigan and this was explained by assuming homogeneous conditions in the Lake.

Various indices of organic pollution have been developed using benthic organisms which seem appropriate in view of the relatively fixed nature of the group. Insofar as faunal gradients are concerned, oligchaete populations seem to be concentrated in the southern portions while amphipods are more abundant in the nearshore zones of the more northerly portions. Distributional maps for pollution-tolerant tubificids essentially correspond to locations of larger cities on the Lake.

Early data on Lake Michigan also indicate little change in the species composition of plankton in the forty-year interval prior to 1926. Recently a number of faunal additions have been reported. It has been suggested that shifts in species composition may reflect the acceleration in eutrophication, but the picture is confused by taxonomic difficulties.

Attempts have been made to generalize regarding possible correlation of Lake Michigan benthos with depth, but this has been difficult due to the variation in sediment deposits and sediment types. It would seem certain that the combination of substrate type and exposure to wave action exert considerable influence on the quantity and quality of these invertebrates, but organic content is also a significant factor. Temperature is also of importance in several ways: as it is affected by depth, as it changes with season, and as it is increased through human activity.

Algae

Benthic algae seem to be of lesser importance in the Great Lakes than periphytic algae, but euplanktonic forms are more diverse and greater in biomass. The Great Lakes flora consists of a great number of species of phytoplankton and so considerable difficulty exists in taxonomic discrimination.

Nuisance algae has been used as an indicator of a decline in water quality in Lake Michigan. In the period, 1967-1970, both *Cladophora* and *Spirogyra* caused problems by windrowing on the beaches, by creating odor and color problems, by creating unsightly conditions, and by fouling fishermen's nets. *Cladophora* and certain diatoms have also been blamed for taste and odor problems and for clogging filters of public drinking water supplies, but these seem to have been transient problems not in current evidence. Various other forms have been indicated in the production of algal toxins which cause sickness and death in waterfowl and fishes and which are capable of affecting mammalian populations.

Various types of indices to compare species and abundance have been applied to the Great Lakes. As might be expected, it has been found that Green Bay and a near shore Lake Michigan site were more eutrophic than another Lake sampling station.

The timing of planktonic pulses appears to exhibit differences between southern, more northern and mid-lake areas in Lake Michigan. Regional differences in species have been observed and the thermal bar has been shown to exert a profound influence on planktonic abundance. In addition, spring phytoplankton standing crops were higher on the shoreward side of the thermal bar than on the lake side with the greatest standing crop at the thermal interface of the bar.

Evidence of long-term trends of phytoplankton standing crop taken from Chicago filtration plant records indicates an increase in phytoplankton over the years, but evidence of taxonomic shifts are ambiguous. Some species are apparently declining and invasion by new species, some of a nuisance variety, has been described.

Seasonal patterns of abundance are considered bi-modal in Southern Lake Michigan with, as has been mentioned, some variations in timing in other lake areas. In one study, it was concluded that the major influences on spring pulse are temperature and turbidity and that fall maxima are more limited by chemical and physical factors. In another study, primary pulse impetus has been attributed to temperature alone. Other workers have expressed doubt that temperature alone can be simply correlated with phytoplankton pulses and have attempted to relate nutrient distribution to these phenomena.

Patterns of abundance in phytoplankton have been attributed to a number of factors including nutrients, phosphorous, nitrogen and carbon. Since the photosynthetic process and the rate of growth are highly dependent on temperature and light, these factors must also be woven into any scheme which presumes a limiting factor. It is abundantly clear that temperature and light effects are difficult to separate in analysis of field investigations of phytoplankton.

Fish

Commercial and sport fisheries have probably taken place on the Great Lakes since the arrival of man to its shores, but the nature of the lakes has permitted a profound effect to take place due to man-caused disturbance. Changes in species composition and abundance have been observed in all the lakes, but particularly in those most closely influenced by population and urban growth.

The large sizes of the lakes have not encouraged an adequate understanding of the distribution and population of resident species so that, in many cases, historical trends are difficult to deduce. In addition, current records are derived from commercial catch records which do not provide data on certain important groups, especially, forage fishes. The openings between the lakes permit migration, in general, but passage through the St. Lawrence River allowed invasion by essentially foreign species and man has permitted and encouraged the introduction of other exotics.

Salmonids have largely dominated in establishing goals for management of fisheries of the lakes, including lake trout, the coregonines and more recently the Coho and Chinook Salmon.

Other introduced fishes significant to the development of current lake conditions have included: the smelt, carp, and goldfish, the alewife, sea lamprey and white perch.

In Lake Michigan, commercial fishing practices probably accounted for the decline of the lake sturgeon. Other changes seen in commercial activities are the decline in the lake herring, whitefish, lake trout, and the increasing appearance of smelt and alewives. The decline in trout and whitefish is jointly attributed to predation by the introduced sea lamprey and by fishing; the decline in lake herring is attributed to overfishing and competition by smelt and alewives; decline in the chub fishery and changes in the species composition have been attributed to overfishing and alewife competition.

Fish are excellent indicators of environmental conditions; both species composition and abundance reflect an integration of cyclic and spatial environmental change; hence the environmental interest in fish. Unfortunately changes in the fishery do not separate direct causes from indirect causes such as those resulting from preemption of shallows and nursery grounds, commercial and sports fishing, damming spawning tributaries, increased sedimentation from agriculture and deforestation, and those wrought by the introduction (however, inadvertent) of predator and competitive species.

It has been, in addition, of insufficient interest, or at least very difficult to obtain and keep adequate records of fish distribution and abundance to facilitate the recognition and prediction of fisheries trends.

Summary of Outstanding Features

1. It is the sixth largest freshwater lake in the world.
2. It is extremely deep, with a mean of 276 feet (84 m) and a maximum of 923 feet (281 m).
3. It has a relatively small proportion of shallow waters.
4. It is relatively regular in outline.
5. It has a relatively small drainage basin.
6. Aside from the peripheral waters, particularly in the southern basin, and the waters at Green Bay, its transparency is high.
7. It is a relatively infertile lake and might be classsified as somewhere between oligotrophic and mesotrophic.
8. Detention time of water in the basin is extended.
9. With some notable exceptions, the quantity of accumulated knowledge regarding the lake ecosystem is relatively small.
10. Lake Michigan is lower than Erie, but higher than Superior and Huron, in fish productivity and species composition and the fishery has been greatly influenced by man both directly and indirectly.

Use of the Resource

The 13.5 million people of the Lake Michigan Basin (including the Chicago Metropolitan Area) have at their disposal a resource of magnificent dimension; it is an "inland ocean" of drinkable quality. In 1970, over 2,000 mgd of water were withdrawn from Lake Michigan for municipal use; that is projected to increase nearly 500 mgd by 1980. Barring further degradation, over 1,100 cubic miles of drinking water are available.

Excepting the coldest months of the year, waters of the Great Lakes are widely used for shipping; in 1972, that amounted to over 200 million tons of cargo, largely landed at or near Chicago. Much of this was iron ore, limestone and coal transported from Lake Superior to the steel mills of Gary-Hammond.

Other uses include sport fishing, boating, swimming, and bird watching. In Chicago and Milwaukee the lake provides a pleasant setting for the urban background and permits the inhabitants an escape to open space. During warmer months, the shores of the Lake are widely used for biking, walking, swimming, and visual relief.

The Lake mediates domestic sewage and industrial wastes and these introductions probably have had greatest impact on the other uses. The effects are felt largely in the peripheral areas of the Lake since economics encourages disposal close to shore. It is also true that the littoral zone is ecologically of greatest value and of greatest concern in protection of drinking water quality. Treatment at municipal sewage plants around the lake in the 1970's was in excess of 660 mgd with capital costs exceeding 350 million dollars. These costs may double by 1980, and operation and maintenance is rising. Industrial wastes, largely in the southern basin, are unestimated but contribute substantially to water quality problems. Lake waters are also used to mediate the effects of waste heat produced in the process of electrical generation. Power demands from both the domestic and industrial sectors in the future will probably increase pressures for this use.

Lake Michigan also has an important role in the total commercial fisheries catch of the Great Lakes Basin. Preliminary data indicate that 47.4 million pounds, worth 5.2 million dollars were landed in 1973. These landings account for 76 percent of the total weight taken in the U.S. Great Lakes and 61 percent of the dollar value with the discrepancy between percent weight and percent value explained by alewife harvest.

Sports fishing in the Great Lakes has increased in value, due in part to massive stocking programs of state and federal agencies, to an estimated 350 million dollars per year (not including capital equipment), with the value in Lake Michigan estimated at 73 million dollars per year.[1] These numbers are estimated due to the difficulty in determining the value of a resources so highly dependent on services of a diverse nature, such as the fuel, baits, lodging, food, boats and equipment, required to participate in the sport.

Basin Growth

The total Great Lakes Basin population accounted for 14 to 15

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[1]Personal Communication, 1975. Great Lakes Fisheries Commission, Ann Arbor, Michigan.

percent of the U. S. population in the decades 1940-60 with the Lake Michigan Basin containing 46 percent of that total during the same period. In the decades 1980 to 2020, this Basin total is projected to decrease slightly to 13.5 percent of the national by 2020 with Lake Michigan maintaining a relatively steady 45 to 46 percent. Absolute numbers in the Lake Michigan Basin are expected to increase nearly threefold (U. S. Army Corps of Engineers, 1972) and this addition will cause water uses to increase. Extended concern for the well being of the Lake is anticipated.

Correlation of Basin Growth to Basin Uses

Development of data which would indicate trends of water or lake use is difficult. Increases (from 1940 to 2020) from approximately 8.5 million to nearly 25 million total Lake Michigan Basin population can be surmised to add to uses of the Lake for recreation, domestic consumption and for waste disposal. Certain aspects of use for transportation might also increase but would require a detailed breakdown of cargo.

Employment projections indicate that the total workers in the fields of agriculture, forestry and fisheries will decrease from 267,216 in 1940 to 49,700 in 2020, repeating a decrease of 81 percent. For workers employed in manufacturing industries, projections are for 1,085,201 workers in 1940 to increase 149 percent to 2,705,000 workers in 2020. Clearly, since these are projections and since the respective impacts of these jobs are not known, these numbers must be used with caution.

National trends of surface water use for recreational activities are increasing. This is due to the increased urbanization of the population and a tendency to desire escape or change, along with an increase in leisure time due to a shortened work week. This indicates that water quality must continue to be upgraded for water contact, and that management of fisheries must take sport fishing into greater consideration than has been done previously.

PROBLEMS RESULTING FROM INCREASED USE

Conflicts of Multi-Use Concept

Designation of a water body for multi-use either formally or informally means that the most stringent water quality demands must be met on a total basis. For Lake Michigan, use for drinking requires that the water be oil and grease free, that organisms which might impart unacceptable tastes and odors be absent, that organisms which would clog filters be absent, and that bacterial levels be acceptably low. The level of required quality for use of Lake Michigan waters for industrial processes, for waste disposal, for shipping, or for power boating are rather low and in fact, these latter purposes are likely to contribute to poor quality unless controls are exacting. The possible conflicts between these intended uses can be great.

This is especially true in a water body like Lake Michigan with its oligo-mesotrophic characteristics of cold, transparent, relatively infertile waters. The conflict becomes exaggerated since the human population which aesthetically desires transparent blue water causes the lake to attain a progressive degree of greenness merely through its existence on the shores. Furthermore, the Lake is most green within sight of shore and more pristinely blue nearer the center of the Lake, out of sight and reach of the majority of the inhabitants.

The simplest answer is to insist on maintenance of the entire Lake at a level of quality appropriate to all uses. Such uniformity cause it to be most easily monitored and regulated, and certainly most acceptable for the variety of uses, but it is also clearly the most expensive. It may even be an unwise use of the resource. The alternative of zoning or use designation where controlled disposal or use for shipping, for example, may be limited to certain areas, is a possible answer, but this solution is not in consonance with the national trend to clean up our surface waters. It is also more difficult to monitor and regulate, and by natural forces, difficult to control and limit the areas of effect. However, it may be more in keeping with the notion of wise use in contrast to the purest conservation.

It is not the purpose of this document to rule or decide on these questions, but rather to discuss them. The technical expertise available to us, as a nation, may, in fact, permit us to understand what are the costs, the techniques, and the efficacy of a return of this Lake to a "blue or a greenish color" but it is a social decision as to what that color should be. It is worth noting that this is a group decision and not one for a select few, whether they are scientists or informed citizens.

Eutrophication

In the current ecological movement, the term "eutrophication" has been widely used to mean a deterioration in water quality and excessive productivity due to man's activities. In a scientific context, it is a term describing the aging process undergone by all lotic waters. Scientifically, it has been used most extensively in reference to small upland lakes; this continuum of aging has been designated by three terms and characterized as follows:

1. oligotrophic - deep, abundant oxygen, low nutrients, few individuals of the biota from a large number of taxa.
2. mesotrophic - characterized similarly but with an increase number of individuals of the biota from a decreased number of taxa.
3. eutrophic - shallow, lower oxygen (especially at depth), high nutrients, large numbers of individuals from a relatively few taxa.

Lake Michigan is certainly undergoing these changes in the process of aging, but the vast quantities of water involved tend to slow the process. The lake's depth provides a buffer against the tendency to become more shallow, and the great water mass resists seasonal warming, and dilutes the effects of nutrients that cause increase in productivity. It is probably true, as mentioned previously, that the more peripheral, littoral waters in the southern basis of Lake Michigan are exhibiting the symptoms of eutrophy and this is more certainly true in Green Bay. This is primarily caused by land run-off and contributions from smaller municipalities, and in the southernmost part of the Lake, to industrial discharge. The limited literature suggests that subtle, though not necessarily irreversible degradation of the Lake has already taken place; retardation of these processes is a desirable end.

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SECTION II

DATA REQUIREMENTS RELATED TO LAKE MICHIGAN STUDIES

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Section II. DATA REQUIREMENTS RELATED TO LAKE MICHIGAN STUDIES

Introduction

This section of the Report presents recommendations toward the objective quantification of the effects of cooling water use on surface waters. Many environmental studies have suffered from insufficient statistical confirmation of ecological conclusions. This can best be remedied by more thorough statistical planning during early stages of program design. Objective statistical support of ecological conclusions can be achieved through adequate, informed planning of the number of stations, intervals, frequency, and replicates. Suggestions are also made regarding study design, data collection and some fundamental statistical analysis.

Concern has also been expressed with the great amount of data on Lake Michigan which are scattered widely in formal and informal publications and accumulated in files unavailable for comparison and analysis. Lake Michigan investigators are encouraged to make all Lake data available for review and analysis through central data storage. The answers to many current questions regarding the ecological status of the Lake lie within reach through data which have already been collected; this section of the Report proposes efficient utilization of those data.

Declaration of Intent

It is important to define the goals of each proposed research project and the relationship of that project to the overall goals of assessing the effects of cooling water use. This should be accomplished in a written proposal of study prior to actual data collection. Such proposals should be carefully developed and closely scrutinized by the funding agency, since it serves as a basis for both the quality and the usefulness of the proposed work. Submission of the proposal to the funding agency should be preceded by a critical external review by colleagues and other professionals to increase utility of the study.

Collection of data on each environmental parameter should be justified. The collection of data and samples "which might be useful later on" can be very compelling. Clearly, data collection can save time, effort and money as long as future use is not only anticipated, but is an integral part of the program plan. The collection of data and samples with no planned purpose should be discouraged.

The types of measurements which should be made are defined in later sections by suggesting standard techniques for the subject organisms or parameters. A study proposal should include a detailed description of the type and desired precision of those measurements selected, with justifications. In addition, the study area and areas of concentration and a rationale for those limits should be indicated. The duration of the research project should be stated with some realistic estimate of the possibility of meeting target dates.

Sampling Considerations

After problem selection, an explicit statement of that problem should be drafted to relate the proposed sampling scheme to it. For example, if an attempt is made to determine changes in water chemistry caused by the introduction of heat, the possible reasons for an expected change should be stated, based upon the physics of the system and the chemicals in question. Sampling plans should provide details of suspected spatial and temporal changes (or differences) and the manner in which these will be statistically quantified so as to leave no reasonable doubt of the magnitude of change (or difference). Extensive and statistically sound use should be made of reference locations and times.

After the problem is defined and the measurements are selected, the associated assumptions must be made and clearly stated; for instance, it could be assumed that release of biocides into a cooling water discharge is not time dependent, i.e., with neither diurnal or seasonal variation, since power plants operate more or less continuously. These assumptions affect the economics of the proposed work to a great extent; sampling may be conducted during working hours and in seasons of comfortable ambient conditions. If later information indicates that plant operators apply reduced quantities of biocides in winter months when fouling of the coolant system is less likely, or should biocides be applied at specific daily periods, the statement of these assumptions become valuable. They may cause data to be discarded or at very least, reevaluated, and effect new experimental design. Further, and perhaps most importantly, statement of the most trivial assumptions forces the investigator to more critically examine the precise nature of his problem and proposed methods of investigation.

Prior to the problem statement, a review should be conducted of existing data and studies which bear on the proposal. This should be done in a form suitable for publication. Should previous data or studies be unavailable, a modest pilot study should be conducted to develop information on which to base an informed proposal. Both literature reviews and pilot studies are used for justification of the proposed studies, for forming a data base upon which to build, to serve as a source of appropriate techniques, methods and tools (including statistical considerations) for comparison with new data, and as an indication of careful proposal preparation. The intent of both literature survey and pilot study is to estimate the magnitude of central tendency and the magnitude of variation of each parameter, and to determine the potential for discrimination of environmental differences.

In its final form, the sampling design should reflect the full range of each parameter, to differentiate human influences from natural variability due to climatic, seasonal, daily and other periodic and aperiodic changes. This necessitates random, or other statistically sound sampling. Replication and the provision of reference data, reference samples and reference stations are also required. The number of replicates needed for statistical treatment is dependent upon the variation in the parameter of interest, the accuracy with which one desires to describe the parameter and the magnitude of difference one desires to detect (See Cochran and Cox, 1957). Careful selection of this number will assure a sound comparative base without collection of excessive or redundant data. The number of replicates need not be regarded as fixed but rather subject to adjustment on the basis of periodic review and analysis.

In cases where the number of replicates required for statistical validity is too great due to economic or physical limitations, the desire for statistical acceptability must be balanced against practical considerations. The investigator must also consider if:

(a) the question is valid,

(b) the question is sufficiently important to justify possible upheaval in the subject population, and

(c) the effort and expense which the investigator must expend to achieve statistical validity are warranted.

To serve these desired ends, benefit/cost analysis may be appropriate.

When these costs, both economic and environmental, have been balanced, the information and measurements may be designated as "special studies" for intensive investigation at a single site. When this occurs, the investigator should select a site with broad characteristics that could apply to several sites or to an entire system.

Although the emphasis in this section of the Report is toward meeting satisfactory statistical goals, it should be noted that statistical significance does not imply ecological significance and vice versa.

The proper order for development of the statistical rationale should be:

(1) observation or proposal of a change or difference,

(2) preparation of an hypothesis which is a statement of that change or difference,

(3) preparation of a test for that hypothesis which would tend to verify the existence of change or differences and would establish their magnitudes,

(4) preparation of a statistical framework for the test which verifies that observed differences are not due to random chance and which establishes the probability that the changes or differences in collected samples reflect actual changes or differences in the environment,

(5) review of tests and statistical requirements to determine feasibility within physical, biological, temporal, and spatial constraints.

It is clear that the state of knowledge of organism groups and the available investigative techniques and tools strongly influence testing, sampling, and the ability of the investigator to draw conclusions regarding ecological significance. Any ecological significance perceived should be declared, with specific limitations of the tests.

The great number of variables in the lake makes the attainment of true ecological "controls" virtually impossible. However, this does not preclude the demonstration of meaningful differences between areas of suspected effect and reference stations. Reference stations might be considered sampling locations at which measurements are made which typify natural or ambient conditions in a given time and space.

When the decision has been made to collect data, a sampling schedule should be developed to facilitate field study. Frequently, biological data are separated from physical, chemical, geological and meteorological data due to the relative difficulty of collection. In many cases, the measurement of biological parameters _in situ_ is not possible, and laboratory time may be greater than field collection time by a factor of 20. Therefore, it is usually easier to collect chemical and physical _in situ_ data which more accurately reflect ambient conditions, and there is a reluctance to collect biological data simultaneously. However, biological, chemical and physical data should be collected concurrently insofar as is possible.

Sample Collection and Processing

The absence of comparative data is frequently a major problem in environmental study. Regardless of the nature of the study, temporal and spatial changes, rates and instantaneous magnitudes are measured only against data collected expressly to provide background. Data collected for other studies are rarely directly comparable to proposed work for one or more of the following reasons:

(1) the time frame is not comparable; e.g., previous data were collected in winter, or during the night, or were not collected

with the desired frequency;

(2) the location is not comparable; e.g., previous data were collected two miles further from shore, only at the surface, or were all collected across the Bay which has been filled in with dredging spoil;

(3) unusual ecological conditions prevailed during the previous collection that cannot be duplicated; e.g., mean temperatures exceeded the 20 year average, flows exceeded the 100 year expected high, or water level was less than the predicted lows for that water body.

These variations are usually impossible to control and difficult to predict. However, some variation in design and data collection can be standardized through agreement. This subcommittee recommends careful review and standardization of the following wherever possible:

(a) Collecting gear and other equipment
This includes nets, seines, dredges, pumps, water samplers, traps, and instrumentation and pertains to overall dimensions, orifice sizes, net apertures, rates of water passage, sizes and location of supporting structures, and methods of suspension and deployment.

(b) Techniques of collection, processing, and analysis
This includes methods of calibration; field collection

period, distance, or volume; sequence of deployment, sample removal, gear cleaning, sample sorting, sample treatment and preservation, and sample storage; laboratory sequences of sample removal, washing, treatment, examination, sorting, enumeration, and recording; and a basic series of analyses which may be applied to the data.

(c) <u>Reference collections of permanently preserved samples which are entire, or aliquots representative of the original sample</u>

This requires specification of storage facilities recognized by investigators for routine deposit of all preservable field samples. These reference collections permit examination, identification, emuneration and analysis subsequent to the original treatment, for confirmation of the original results, or to permit application of analyses not considered at the time of original treatment.

(d) <u>Standard and accepted biological keys</u>

This presumes that, (1) texts exist which permit organism identification through comparison with a series of recognized characteristics, and (2) that those characteristics, organisms, and keys have the sanction of authorities in the field or discipline, and have applicability and the desired accuracy for use in a limited geographic area.

(e) Methods and forms for reporting

Development of recognized and accepted forms for field and laboratory data recording permitting immediate transfer to computer/storage and processing.

(f) Units for reporting environmental data

Metric units are preferred for all parameters; English units are included in this report as supplements to metric units only where they were collected in earlier studies.

(g) Accuracy of reported data (i.e., significant figures)

Precision should meet the objectives of the project for which the measurements are being obtained. When limitations to precision are built in, as in the use of instruments that are calibrated to, for instance, the second decimal place (0.01), there is no advantage in attempting to interpolate between the lines nor is there reason to read multipliers of that second decimal place to an accuracy greater than that which is real or justified.

(h) Horizontal positioning and mapping

Measurements of distance are used in nearly all phases of environmental sampling and monitoring. In general, the greatest accuracy is required for mapping horizontal distances for locating discharge plumes and obtaining accurate current measurements. Systems for obtaining distance measurements with varying degrees of precision are readily available. Methods of determining distance should be routinely reported with the precision of the instruments, and where appropriate, with the observed variability of repeated measurements of the same distance.

As a special case, the location of the near-field isotherms to thermal discharge structures dictates that the position of the temperature measurement be known with an accuracy of no less than 10 percent of the width of the discharge orifice. For geometrical reasons, the error in position will always be equal to or greater than the error in the distance measurements that define that position. Therefore the maximum error for distance measurements when mapping the near-field region of the plume should be about 5 percent of the width of the discharge.

In mapping the far-field region of the plume, accuracy of position is less critical. Inaccurate distance measurements will produce inaccurate areal measurements within isotherms but the major source of inaccuracy results from the artistic freedom assumed in drawing isotherms through widely scattered data points. Accuracies of $\pm$ 10 to 30 meters are reasonable in mapping far-field regions of the plume.

(i) Vertical distance

Depth is usually measured relative to the water surface elevation at the time of sampling but, in some instances a fixed vertical distance should be used. For example, accurate depths are essential in studies involving physical effects such as erosion, sediment deposition or organisms on the bottom of the Lake. The precision for depth measurements for most studies is ± 0.5 m (± 2 feet), but studies in the beach zone require proportionately greater precision. A precision of ± 0.01 mm (± 0.25 inches) or better may be required for studies of erosion or sediment deposition.

(j) Level of statistical significance

Five percent, unless otherwise justifiable.

Data Handling

Modern computers permit investigators to collect and analyze large amounts of data. In a system as large as Lake Michigan, and with investigators widely scattered in academic and governmental institutions, universal access to data collected on the Lake is imperative. Data released by a scientist subsequent to collection, computation and even publication should be placed in recognized, accessible storage for possible use by others. Thus, the original collection becomes even further justified, redundancy is decreased and conclusions regarding the environmental state of the Lake become more widely known. In view of recent national constraints regarding access to data collected through public funds, sharing may be mandatory once the information is released by the original investigator.

Universal access to shared data requires development of a compatible format for collection and storage among investigators and institutions of Lake Michigan. In addition, provisions should be made for translation and transfer of data and analyses packages between different computer systems.

Data Evaluation

In the section of the environmental proposal or report describing material and methods there should be a statement of minimum acceptable standards for data treatment. This statement should express not only the form for data presentation (e.g., the arithmetic mean, the median, standard error, etc.), but should also state confidence limits acceptable to all investigators and describe the statistical treatment in detail. This initial commitment will permit the reviewer to judge the rigor with which the data were or are to be evaluated and will provide the investigator with some targets at which to aim.

When describing the effects of environmental difference or alteration, numerically, through species counts, biomass estimates, or density, or when physical or chemical values are stated, the following values should be presented, using data transformations when appropriate:

(1) arithmetic mean,

(2) standard error.

(3) sample size, and

(4) confidence limits for the mean.

Reference to these values and other statistical procedures may be found in Snedecor and Cochran, 1967; Sokal and Rohlf, 1969; Steel and Torrie, 1960; and Zar, 1974. In circumstances where nonparametric analysis is appropriate, the investigator should present the median, sample size and nonparametric measure of dispersion.

When describing the effects of environmental difference or alteration through an evaluation of the structure of the biotic community, the following forms of expression are appropriate:

(1) species diversity, with the specific form dictated by convention of the biological group (see Dorris and Wilhm, 1968; Lloyd, Zar, and Karr, 1968; Pielou, 1966),

(2) equitability indices (e.g., "evenness"; see Pielou, 1966),

(3) species richness, an indication of the number of species accounting for a specified portion (e.g., 95 or 99 percent) of the community.

The results of a study of suspected environmental alteration or difference should be evaluated to determine the extent of difference, and to determine statistically whether the differences observed are greater than those which could reasonably be expected to have occurred through random variation.

For an assessment of spatial and temporal differences, the following statistical procedures are recommended:

The procedure known as "analysis of variance" is a widely applicable method of statistically analyzing lake data. By analysis of variance one may, for example, infer from samples taken at different locations (or times) whether the lake means at these locations (or times) are the same or different.

Strictly speaking, analysis of variance requires certain mathematical assumptions (e.g., an underlying normal distribution of data) be met, although moderate departures from these assumptions are not serious. However, there are many cases where such departures from the assumptions of normality are not only predictable, but may be corrected for by transforming the raw data. This is the case when dealing with percentages or with frequencies, for example, in counts of biological entities. Therefore, data transformations should be considered wherever appropriate.

If the transformation of data does not correct for severe violations of the statistical assumptions for analysis of variance, then techniques of non-parametric statistical analysis should be considered to answer questions regarding spatial or temporal differences in the lake.

Following analysis of variance, multiple comparisons are often desirable when more than two means are compared. Procedures commonly employed are:

(1) Student - Neuman - Keuls' test,

(2) Tukey's test,

(3) Scheffe's test.

Similarity indices might be used to indicate uniformity of biological assemblages between season or area (Grieg - Smith, 1964; Horn, 1966; Whitaker, 1967). Cluster analysis may also be utilized to indicate similarities among biological assemblages (Cairns and Kaesler, 1969, 1971; Cairns, Kaesler and Patrick, 1970; Kaesler and Cairns, 1972; Kaesler, Cairns and Bates, 1971; Roback, Cairns and Kaesler, 1969; and Sneath and Sokal, 1973).

Interrelationships among biological and physical parameters may be examined by simple or multiple regression and coefficients of correlation.

In the visual presentation of data by tables and figures, planning and clarity of expression are paramount. It can also help to have the aid of someone trained in graphics or with a practiced eye for visualization. Tables should be fully self-explanatory and the units for each numeric variable should appear on each table or group of tables. When measures of central tendency are depicted in tabular form they should be accompanied by an indication of sample size and a measure of variability (e.g., standard error). Where numerical entries are zero, they should be explicitly written rather than indicated by a dash or a dotted line, and a numeric entry should never begin with a decimal point.

Figures should also be self-explanatory and should tend to clarify data trends rather than to confuse or complicate them. Overcrowded graphs and figures cause the reviewer to lose interest and perhaps miss a major point of emphasis. Both vertical and horizontal scales should be clearly labeled (including units of measurement) on all figures or groups of figures and samples sizes should be identified.

Scientific Acceptability

It is apparent that, faced with serious gaps in basic information, it is neither possible nor desirable for the Lake Michigan Cooling Water Studies Panel to compose "cookbook" or *pro forma* exercises which would result in approval to discharge heat into Lake Michigan. A more fruitful approach is to cast recommendations in the form of criteria of performance. Such criteria are common to all scientific investigations and rest on the following points:

- *Adequacy* - Is the investigation of sufficient scope and intensity to answer the questions posed?
- *Reliability* - Does sampling and measurement quantify answers with a degree of certainty which would support meaningful conclusions?
- *Accountability* - Will basic measurements and determinations stand inspection by independent experts?
- *Validity* - Do the measurements actually relate to the quantity sought and are they independent of other variables?

Following is a further elaboration of these points:

Adequacy

Clearly, the adequacy of studies is crucial in determining effects of thermal pollution on biotic communities in Lake Michigan. In simplest terms, several desirable or undesirable consequences may be envisioned:

1. extirpation of native populations through intolerable habitat modifications,
2. introduction of exotic populations through modification of existing habitats,
3. change in the community structure or abundance of existing biotic assemblages,
4. changes in process rates of individual populations or of integrated biotic communities.

The overall objectives of studies to evaluate the effects of cooling water use include demonstration of the ecological changes induced by a small temperature increase in a limited area of the receiving waters. If changes are found through comparative studies, ultimately causes must be ascribed to those changes through comprehensive laboratory experiment on individuals and populations. Such experiments, in and of themselves, are not sufficient demonstration of acceptability unless they relate findings back to the field. In order to support the criterion of adequacy, investigators should demonstrate that they have performed studies both before and after the construction and operation of a licensed facility which:

1. have determined biological populations occurring in the body of water under consideration,
2. have determined abundance of populations,
3. present meaningful indices of the structures of biological communities,
4. have obtained valid estimates of basic process rates associated with biological communities present,

5. have extended over a time interval sufficient to detect and quantify both existing trends and cyclic natural variations within the system,
6. have been coordinated with physical and chemical studies such that a comprehensive description of the environmental milieu has been presented.

In the last analysis, the most convincing demonstration of the adequacy of studies is repetition and confirmation by independent experts. It is therefore strongly recommended that corroborative studies be sponsored by agencies responsible for the protection of the public interest.

Reliability

1. Accuracy: The accuracy of tests, measurements, or procedures should be supported by known standard samples and evaluation by independent methods. Estimates of the magnitudes of inaccuracies should be clearly defined and included in data reports.
2. Precision: Tests, measurements and procedures should be replicated to provide clear estimates of uncertainties in precision, and those estimates should be included in all reports.
3. Acceptable levels of uncertainty: The investigator should routinely provide estimates of uncertainties which may exist in all aspects of his work.
4. Independent review and verification of evidence by recognized experts should be encouraged.

Accountability

1. Where techniques permit, voucher specimens should be permanently preserved in a recognized repository for possible taxonomic or qualitative verification.
2. Copies of original data on destructive analysis (chemical and biochemical measurements) and measurements of transient phenomona (physical and meteorological) should become part of the public record. "Original data" is construed to mean the first digital output in standard measures.
3. For analyses using both qualitative identification and enumeration (analysis of biological assemblages), original data (as defined above) should become part of the public record and should be permanently preserved in a recognized repository.
4. For all determinations requiring interpretation or expert opinion, all authors of interpretations and opinions should be clearly identified and qualified.
5. Independent review and verification of supporting evidence by recognized experts should be encouraged.

Introduction to Priority Needs

The term priority research is inappropriate to the purpose of this section of the Report which would seem to be more to recommend corrective measures to improve the usefulness of current and future data, than to propose further development of a methodology or of data. Priority numbers assigned therefore reflect the relative values of those steps which, in the best judgment of the Panel, would tend to push forward the goal of data improvement with greatest possible speed. Priority values have been ranked according to the following scheme:

1 - highest priority consistent with achieving primary goals of the Panel,

2 - high priority studies supporting priority 1 items,

3 - intermediate priority but ultimately providing support to both 1 and 2.

Since tried and acceptable techniques exist for these analyses, categorization based on current status of the data is unnecessary.

PRIORITY NEEDS

1. To standardize units of measurement for each parameter for which environmental data are collected, by agreement between Lake Michigan investigators and institutions.
   Priority 1

2. a. To develop uniform specifications for environmental data which render them appropriate for computer storage.

   b. To investigate the feasibility of, and to adopt where feasible, standardized data forms which would facilitate transfer and computer storage.

   c. To adopt standardized coding for environmental data which would permit computer storage.

d. To arrange for a central data bank to contain, analyze and distribute raw and analyzed data on thermal problems and their associated effects.
Priority 1

3. To negotiate for, and to designate specific public libraries as repositories for all reports to assure the availability of information on Lake Michigan thermal problems.
Priority 1

4. To determine the levels of statistical significance necessary for routine analysis of the various types of environmental data (acceptable levels depend on the depth of knowledge of the sub-discipline or organism-group, the frequency and number of species and the base of experience in testing the effects of environmental perturbation on the population and community structure).
Priority 2

5. To recommend revision, production and uniform acceptance by Lake Michigan investigators and institutions of biological keys which are inadequate or which do not now exist.
Priority 3

6. To determine from available data the within-sample variation which might be expected from biological, chemical and physical parameters of interest in determining the effects of the introduction of waste heat into Lake Michigan.
Priority 2

7. To estimate, based on data on within-sample variability, the numbers of replicate data necessary to detect various magnitudes of difference between groups of data.
Priority 2

8. To specify descriptive statistics and accompanying confidence limits to be reported for each type of environmental data collected.
Priority 1

9. To specify measures of biotic diversity (if any) which are appropriate for each biological parameter.
Priority 1

10. To specify the analytic procedure or procedures to be used to assess each type of spatial or temporal environmental difference. If alternative analyses are available, the criteria through which a choice may best be made should be clearly stated.
Priority 1

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SECTION III

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON PHYSICAL PARAMETERS

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Section III. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON PHYSICAL PARAMETERS

Definition of Physical Parameters

The physical parameters considered significant to this program are variables which may be changed from their natural values by the use of lake water for once-through cooling, and related meteorological variables which affect mass movement of the lake water and heat exchange between the lake and the atmosphere.

The direct effect of a condenser cooling water discharge is to change the values of some physical variables such as temperature, gas solubility, etc., in a relatively small area of the lake. The biological effects of the discharge itself (as differentiated from intake or condenser passage effects which are considered in a separate section of this report) are indirect effects resulting from the physical changes. In order to determine both the immediate and persistent biological effects of the discharge it is necessary first to determine the area in which measurable physical perturbations occur. These man-made physical changes should be related to the averages and extremes of the natural physical variables in the lake. Designation of the physical measurements to be made depends upon the study objectives.

Objectives of Measurement of Physical Parameters

1. To describe the distribution through time and space, particularly in the littoral area, of those physical variables influencing water quality and the biota of the lake;
2. to provide adequate physical data to improve prediction of variations in physical aspects of the water mass caused by discharge plumes;
3. to verify thermal plume models which aid in describing the variability of plume behavior in the lake;
4. to collect data for monitoring the physical effects of condenser water discharges.

Questions Answerable Through Physical Measurement

Natural Physical Conditions

1. To what extent is the water of the sublittoral and littoral area and water inshore of a thermal bar restricted in interchange with the remainder of the lake?
2. What is the rate of dispersion of pollutants away from the shoreline and what physical parameters influence this rate?
3. What is the relative importance of the wind and of density differences induced by solar heating in driving the circulation of the lake?
4. Can the heat added by condenser water discharges significantly increase the volume of water in the epilimnion in the summer and/or significantly affect the vertical distribution of temperature and dissolved material?

5. How frequent, extensive, and persistent are upwellings and what role do they play in bringing nutrient laden waters into the euphotic zone?
6. What is the normal, and what are the extremes of, light penetration in the lake?
7. What is the normal, and what are the extremes of, winter temperature distribution in the lake?
8. To what depths are sediments disturbed by wind induced mixing of the lake in different seasons of the year?
9. What, if any, is the influence of ice on shore erosion?

Predictive Information

1. From what strata of the lake is the intake water withdrawn?
2. For what periods of time and to what extremes and average temperatures are aquatic organisms exposed when they meet elevated temperatures in discharge plumes?
3. What is the extent and temperature range of a sinking plume?
4. What is the velocity field around the intake?
5. To what extent can a discharge plume be confined to the shoreline by lake motion?
6. What are the appropriate methods for predicting the size and location of a discharge plume under natural conditions of lake variability?
7. Where and how should discharge and intake structures be located and designed to minimize important biological effects?
8. What influence does bottom configuration have upon the dispersion of thermal discharges?

Monitoring Discharge Plumes

1. Can discharges significantly influence turbidity and light penetration?
2. To what extent do discharges erode and transport bottom sediments?
3. To what extent might a discharge plume prevent or destroy the formation of ice and result in additional shore erosion?

Distribution of Chemicals Added to the Discharge

1. How do physical forces act upon additives to the discharge and what is the distribution of additives in the discharge itself?

Physical Sampling Sites

The following sections identify those locations where physical parameters should be measured to answer questions related to physical and biological effects of use of the lake for cooling water. Details of how the measurements and frequency relate to the study objectives are discussed in a later section. Meteorological variables apply to all locations; however, they can usually be grouped as relating either to inshore or offshore conditions.

Intake

Temperature and water currents are important physical parameters in the area of the intake. Preoperational studies can determine ambient water temperatures and, if recirculation from the discharge does not occur, help in prediction of intake temperatures during operation. During plant operation, intake temperatures can be monitored routinely in the plant. Preoperational current studies at the intake can be used to identify the permanent effects of currents caused by plant operation. Measurements for verification may be made during plant operation.

Discharge

Temperature and currents should also be studied at the discharge. Discharge water temperature can be monitored in the plant. Current and turbidity measurements can be made from the point of discharge into the lake to points beyond the expected zone of influence. Pre-operational studies of ambient conditions near the discharge will determine physical characteristics of the receiving waters before plant operation. During operation these data may be used for comparison with reference areas outside the zone of plant influence.

During plant operation, physical variables are measured to define (1) temperature distribution of the thermal plume, (2) currents in the plume as compared to ambient conditions, (3) mean and maximum residence times of entrained organisms, (4) relative mixing and dispersion of the discharge water into ambient lake waters, and (5) changes in turbidity resulting from the other identified changes.

Littoral Area

All cooling water withdrawal and discharge occurs in what would be classified as the littoral areas. Extensive measurements of physical parameters at numerous littoral sites are required for an adequate categorization of uses currently made in the nearshore water of Lake Michigan.

These comparative measurements are useful in evaluating alternative locations for new cooling water uses as for evaluating the differences in physical effects of existing uses. The Physical Subcommittee offers a tentative selection of five areas based on:

1. Similarities in the nature of shoreline, bottom material and depth contours.
2. Similar biological characteristics.
3. Distribution of power stations and other sites at which data are regularly collected.

AREAS INCLUDED:

a. Kewaunee-Point Beach
b. Waukegan-Zion
c. Michigan City-South Haven
d. Ludington
e. Northern Rocky Shoreline

Profundal Area

Measurement of physical variables in the profundal area is much more difficult than in the intake, discharge or littoral areas. Consequently, sampling programs for measurements at offshore locations require justification. The only questions linking the characteristics of offshore waters with cooling water in a physical sense relate to the rate of interchange between the offshore and inshore waters. Special programs (involving temperature, current or dispersion measurements) should address this question. A sampling program designed for long-term or routine monitoring of physical variables of profundal areas does not seem germane.

Iterative Sampling Changes

The physical sampling program will necessarily change as biological problems are identified. For instance, if it is determined that the far field region, where temperatures are less than 2C (3F) above ambient, is biologically unimportant, physical measurements of the energy exchange coefficient at the surface of the lake becomes relatively unimportant. If this far field region is unimportant, ambient lake turbulence is also relatively unimportant for predicting plume behavior.

Physical Parameters of Interest

The physical variables of interest for study of cooling water effects on Lake Michigan include water temperatures, lake currents ambient turbulence defining dispersion (eddy diffusivities, entrainment coefficients), turbidity, light penetration, surface heat exchange coefficients, and meteorological variables such as wind speed and direction, air temperature, relative humidity, and incident and reflected radiation.

Water Temperature

Temperature is the most significant physical variable to these studies because it determines the buoyancy field and relates directly to the physiological responses of the biological organisms. Fortunately, it is also one of the easiest variables to measure. Using water temperature, or its increase, as a conservative label it is possible to trace cooling water passing through the plant. Unfortunately, temperature is not a unique tag or tracer and at times temperature increases due to added heat can become confused with natural temperature variation. Using temperature as a tag often leads to problems in defining the plume due to local differences in ambient water temperatures.

The temporal and spatial characteristics of ambient water temperatures in Lake Michigan are not well known. Data are needed on the temporal and spatial variations of ambient water temperature at specific sites, to compare operational biological data with natural conditions. Specifically, data are needed to define and describe (1) spatial and temporal variations in surface temperature, and (2) temperature variations with time and depth, providing information on upwellings, natural stratification, thermal bar phenomena, sinking plumes, and possible recirculation of plume water into intakes. Preferred units of expression are degrees Celsius (degrees Fahrenheit). Water temperature measurements for most studies should be made to the nearest 0.1C (0.2F). When the change in heat content is to be calculated over a short time period, a precision of 0.01C (0.02F) may be required.

Lake Currents

A number of parameters are associated with the dispersive mechanisms that act upon the cooling water plume. Some of these are actual physical variables (currents) and some are mathematically defined parameters (eddy diffusivities) depending upon the particular mathematical formulation used to describe the situation.

Lake current is the primary mechanism transporting heat into the lake from the point of discharge. Currents affect the trajectory of the plume, and the intensity of turbulence. Very little is known about the speed, direction and persistence of near-shore currents (within 10 km). Data of this type are not only essential for thermal plume predictions, but also in understanding erosion problems in the lake. To describe and interpret near-shore currents, information is also needed on wave heights and periods, offshore currents, wind speed and direction, atmospheric stability, in addition to data on near-shore currents themselves.

There are two types of currents directly associated with the thermal plume instrumental in dispersing heated water: those induced by the initial momentum of the discharge and those induced by density differences (buoyant spreading).

One of these effects usually dominates, depending upon the location of that point where momentum dissipates and buoyant forces become dominant. Currents induced by momentum effects are relatively well understood for simple configurations, but more data are needed for an understanding of boundary effects such as those caused by the bottom and the interactions with ambient lake currents; specifically, how are forces exerted on the plume by the ambient current and the bottom? Currents produced by buoyant forces are less well understood and no mathematical models available for predicting plume behavior in large lakes specifically include this phenomenon, even though it is important in producing the sharp interface observed on the upcurrent side of the plume. Data are especially needed on the temperatures and currents at this interface.

The flow of the water is a function of current speed and direction. Preferred units of expression are cm/sec (ft/sec) for current speed, and degrees of the compass for direction. The precision needed for current speed is embodied in a current meter with a threshold of 3 cm/sec (0.1 ft/sec) and an accuracy of 10 percent; and $\pm$ 5 degrees in direction.

If current measurements are to be made in areas where the orbital wave velocities affect the currents, a current meter must be chosen that is insensitive to orbital motion. (Current meters with Savonious rotors as sensing elements are not recommended.)

Properly designed drogues and suitable position location techniques are an acceptable and inexpensive method of obtaining current data. The cross sectional area of a drogue exposed to underwater drag should be at least 100 times the area above water that is exposed to wind forces.

Turbulent Diffusion

Turbulent diffusion is an hydrodynamic process related to flow and turbulence which describes the distribution of suspended material, solutes, and heated waste as by measuring velocities, temperatures, and/or tracer concentrations and fitting mathematical models to the data. Values are therefore dependent upon the model. It is not feasible to specify precision for measurement of diffusion because there is no clearly defined reference value. Turbulent eddies, the mechanism by which energy is provided to produce mixing, occur over a wide spectrum of eddy sizes. Thus, measurements of turbulent dispersion (eddy diffusivities) must include eddies that are at least as large as the largest dimension of the plume. Values of turbulent diffusion coefficients are usually several orders of magnitude greater in the horizontal than in the vertical direction, particularly under stratified conditions. Dye dispersion is a technique used to measure diffusion, however, erroneous results may be produced where buoyant forces are significant.

Wave Height and Wave Length

Height, frequency and directional characteristics of surface waves determine their effects on water motion at various depths and their effect on turbidity and sediment movement. A number of waves are always present at any location or time so that representative wave height, wave length, and period would normally be obtained from a time-varying record. Suitable measurements might be obtained visually or may require a lengthy and accurate time series record for power spectrum analysis. Additional approaches may use wave prediction techniques through meteorological data and airborne sensors.

Wave height measurements should be expressed in meters (feet). Calculated values for wave length and direction should be expressed in meters (feet) and degrees of the compass (true), respectively. Desired precision of wave height measurement depends on the purpose, though an accuracy of 10 cm or 2 percent of full scale is readily attainable.

Turbidity

Turbidity may be determined roughly from Secchi disc depths or more precisely from photometric attenuation. Turbidity is a biologically important parameter that can have a profound effect on primary productivity. Turbidity can also be a measure of turbulent mixing for it is this turbulent energy that lifts the sediments from the bottom and holds them in suspension. Turbidity can also be used as a tracer to identify various water masses. Measurements would be limited to the relatively shallow water areas.

Light Intensity in the Water

The objective of the measurement of light intensity is usually the measurement of the depth of the euphotic zone, the principal zone of energy conversion by green plants. In this context precise depth measurements are more important than precise light intensity measurements. The instrument preferred for light intensity measurements in the water is a submarine photometer. Photometer readings at various depths in the lake can be converted to extinction coefficients and related to turbidity readings made on water samples in the laboratory. Photometric techniques lend themselves to spectral analysis, should this be required. Secchi disc readings are difficult to relate to measurements made with other instruments or to models of primary production and are therefore of limited value.

Related Meteorological Variables

Thermal energy introduced into the lake is eventually given up to the atmosphere and to outer space. Various mass and energy exchange phenomena that take place at the air-water interface are important in the rates of exchange. Analyses of existing plumes indicate that most of this energy is lost from the plume regions that are less than 2C (3F) above ambient. If the peripheral region of the plume, where the temperature differential is less than 2C (3F) above ambient, is important from a biological point of view, then measurements of the factors influencing surfacing heat exchange must be made. These factors include gradients in the air temperature, velocity and humidity above the water surface, water temperature, solar and atmospheric radiation and reflected and emitted radiation from the surface of the water.

Meteorological measurements are needed as mentioned above, to evaluate surface energy exchange rates, and these measurements are desirable to correlate near-shore surface conditions to parameters more easily measured than near-shore currents. These measurements are readily made with existing equipment and techniques. The major difficulty that may occur is in obtaining suitable towers or sites for measurement over the water. Related meteorological variables are those influencing temperature, flow, turbulence, dispersion rates, exchange of heat between the lake and the atmosphere, and local water turbidity. The following variables may be measured, though not necessarily at each site.

1. Air temperature in C (F), ± 1C (2F).
2. Lake surface water temperature (for determination of atmospheric stability) should be measured with a precision of ± 1C (2F).
3. Relative humidity in percent, ± 5 percent.
4. Wind speed in km per hour (miles per hour), ± 3.0 km per hour (± 2.0 miles per hour).
5. Wind direction in degrees (true) of the compass, to ± 10 degrees.
6. Net radiation balance in langleys per day (Btu/ft^2/hr), ± 10 langleys per day (± 1 Btu/ft^2/hr.).

Other Physical Measurements

Two specific phenomena, occurring in Lake Michigan and important to thermal plume dispersion, are development of a thermal bar during spring (and sometimes in early winter) and possible occurrence of sinking plumes. Both occur when water above 4C mixes with water below 4C. Observations of both phenomena are made primarily by temperature measurement. Development of a thermal bar is a dynamic process and, in general, is easily measured by instrumentation located on a boat or be infrared overflights. Sinking plume data can be obtained through fixed sensors on the lake bottom or measurements taken from a boat; both methods have advantages and disadvantages. Unfortunately weather sometimes prevents research vessels from obtaining sinking plume data during cooler months when the sinking condition is most likely to exist.

Determination of Ambient Temperature

Water Quality Standards for temperature proposed for Lake Michigan by the U.S. EPA and adopted at least in part by all four states (Illinois, Indiana, Michigan, Wisconsin) are based upon an allowable mixing zone of approximately 72 acres in area for those waters with temperature greater than 3F above the "natural" temperature or less than a specified maximum temperature for the month. "Natural" is defined as the temperature that would exist in the absence of artificial heat inputs. At present there is not clear definition of how "natural" temperature is to be determined.

"Ambient" temperature, the temperature that would exist in the absence of heat input, must first be determined. Attempts to define ambient temperature have created considerable difficulty in the reduction and interpretation of field data acquired over the last four years. For instance, natural surface temperature measurements have shown changes greater than 1C (2F) over a distance of 180 meters (600 feet) in a direction parallel to the beach. Moving in a direction perpendicular to the shoreline, data have shown differences as much as 3C (5-1/2F) in distances of 600 meters (2000 ft.). This was a case of shoreline heating where temperature decreased moving away from shore; a completely natural process. With upwelling conditions, which occur rather frequently, differences of as much as 4C (7F) in 910 meters (3000 ft.) have been observed. Under these conditions ambient temperatures also vary with time. Data have shown that the ambient surface temperature increases as much as 3C (5-1/2F) over a 2 hour period during a calm day with a large solar energy input. This layer of warm water was less than 1 ft. deep.

This questions the point in time and space at which a temperature to be called "ambient" can be identified. Both cooling water users and regulatory agencies need a clear definition of the method of identifying the ambient temperature. Should a method be considered that uses measurements at greater depths than the upper few microns, infrared scanning cannot be used as a monitoring tool.

Physical Data and Ecological Effects

Collection of physical information is intended to assess the ecological effects of the use of Lake Michigan for cooling. Contributions fall into two main, interrelated categories, which provide: (1) a description of the influence of natural variables operating on physical characteristics of the lake, over both long and short time scales (e.g,, both seasonal and episodic during storms or upwelling, and on the life history, growth, and mortality of lake organisms which live or migrate within the influence of cooling water); and, (2) a description of the intensity, extent, and direction of the mechanical and thermal perturbations imposed on living organisms by the cooling water in its passage through the intake, pumps, and condensers and continuing during its dispersion from the outfall.

It follows that an adequate description of category (2), this panel's ultimate objective, is not possible without substantial knowledge of the natural variation under category (1). It also follows that the program of physical measurement must be designed using the best information biologists can provide on the life histories, distribution, movement, and thermal and mechanical tolerances of those groups of organisms which either represent a direct resource (e.g., fish and fish food), or which contribute in a more subtle way to a healthy ecological situation in the lake.

The scale of time, distance and the frequencies over which tolerances and physical variables are measured must match the scales and frequencies of exposure of the organisms to the perturbation in question. However, these scales and frequencies may differ among organisms; for example, planktonic organisms making a single passage through the plant and plume differ from organisms entrained only in the outer plume, or from sessile groups only occasionally or remotely influenced by a plume. However, it seems that the assessment of ecological effect on these relatively local scales is a prerequisite for any reliable assessment of lakewide effects.

Introduction to Priority Research

The following research is identified in the body of the discussion on physical parameters which are considered necessary to adequately assess environmental changes resulting from the introduction of waste heat into Lake Michigan. These questions have been selected as possible keys to a more rapid accomplishment of research, resulting in a better understanding of lake conditions. Assigned priorities represent the judgement of the Panel as to the relative importance of these key topics balanced against the availability of data. The need for physical measurement by other subcommittees committed to assessment of the aquatic environment through chemistry or through the biota have been used to adjust these priorities. Priority values may be ranked according to the following scheme:

1 - highest priority consistent with achieving primary goals of the Panel,

2 - high priority studies supporting priority 1 items,

3 - intermediate priority, but ultimately providing support to priority 1,

4 - low priority, supporting other programs but not of critical importance in itself,

5 - deferred priority of a general supporting nature.

These research topics have also been placed in categories which reflect the current status of the data, and the assigned values may be interpreted in the following way:

1 - as soon as possible using available data,

2 - using data currently being collected,

3 - by means of individual research projects not now underway.

Priority Research

A. Toward Assessment of Natural Physical Conditions

1. To determine the extent to which the littoral and sublittoral area, or water inshore of a thermal bar is restricted in interchange with the remainder of the Lake.
   Priority 2, Category 3
2. To determine the rate of dispersion of pollutants away from the shoreline, and physical parameters which influence this rate.
   Priority 2, Category 3
3. To determine the relative importance of the wind and of density differences induced by solar heating in driving the circulation of the Lake.
   Priority 2, Category 3
4. To determine the effects of water exchange on epilimnetic volume and/or vertical distributions.
   Priority 5, Category 1
5. To determine the frequency, extent and persistence of upwellings and the role they play in bringing nutrient laden waters into the euphotic zone.

Priority 2, Category 2

6. To determine the normal and the extremes of light penetration into the waters of the Lake.
   Priority 3, Category 3
7. To determine the normal, and the extremes of, winter temperature distribution in the Lake.
   Priority 5, Category 1
8. To determine to what depths sediments are disturbed by wind-induced mixing of the Lake in different seasons of the year.
9. To determine what, if any, is the influence of ice on shore erosion.
   Priority 4, Category 2

B. <u>Toward Development of Predictive Information</u>

1. To determine from what strata of the Lake intake water is withdrawn.
   Priority 5, Category 2
2. To determine the periods of time and extremes and average temperatures to which aquatic organisms are exposed when they meet elevated temperatures in discharge plumes.
   Priority 1, Category 2
3. To determine the extent and temperature range of a sinking plume.
   Priority 1, Category 2
4. To determine the velocity field around an intake.
   Priority 1, Category 3

5. To determine the extent to which a discharge plume can be confined to the shoreline by lake motion.
   Priority 3, Category 1
6. To determine appropriate methods for predicting the size and location of a discharge plume under natural conditions of lake variability, and the influence of bottom configuration on thermal dispersion.
   Priority 2, Category 2
7. To determine where and how discharge and intake structures should be located and designed to minimize important biological effects.
   Priority 1, Category 3

C. <u>Toward Monitoring Discharge Plumes</u>

1. To determine the extent to which discharges erode and transport bottom sediments.
   Priority 3, Category 2
2. To determine the extent to which a discharge plume might prevent or destroy the formation of ice and result in additional shore erosion.
   Priority 4, Category 1

D. <u>Toward a Determination of the Distribution of Chemicals</u>

1. To determine the action of physical forces upon additives to the discharge and distribution of additives in the discharge itself.
   Priority 2, Category 3

SECTION IV

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON CHEMICAL PARAMETERS

Section IV. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON CHEMICAL PARAMETERS

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Section IV. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON CHEMICAL PARAMETERS

Introduction

The chemical parameters considered in this section are those used in definition of water quality. In many instances, chemical analyses are considered a part of or a supplement to biological studies; these analyses might be more approporiately considered an integral part of the biological studies. This section is concerned with those studies needed to determine the changes in water quality which might result from cooling water use.

There are several committees addressing problems in the water quality of Lake Michigan. These include the Laboratory Directors of the Calumet Area-Lake Michigan Conference, the Monitoring Committee and Toxic Substances Committee of the Lake Michigan Enforcement Conference, the Environmental Quality Committee of of the Great Lakes Commission, and the Upper Lakes Reference Group and the Great Lakes Water Quality Board of the International Joint Commission. The Lake Michigan Cooling Water Panel is concerned with the effects of cooling water use on water quality and on its effects on the biota. It is anticipated that lines of communication will be established with these other committees, so that information on chemical parameters can be easily exchanged.

Definitions of Chemical Parameters

Cooling water use may produce changes in water quality by changing the solubility of dissolved gases, by changing the rate of biological processes which produce water quality changes, and by the addition of materials used in plant operation. In coal fired power plants, drainage or leachate from fly ash holding ponds may reach the cooling water discharge. In a plant where cooling towers are used, the evaporation of water causes increases in the concentrations of substances already in the cooling water. Chemicals used for slime and corrosion control and air pollutants scrubbed from the atmosphere may also be discharged.

General Water Quality

The parameters used to describe water quality in general are listed in Table IV - 1.

Additions from Plant Operation

Representative substances which might be used in plant operation are listed in Table IV - 2.

Air Pollutants

Representative substances which might be scrubbed from the atmosphere and appear in cooling tower blowdown are listed in Table IV-3.

Precision and Units of Expression

The preferred units of expression for chemical parameters are metric, usually milligrams per liter (mg/l) for chemical substances dissolved or suspended in the water. Occasionally micrograms per liter is the appropriate unit of expression. The units of expression used in reporting for the results of chemical analyses should conform to those of the USEPA STORET System.

Table IV-1. Water quality parameters to be considered in site selection studies and monitoring studies

Wastewater Components	Water Supply Parameters	
Bacteria, Fecal Coliform*	Alkalinity*	
Biochemical Oxygen Demand*	Color	
Chemical Oxygen Demand	Chloride	
Cyanide	Fluoride	
Hexane Soluble Materials	Hardness	
	Iron	
Nitrogen, Organic*	Manganese	
Phenols	Oxygen, Dissolved*	
Total Organic Carbon	pH*	
	Solids, Total Dissolved*	
	Solids, Total Suspended	
Plant Nutrients		
	Sulfate	
Nitrogen, Ammonia*	Turbidity	
Nitrogen, Nitrate*		
Nitrogen, Nitrite*		
Phosphorus, Soluble*	Potentially Toxic Materials (examples)	
Phosphorus, Total*	Arsenic	Nickel
Silica*	Boron	Selenium
	Chromium	Silver
	Lead	Zinc
	Mercury	Pesticides
	PCBs	Phthalates

* Parameters which should be a part of all water quality evaluation; other parameters are suggested for consideration when there is reason to believe that they may be present in unusual concentrations.

Table IV- 2. Chemicals used in plant operation.

Name	Use	Form to be Monitored
Alum	Water Treatment	Al ion
Chlorine	Water Treatment	Free and combined chlorine
Lime	Water Treatment	Ca ion, hardness, alkalinity, pH
Phosphates	Water Treatment	Total and orthophosphate
Sodium Carbonate	Water Treatment	Na ion, alkalinity, pH
Sodium Hydroxide	Water Treatment	Na ion, pH
Sodium Sulfite	Water Treatment	Na ion, oxygen
Sulfuric Acid	Water Treatment	SO_4 ion, pH
Boric Acid	Reactor	Boron
Hydrazine	Reactor	Ammonia - N
Morpholine	Reactor	Ammonia - N
Phosphates	Reactor	Total and orthophosphate
Chromates	Cooling Tower	Trivalent and Hexavalent Chromium
Phosphates	Cooling Tower	Total and orthophosphate
Organic Phosphates	Cooling Tower	Total and orthophosphate
Zinc	Cooling Tower	Zinc ion
Chlorine	Cooling Tower	Free and combined chlorine
Silt control, polymers	Cooling Tower	
acrylamide		Ammonia - N
polyacrylate		Organic - N
		BOD

Table IV - 2. Chemicals used in plant operation.

(continued)

Name	Use	Form to be Monitored
polyethyleneamine		etc.
Dispersants	Cooling Tower	
sodium lignosulfonate		BOD
Organic biocides	Cooling Tower	
sodium polychlorophenol		Phenols
quaternary amines		Organic - N
methylene bis-thiocyanate		Ammonia - N
etc.		etc.
Oxygen inhibitors	Cooling Tower	
sodium mercapto-benzothiozole		BOD
benzotriazole		Organic sulfides

Table IV - 3. Some atmospheric contaminants which may appear in cooling tower recirculating water.

Iron	Phosphorous
Lead	Chromium
Copper	Cadmium
Nickel	Mercury
Vanadium	Arsenic
Zinc	Ammonia
	Sulfite

The precision and accuracy required for each individual determination depends upon the objective of the measurement, the natural variation in ambient concentration, and the availability of analytical techniques and instruments with appropriate precision. The laboratory responsible for the analysis should be prepared to demonstrate that the sample collection, sample handling, and laboratory methods are adequate to provide the required precision and accuracy for the parameter. As a part of this demonstration, Standard Samples prepared in EPA laboratories, should be analyzed. Samples should occasionally be replicated to demonstrate that the methods give reproducible results. Other uncommitted laboratories should analyze aliquots of the same sample.

The regulations, 40 CFR, Part 130, TEST PROCEDURES FOR THE ANALYSIS OF POLLUTANTS, of the Federal EPA should be followed in making the chemical analyses except when greater sensitivity than provided by those techniques is required by the objectives of the analyses. In those instances where alternative analytical techniques are required, approval should be requested through the Regional Director of EPA Region V or the State Pollution Control Agency.

Objectives of The Measurement of Chemical Parameters

To monitor cooling water to determine:

a. if the cooling water use produces changes in water quality or,

b. if there are changes in water quality from other sources which might produce biological changes.

Questions Answerable Through Chemical Measurements

1. Does cooling water use result in dissolved gas super-saturation to the extent that it is a threat to organisms in the discharge plume?
2. Does cooling water use result in loss of significant amounts of dissolved oxygen from the discharge plume?
3. Does cooling water use result in increase in Biochemical Oxygen Demand in the discharge plume?
4. Does cooling water use result in an increase in total quantities of algal nutrients or an increased availability of algal nutrients?
5. What chemical substances are present in the drainage or leachate from a fly ash holding pond?
6. What chemical substances are present in the blowdown from a cooling tower which is introduced into the discharge?
7. Does cooling water use increase taste and odor problems in the lake water?
8. Are there substances present in the water whose rate of uptake, accumulation and toxicity might be changed by a temperature change?
9. Are power plants a source of toxic, persistent organic compounds?

Chemical Sampling Sites

NOTE: Whenever possible, stations should be located at sites previously occupied or logically selected to maximize continuity of data.

1. Measurements of chemical water quality should be made at intake and discharge to determine changes in water quality occurring in the plant and long-term water quality trends of the lake water.
2. Point sources (including tributary contributions) of wastewater discharge in the area of the power plant (within 5 miles) should be monitored to determine effects on the local aquatic communities.
3. Water quality should be monitored in the discharge plume to determine the concentration gradients of materials discharged and to determine possible biological effects of the discharge on water quality.
4. Special studies of chemical water quality should be conducted at shallow and deep water stations to define quality differences between these two areas.
5. Special studies of water quality should be conducted at reference stations near and at some distance from power plants to determine long terms trends of water quality in Lake Michigan.
6. Special studies should be undertaken to answer questions raised under item 3.

Method of Sampling

A wide spectrum of sampling methods is required for water quality analyses as a part of the studies of cooling water use. Continuous recording instruments and composite samplers are needed for monitoring intake and discharge while a Kemmerer or Van Dorn sampler may be appropriate for lake samples. Careful attention should be given to containers used in transporting samples and appropriate methods for preserving and handling samples so that alteration or contamination is minimized.

It is not feasible to specify methods and special considerations for sample handling and preservation required for each of the possible water quality analyses. The laboratory responsible for the results should demonstrate that the methods provide the precision and accuracy required by the objectives.

Frequency of Sampling

Sampling frequency depends on the type and the objectives of the study and availability of background data. The types of studies considered here are site evaluation studies, plant monitoring studies, and special studies.

Site Evaluation Studies

Site evaluation studies should provide data to aid in selection among alternative sites and determination of problems particular to a specific site. Water quality factors are usually less critical to site evaluation than are physical or biological factors.

Water quality surveys similar to sanitary surveys should be considered part of site evaluation studies: sources of waste water within five miles of the proposed site should be located and characterized, rivers discharging to the lake within the area should be evaluated, surface runoff within five miles of the proposed site should be surveyed, and specific sources of waste materials in the runoff (animal raising operations, fertilized agricultural fields, highways which contribute oils and salt, etc.) should be identified.

Use of water in the area of the proposed site should also be identified; withdrawals for either domestic or industrial water supply, and the extent of recreational water use in the area of particular interest.

Water quality samples should be collected from the area of proposed intake and discharge and analyzed for the parameters listed in Table 2. Preferably these samples should be collected and analyzed once each season for at least one year. Where there are severe time limitations, at least one set of samples should be collected and analyzed.

Unusual findings obtained during the site evaluation survey should be related to specific inputs of materials.

Monitoring

This program should be a continuation of the site evaluation study and should provide a basis for evaluating the results of operational monitoring. The location of sampling sites depends on plant design and the expected operational monitoring program.

Operational Monitoring

This program should include parameters measured continuously, weekly, seasonally, and semiannually. Measurements should be made in the intake and discharge to determine the direct effect of plant operation on water quality and on areas unaffected by the discharge plume to provide data on the rate of dispersion of chemicals discharged and to identify other inputs in the area.

1. Continuously

   The following should be monitored continuously in the plant intake and discharge: temperature, dissolved oxygen, specific conductivity, and turbidity. In addition, if chlorine is used for disinfection in any part of the plant operation, the discharge should be sampled for total residual chlorine at the time of introduction.

2. Weekly

   The following should be measured weekly in the intake and discharge: alkalinity, ammonia nitrogen, fecal coliform, biochemical oxygen demand, chloride, color, hardness, nitrate, nitrite, organic nitrogen, orthophosphate, pH, total dissolved solids, total suspended solids, and sulfate.

3. Seasonally

   The following chemicals should be measured in the intake, discharge, and the discharge plume once per season: aluminum, arsenic, boron, cyanide, chloride, hexane-soluble materials, magnesium, phenols, sodium, and strontium.

4. Semiannually

   The following should be measured in the intake and discharge on a semiannual basis: barium, beryllium, cadmium, chromium, copper, lead, mercury, molybdenum, selenium, silver, strontium, tin, vanadium, and zinc.

Replication of Samples

Replication of samples and analyses should be built into these programs to define the range of variability. A minimum of two replicates should be taken at each sampling. Additional replicates may be required for those parameters which show high variability in the intake water and for which detection of small changes in concentration may be of significance to the measurement of biological effects.

Changes in Operational Monitoring Program

Changes in the sampling programs could be considered when:

1. the concentration of a given chemical parameter does not change significantly over a one year period, or
2. the concentration of a parameter is in a range in which the cooling water use would have no effect, or
3. the range of variability is so great that detection of changes in the value of the parameter is excessively difficult, or
4. there is a process change in the plant which would alter the characteristics of the discharge.

Chemical Data and Ecological Effects

Chemical water quality data are of value primarily for determining mechanisms of ecological changes. For example, a sudden decrease in photosynthetic rate in the area of the discharge might be due to excessive temperature, mechanical damage during condenser passage, toxic chemicals, or a combination of all three. If such an effect is measured, then its cause should be determined. An investigation would include chemical analyses of the samples in which the effect was noticed.

The relationship of chemical data to ecological effects depends first upon measurement of the ecological effect and then the use of chemical analyses to determine the cause. Thus, it is not possible to specify *a priori* what chemical analyses are needed. Hypotheses describing the mechanisms by which changes in chemical water quality could cause the observed ecological effect must be formulated and tested using appropriate chemical procedures. However, well known changes in chemical water quality can cause large ecological effects for example: a depletion of hypolimnetic oxygen for several weeks completely changes the benthic community, or an increase in the concentration of soluble orthophosphate from levels below the limiting concentration greatly increases the likelihood of nuisance algal blooms. Monitoring water quality changes due to cooling water use should detect types of water quality changes which cause these predictable ecological changes.

Priority Research

Research priorities identified here are questions which were developed while describing studies to increase understanding of the effects of thermal introduction on water chemistry. The selection itself, and the assigned priority values were determined by a demonstrated need for answers in these areas and because other, perhaps more far-reaching research, depends upon the results of these studies. In addition, the available data, or the relative ease with which data may be obtained, has been used as a factor for selection and for categorization. Adjustments have been made in priorities and categories originally assigned by the subcommittee based on best judgment and needs of the entire Panel.

Priority values have been ranked according to the following scheme:

1 - highest priority consistent with achieving primary goals of the Panel,

2 - high priority studies supporting priority 1 items,

3 - intermediate priority but ultimately providing support to priority 1,

4 - low priority supporting other programs but not of critical importance in itself,

5 - deferred priority of a general supporting nature.

Since this subcommittee chose to arrange these studies by category, categorical criteria are self-explanatory.

Category 1. Answers to these questions should be developed as soon as possible using available data.

1. To determine dissolved oxygen at the intake and discharge of representative Lake Michigan power plants and the extent to which cooling water use results in the loss of dissolved oxygen from the discharge plume.
   Priority 1
2. To determine the extent to which cooling water use results in an increase in biochemical oxygen demand.
   Priority 1

Category 2. Answers to these questions should be developed using data currently being collected.

1. To determine if cooling water use results in an increase in total quantities of algal nutrients or in an increased availability of algal nutrients.
   Priority 1

2. To determine chemical substances present in the drainage or leachate from fly ash holding ponds at representative Lake Michigan power plants.
   Priority 3

<u>Category 3</u>. Answers to these questions should be developed by means of individual research projects not now underway.

1. To determine chemical substances in cooling tower blowdown.
   Priority 2
2. To determine if cooling water use results in dissolved gas supersaturation to the extent that it is destructive of aquatic life.
   Priority 2
3. To determine substances present in the water whose toxicity is significantly altered by a temperature change.
   Priority 4
4. To determine the toxicity of chemicals used in plant operation or in cooling tower operation.
   Priority 1
5. To determine if increased temperature results in a significant increase in the rate of uptake of materials injurious to fish.
   Priority 3
6. To determine the rate of oxygen demand by benthic organic deposits in Lake Michigan and the effect of increased temperature on that rate.
   Priority 4

SECTION V

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON PRIMARY PRODUCER AND CONSUMER COMMUNITIES

Section V. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON PRIMARY PRODUCER AND CONSUMER COMMUNITIES

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Section V. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON PRIMARY PRODUCER AND CONSUMER COMMUNITIES

Introduction

It should be recognized at the outset that a good deal more quantity and quality of information is necessary to assess the effects of thermal effluents on communities of microscopic organisms in Lake Michigan than that which is presently available. Insufficient attention has generally been given to some or all of these communities in available studies on thermal effects. In many cases, it is necessary to pose questions which have not yet been asked of the Lake Michigan system to provide a basis for management decisions. Some of the problems particular to microbiological communities are discussed briefly below.

Principal Problems

Perhaps the most fundamental problems with microbiological communities is their extreme complexity. Hundreds of species may be found in a single sample from certain primary producer communities in Lake Michigan and many more may be expected to fall within the thermal effect of any single facility.

Unfortunately, the composition of such communities is poorly known at even the fundamental level of identification. Taxonomic treatises which comprehensively treat many of the important groups are unavailable. Even basic historic works are scattered and scarce. Detailed investigations of thermal effects at the community level will frequently require development of a taxonomic base during the study. In addition, there is a paucity of investigators with training and background necessary to approach these problems in Lake Michigan. Perhaps because of this lack of fundamental knowledge, there are potentially important types of communities for which practically no information exists. This is true of all indigenous bacterial communities and of most benthic primary producer communities, particularly those occurring in deeper parts of the Lake.

Another characteristic of microbiological communities which impeded an understanding of their responses is the variation in abundance and composition in a single season, at any given sampling station (Vollenweider et al., 1974). Any microhabitat may be occupied by several associations during a season. Natural seasonal succession is responsible for a large part of this variation but it is strongly suggested that succession is increased by environmental disturbance. This means that to detect natural patterns of change, more replicate samples of microorganisms should be collected per unit time than for larger organisms, especially in disturbed areas such as the nearshore zone of Lake Michigan. It is also true that the grand growth period for many associations occurs during the late autumn and early spring when field operations are most difficult on Lake Michigan.

Many microbiological communities in Lake Michigan contain representatives of fundamentally different biochemical divisions: This causes serious problems in sampling and preservation for population studies (Utermöhl, 1958) and equally serious problems in designing and implementing quantitative experimental studies. In many instances, it is necessary to preserve and/or analyze multiple aliquots using different methods to insure that all important groups are adequately treated.

Rapid turnover and specific responses of the microbiota to heat also causes difficulty in the study of thermal addition on microbiological communities. Doubling times of the species, where known, range from hours to days and significant population changes may be effected by short exposure to a stress. (Goldman and Carpenter, 1974). In the Great Lakes, the change may be extirpation of native populations and/or introduction of exotics (Stoermer and Yang, 1969; Hohn, 1969). Unlike higher organisms, the dispersal of most primary producer species is relatively rapid (Rosowski and Parker, 1971). It appears, for example, that the phytoplankton flora of Lake Michigan is presently changing quite rapidly (Stoermer,1972). It also appears that benthic primary producer communities have changed drastically in the past 100 years, although this situation is not as well documented as changes in the phytoplankton.

The rapid response time of microbiological communities hinges on the fact that most communities are self-regulating to at least some degree either through biochemical antagonisms or by sequestering nutrients (Schelske and Stoermer, 1972; Fogg, 1965). Exposures to increased temperatures have been known to select for populations which pre-empt space, nutrients or both and which become widespread in the system through those mechanisms (Foerster et al., 1974). Certain species of blue-green algae which are both favored by relatively high temperatures (Cairns, 1972) and known to excrete antagonistic fractions, may constitute a serious potential nuisance in Lake Michigan.

Unlike higher organisms, these organisms have little or no avoidance capacity. Effects of multiple passage or relatively long thermal exposure in plumes can be expected to be more severe in the microbiological communities than with organisms with sufficient mobility to escape. It is basically understood that in the trophic dynamics of an aquatic ecosystem, measurable effects on the primary producers are manifested throughout the system. Changes in the abundance or composition of carbon reserves fixed at low trophic levels are important in the growth and maintenance of fishes and other higher forms (Benson and Lee, 1975). It is also apparent that changes in microbiological communities may have direct effects on human welfare in Lake Michigan. Since primary uses of the Lake include requirements for high quality potable water and utilization of the Lake and its shore zone for recreation, biological over-productivity or changes in the quality of the communities are of immediate and substantial public interest (Vaughn, 1961).

Objectives of the Measurement of Microbiota

Operationally, studies should proceed in several distinct phases:

1. The first should be a background study providing an assessment of spatial and temporal distribution, and baseline numbers in populations occurring in the region of the proposed facility, and existing trends in such populations. Although some of this information may be available from the literature, exploratory field studies are strongly recommended.

2. Based on the above, detailed study of the waters in the immediate region of the proposed facility can then be designed. The output from the latter study should provide a detailed chart of the populations occurring or passing through the region of probable measurable thermal effect, and the seasonal variations in such populations. Reference stations should be included for comparison with stations in the regions of immediate effect and for possible determination of lake wide effects. This study should be initiated well in advance of initial construction when possible and should extend through at least five years of the full operation of the facility.

3. If changes in population abundance, community structure, or process rates are detected, experimental studies should be designed and initiated to isolate and quantify any causes which can be ascribed to cooling water use, directly or indirectly.

Measurement of Environmental Provinces

Studies should recognize and treat with biological provinces within Lake Michigan:

A. The nearshore zone (ca. 8 miles from shore)

1. Milwaukee - Michigan City
2. Michigan City - Little Sable Point
3. Little Sable Point - Pyramid Point
4. Pyramid Point - Mackinac
5. Grand Traverse Bay
6. Northern Islands areas

7. Mackinac - Point Detour

8. Bay de Noc and Green Bay north of Chambers Island

9. Southern Green Bay

10. Deaths Door - Algoma

11. Algoma - Milwaukee

    a. The vicinity of any major stream or other effluent of any of the above regions.

    b. The open water zone

        1. South of 42° 30'N

        2. 42° 30'N - 44° 30' N

        3. Grand Traverse Bay

        4. North of 44° 30' N

        5. Bay de Noc and Green Bay north of Chambers Island

        6. Southern Green Bay

These geographic regions do not precisely delineate habitat types; however, communities in these regions are sufficiently different that caution is necessary in making a direct comparison of results appropriate for another. In addition, it is suggested that there is a consistent difference in plankton assemblages in the eastern vs. western portions of the open water zone and the effects of cooling water use must be determined as it pertains to those assemblages in a further attempt to measure lakewide effects.

Phytoplankton

Introduction

Phytoplankton are microscopic plants which are suspended in water.

In large lakes, such as Lake Michigan, most of the species which comprise the phytoplankton complete their entire cycle free floating; others exist on solid substrates. Such communities are quite complex. At least ten major divisions of the Plant Kingdom are represented in phytoplankton communities of Lake Michigan. Because of fundamental differences in morphology, life histories, and physiological requirements in representatives of these divisions, few generalizations can be made at the community level. Even generalities regarding the representatives of any one of the major divisions are apt to be misleading. Individual species belonging to some of the major divisions have been reported from almost every conceivable aquatic situation. Something on the order of 2000 individual species are now known to occur in the Lake and undoubtedly others will be reported in the future.

The majority of these organisms are either passive, or so feebly motile that they cannot overcome water movements even when velocities are low. Some respond actively to physical and chemical stimuli in the environment but their capacity for avoidance is essentially nil.

Phytoplankton organisms known to occur in Lake Michigan range in size from 1.0 micrometer in greatest dimension to something over 500 micrometers. The great majority are functionally unicellular, although colonial aggregations are common in most of the divisions represented.

Both the abundance and composition of phytoplankton communities in

Lake Michigan, particularly in the nearshore waters, is highly variable. Depending on location and season, numbers may range from 200 cells/ml to over 30,000 cells/ml (Stoermer,1972). Composition in different localities ranges from domination by species usually considered to be indicative of very high water quality, to domination by species which are abundant in highly eutrophied waters in the Great Lakes system (Stoermer and Yang 1970).

Perhaps the most outstanding characteristic of primary producer communities in general, and the phytoplankton in particular, is their rapid and total response to environmental change. Most phytoplankters have generation times ranging from several hours to several days so that perturbations of the system may cause rapid reactions. Most of these microorganisms are cosmopolitan in distribution and when conditions are significantly changed indigenous or existing species associations may be rapidly replaced by other organisms. Changes of this type have occurred in Lake Michigan and elements of the present phytoplankton community probably were not present in the Lake before the intervention of man (Stoermer and Yang, 1969).

The principal role of phytoplankton in the aquatic ecosystem is primary production. In a sense, these organisms operate at the interface between the physical and chemical milieu and organisms at higher trophic levels, since they utilize radiant energy to fix essential chemical elements into metabolically useful substances. In large lakes, such as Lake Michigan, the habitat available to phytoplankton far exceeds that available to other primary producer communities requiring solid substrates for their growth, and energy fixed by phytoplankton is the primary controlling factor in total productivity of the ecosystem. A fact often overlooked is that while the abundance and physiological condition of phytoplankton controls the amount of material available to higher levels in the food chain, the kinds of phytoplankton also determines the type of material available. If changing environmental conditions result in a change in phytoplankton composition from dominance by one division to dominance by another with greatly different biochemical characteristics, serious impact may be observed in the consumer communities. It should be observed that such changes occur with increasing introductions of domestic and industrial waste. Because characteristics of the drainage basin of Lake Michigan and its considerable thermal inertia, indigenous phytoplankton populations still existing in the Lake were adapted to conditions of low nutrients and low temperature. The primary factor controlling productivity was the availability of phosphorus. The characteristic seasonal cycle of phytoplankton abundance has consisted of a spring and autumn maximum and rather uniformly low populations during the rest of the year. (Stoermer and Kopezynski, 1967). The indigenous flora was dominated by diatoms (Bacillariophyta) and microflagellates belonging to several divisions (Chrysophyta, Pyrrophyta, Cryptophyta) with relatively small numbers representing other divisions (Cyanophyta, Chlorophyta) which are usually important in smaller lakes in the regions(Ahlstrom, 1936). Most of these organisms are perennial and appear to be cold stenothermal although experimental evidence regarding temperature requirements of species native to Lake Michigan is almost entirely lacking.

It is suspected that their requirements for low temperatures were met during the summer months by a vertical adjustment to the area of the thermocline allowed by the high transparency of the offshore waters of Lake Michigan.

At present, phytoplankton communities in the Lake are undergoing substantial change. Changes in the ecosystem, apparently human induced, have caused replacement of the indigenous flora of the inshore waters by introduced species particularly during the spring period of maximum productivity (Stoermer, 1972). Productivity levels have been substantially increased and there is growing evidence that phosphorus is no longer the limiting element (Schelske and Stoermer, 1972). Depletion of available silica is of particular concern during the summer stagnation when it is reduced to levels which will not support diatom growth. Since species belonging to other divisions which do not require silica for growth, particularly the Cyanophyta, and Chlorophyta, are favored under such conditions, it is believed that nuisance conditions caused by the proliferation of green and blue green algae may arise in Lake Michigan as they have in Lake Erie and Lake Ontario. Most nuisance species of blue-green algae (Cyanophyta) apparently require relatively high temperatures, so that addition of heat to nearshore waters may contribute to such undesirable conditions.

<u>Questions to be Answered</u>

The following general questions should be addressed both in the context of the system as it is now (pre-operational), and after the addition of heated effluents and other facts associated with operations of a facility with a thermal discharge.

1. What populations are present?

    a. What are the seasonal differences in occurrence and abundance?

    b. What are the spatial differences in the region of the facility?

    Comment:

    Clearly it will be necessary to develop information regarding specific populations to support integrative measures of biological response such as species diversity ordination analyses. Specific identifications may pose considerable difficulties for reasons alluded to earlier, however taxa encountered should be identified to the species level.

2. What is the characteristic population structure of such assemblages?

    a. Are there characteristic seasonal changes?

    b. Are there regional differences?

    Comment:

    It is suggested that comparative measures of assemblage composition and abundance, such as ordination analysis or similar techniques, be employed. Simpler indications of assemblage structure, such as the various diversity indices, are notoriously difficult to interpret for phytoplankton.

3. What are the measurable process rates associated with such assemblages and how are they affected by thermal additions and other factors connected with cooling water use?

a. Growth rates of abundant populations.

b. Productivity rates.

c. Nitrogen fixation rate. (Vanderhoef et al., 1972).

d. Uptake of key nutrient elements.

   1. Phosphorus

   2. Silica

   3. Nitrogen

Interpretation of the answers to these questions may be difficult since the historic data base for the phytoplankton is weak and certain informational links between species and numbers are lacking except on a local and recent basis. To close these gaps, it is important that answers to the following questions be developed by water users as a group, for use in individual site investigations:

1. What was the composition of the plankton populations which were present in earlier years? Phytoplankton communities in most areas of Lake Michigan are already severely perturbed and the indigenous fauna and flora, in the strict application of the term, no longer exist. Efforts should be made to reconstruct the original composition through review of literature, preserved collections, or by paleolimnologic methods. This historical perspective is necessary to establish the background of acute and chronic change which has occurred in the Lake's flora and fauna through time, caused by human influence. This background would permit comparisons with current data by providing a standard against which to measure more recent effects.

In addition, a better understanding of the changes which have transpired in plankton populations may permit prediction of future trends and guard against permanent exclusion of the indigenous fauna and flora by thermal pollution.

2. What are the ranges of spatial and seasonal variation within such a system? Since, in phytoplankton, extreme variations in total assemblage abundance and equally significant changes in community structure may occur in lateral distances of a few kilometers, the detection of subtle and long-term effects from cooling water requires extremely sensitive measurement and analysis methods. Program designs should demonstrate this capability and explicitly state limits of detection of modifications which occur.

3. What are the trends and causes of trends of phytoplankton abundance and species composition now present within the system? Since thermal effects are largely synergistic, it is important to demonstrate that additional thermal loading will not intensify problems resulting primarily from other types of perturbation (Beeton and Barker, 1974). If information is inadequate, studies should be focused on explanation of these trends.

Approaches

Field Observations

An extremely comprehensive program of field sampling is necessary to answer the questions posed. Some principal aspects, including sampling location and frequency, should be determined through knowledge of the discharge characteristics of the plant (e.g., shoreline, submerged jet, length of canal or conduit, velocities, etc.) and the regional characteristics of the lake environment (e.g., water quality, location of significant pollution introduction, location of spawning or nursery grounds, etc.). Fixed stations will be necessary for development of comparative data and it is believed that, for initial determination, the sampling area should be equal to an area encompassed by twice the radial distance from the cooling water discharge to the most extreme 1C isotherm. Since the position of this isotherm is extremely variable, and perhaps undefinable, the suggested distance is arbitrary and is certainly subject to enlargement or diminution depending upon sound evidence. In any event, sampling intensity should concentrate in the vicinity of the discharge on the assumption of greatest effect. It should be incumbent on the plant operator to demonstrate valid estimates of microbiota (abundance and species composition) to the 95 percent confidence level for the area sampled in order to detect the extreme of possible effects of cooling water use. In view of variation found in the microbiota through space and through time, the exact number of stations cannot be specified but initial arrays of 64 stations may be justified.

Accompanying physical and chemical data should parallel logical sampling. Again, in view of variability previously found in the microbiota through time (Holland and Beeton, 1972) monthly sampling frequency is a minimum effort. Weekly or biweekly samples are desirable during periods of expected seasonal pulses.

Measurements

Measurements which should be made on samples include:

1. Estimates on standing crop biomass should be made from all samples. Method of choice is assay of extracted chlorophylls (Strickland and Parsons, 1968). Results should be validated by independent methods such as assay of total organic carbon or total organic nitrogen.
2. Estimates of rate of primary productivity should be made from all surface samples and from all depths at not less than ten stations strategically located with respect to depth and distance from thermal source. Method of choice is measurement of ^{14}C uptake rate (Strickland and Parsons, 1968).
3. Estimates of nitrogen fixation should be obtained from all surface samples. Method of choice is acetylene reduction technique (Stewart et al., 1967).
4. Estimates of species composition and abundance of phytoplankton assemblages should be obtained from all samples by microscopic identification and enumeration of organisms in suitable prepared whole water samples. Because of diversity of biochemical groups present, care should be taken to employ techniques of identification suitable for particular groups to insure accuracy. These measurements should be made in a temporal sequence which permits calculation of growth rates for predominant populations.
5. Estimates of concentration of both particulate and dissolved major nutrients (Phosphorus, Nitrogen and Silica) should be made on all samples.

In addition to sampling in the vicinity of the facility, at least one array of stations, consisting of a line transect at distances of 1/8, 1/4, 1/2, 1, 2, 4, 8, and 16 statute miles from shore should be established within the same biological province as the primary grid, but as far removed as possible from human effects. These stations should serve as a reference for near-site studies and as a monitor of possible whole lake effects. These stations should be sampled in the same manner, and at the same intervals as the primary grid stations and this same suite of analyses should be performed.

After discharge, a much larger volume of water is heated by the mixing and dilution of the plume with surrounding water than the volume of water which actually passes through the plant. Although the temperature elevation is not as great as in the plant, the small increase may have a great effect on the microbial community. Whereas large temperature increases in the plant may result in mortality, inhibition of various metabolic processes or, a short-term stimulation of metabolism, lower temperature elevation in the mixing area may cause a prolonged stimulation of metabolic activity, growth and reproduction.

In addition to a program to measure metabolic rates in the field, experimental studies should be included. Measurement of the rate of carbon fixation by a series of ^{14}C experiments on samples incubated at temperatures artificially elevated above ambient conditions is appropriate. Experimental temperatures bracketing those existing or predicted for a given power plant will reproduce the seasonal response of phytoplankton to increased temperature. This information may then be evaluated for isothermal areas to predict overall response of phytoplankton to thermal elevation.

Evaluation

Experimental procedures should evaluate the following:

1. Effects of temperature elevation on carbon uptake. Rates should be measured at small temperature increments above ambient conditions up to and exceeding maximum temperature observed or expected for the power plant. For example, if the particular power plant has an expected cooling water temperature rise of 10C and the ambient lake temperature is 8C, samples collected from an area not influenced by the plant should be incubated at 8, 10, 12, 14, 16, 18, and 20C.

2. The effect of exposure to elevated temperatures through time.

Samples from reference areas should be exposed to similar temperatures for similar lengths of time. After exposure, samples should be returned to ambient temperature and the rate of carbon uptake determined to assess the effects of exposure to elevated temperatures through time.

Metabolic processes such as respiration, nitrogen fixation and uptake of other nutrients could also be observed in a similar manner to assess thermal effects.

These studies could be extremely valuable for providing design engineers with some of the numbers necessary to design more ecologically compatible systems. By knowing temperature response of the plankton, appropriate condenser temperatures can be selected. Information on temperature response of the plankton and the effects of exposure to elevated temperatures through time could aid in designing discharge structures to minimize harmful effects.

Development of predictive models of the metabolic response of phytoplankton or other microbial groups to elevated temperatures would be an extremely valuable aid in design, or assessing the effects of operating plants. Such models could not be applied to all areas of the Lake due to differences in species composition, nutrient conditions, and other factors, but might provide estimates of impact on the microbial metabolism. Modelling would also reduce repetitions of experiments at proposed power plant sites.

Another experiment which should be considered is observation of natural phytoplankton cultures following exposure to elevated temperatures. Large cultures held at elevated temperatures or elevated for short periods of time and returned to ambient should be observed through time for changes in species composition and abundance. These observations could provide clues to the effects of thermal elevation on the composition of the phytoplankton community at a particular site or in the Lake as a whole.

Each of the experimental procedures outlined above should be conducted at least six times per year during all seasons of the year for at least three years. After evaluation of the results, it may be possible to discontinue the work.

Zooplankton

Introduction

Zooplankton are animals characteristically spending a significant part of their life-cycles suspended in water. Most prominent or quantitatively significant species in the zooplankton of typical continental fresh waters are holoplanktonic, that is, no life stage is spent outside the plankton. Marine zooplankton by contrast includes a significant number of meroplanktonic forms, where suspended egg or larval stages later give rise to sedentary ones. In typical fresh water, including Lake Michigan, this link between planktonic and benthic communities is tenuous, although there are exceptions of possible importance. There is also a blurring of the distinction between planktonic and sedentary or benthic organisms in some inshore waters, since there are organisms which more characteristically attach to bottom materials or surfaces of rooted higher plants and which briefly enter the plankton when migrating vertically (there are examples among the Cladocera, Ostracoda, Mysidacea, Amphipoda, and Insecta). The same phenomenon occurs in waters adjacent to the bottom at distances from the shore. It is one factor distinguishing inshore and offshore zooplankton assemblages.

Exceptions of possible importance in Lake Michigan are the following:

1. Numerous species of insects occurring in a large lake spend only the egg and pre-adult periods there, leaving it as adults (e.g. many Diptera, Trichoptera, Plecoptera). Some are planktonic

for short but well-defined stages (Diptera: Tendipedidae, some species during very early and very late larval, and entire pupal stages; Culicidae, *Chaeoborus*, during entire larval and pupal stages).

2. Most of the species in some of the major zooplanktonic groups (Cladocera, Rotifera, Copepoda; see below) have an encysted, diapausal stage (e.g. the mictic egg in Cladocera and Rotifera) which is highly resistant to damage from mechanical injury, desiccation, or unfavorable chemical conditions, and which can leave the water to be distributed as a dust particle by the wind or other agent. This characteristic gives a species-population the means to avoid unfavorable conditions, and may also explain the nearly cosmopolitan distributions of many planktonic forms.

3. Certain macrozoobenthic species, in Lake Michigan most strikingly *Pontoporeia affinis* and *Mysis relicta*, regularly migrate vertically through a sufficient distance to carry them well beyond the benthic biotope and into the zooplankton, at least at certain seasons or certain time of day.

The bulk of the Lake Michigan zooplankton, as of most inland waters of reasonably large size, is composed primarily of individuals of four major animal groups, the Cladocera and Copepoda (Arthropoda, Crustacea), the Protozoa, and the Rotifera (Aschelminthes).

Under most conditions, members of these groups account for more than 90 percent of the total zooplankton biomass, and probably do so in Lake Michigan. Animal groups contributing less to the plankton biomass in Lake Michigan are Arthropoda: Insecta, Crustacea (Mysidacea, Amphipoda), Arachnoidea (Hydracarina): a few platyhelminths, nematodes, and annelids. Fish eggs and larvae, more properly meroplanktonic, are discussed in the fisheries section.

Among the major groups of Crustacea, there is a general tendency for the Cladocera to become relatively less prominent as lakes become colder and more oligotrophic (and, because of correlations between these factors and size, as lakes become larger); rotifers remain about equal in importance in relation to crustaceans in all cases. Thus, the zooplankton of Lake Michigan consists primarily of protozoans, cladocerans, copepods, and rotifers, with the largest fraction of the biomass normally made up of copepods (Wells, 1960).

Within all groups, there is great taxonomic diversity, a character that distinguishes the zooplankton from, for example, the macrozoobenthos. Each major zooplankton group contains a large number of species with very different responses to environmental conditions and of very different quantitative significance locally and seasonally. For these reasons, it is as difficult to characterize zooplankton of the Lake as having a general response to environmental disturbance, such as discharge of waste heat, as it is phytoplankton. It is worth noting that many of the principal zooplankton forms are complex, advanced metazoans. Because of highly adapted and responsive sensory systems, and because of their advanced degree of organization, they are highly responsive to, and easily injured by changes in their environment.

The majority of zooplankton in Lake Michigan range in size between about 50 micrometers (smaller rotifers and protozoans) and 1 cm (larger cladocerans) in length or greater diameter. Unlike phytoplankton, they are all capable of independent motion, although this is not usually vigorous enough to enable them to resist water currents in the Lake itself, or in the vicinities of intakes and discharges. Within a water mass, independent movement of zooplankton may cause considerable change in density with time. For example, vertical displacement of single plankters over distances of several meters in 24 hours is possible. Changes in local density or organisms complicates sampling, and may mean that the effects of an environmental change, such as a change in water temperature, are removed from the original site of the insult.

Although the capacity of typical zooplankters to avoid unfavorable environmental conditions has very clear limits imposed by their limited mobility, it is not as restricted as it is for phytoplankton.

Because of small size and, in many cases, high reproductive capacities, some zooplankton respond rapidly to environmental change through changes in abundance. In a favorable environment, certain parthenogenetically reproducing cladeocerans can achieve an 8 - to 10 - fold increase in population in a matter of a few days (i.e., doubling times may not be less than those for the more rapidly reproducing phytoplankton). Others, requiring longer periods for development through successive larval stages (e.g. copepods), show slower and even delayed responses. As with phytoplankton, the cosmopolitan distributions of many characteristic species (and the existence of resistant, easily dispersed stages in their life cycles) make possible the replacement of "native" species with "exotics" having competitive advantages under the altered conditions. Such changes have apparently occurred in parts of the Lake Michigan system (Beeton, 1965; Robertson, 1966). Such replacement is possibly unlikely to be as striking for copepods as for cladocerans or rotifers: although the reasons are not well understood, the former show a much higher degree of geographic specificity than the latter, which may mean that one species of copepod is less likely to be rapidly replaced by another as environmental conditions change (Hutchinson, 1967, p. 686 ff.).

With the exception of one group of planktonic copepods (Cyclopoida) and a few specialized calanoid copepods and cladocerans (Leptodora and Polyphemus), the food of major zooplankton is primarily suspended particulate organic matter ---living cells of phytoplankton, or at least organic detritus originating from phytoplankton biosynthesis. Most zooplankton feed with highly specialized mechanisms for filtering, concentrating, or sedimenting suspensoids, each of which depends on a high degree of physiological coordination. Feeding rate and efficiency are strongly affected by food density, temperature, oxygen supply, and other chemical conditions.

Zooplankton are, in turn, food for a wide variety of higher-order consumers, including fish, insects, and other invertebrates depending on size and availability to the predator.

The primary role of the zooplankton community is as the major link between the biosynthetic and energy-fixing function of the phytoplankton and the remainder of the Lake's ecosystem. Disturbance of this function results in disturbance of secondary productivity[1] in the entire Lake, most significantly to productivity of various economically valuable populations of fish.

All species of fish occurring in Lake Michigan probably depend upon zooplankton for food at least during early developmental stages. Those which feed extensively on zooplankton through the adult stage include the alewife, yellow perch, small centrarchids, such as bluegills and sunfish, most forage species of small size (members of the family Cyprinidae), sticklebacks, and darters, and members of the genus Coregonus, such as the whitefish, lake-herrings, bloaters, and ciscoes.

Probably few species of zooplankton are entirely indifferent to the quality of their food, and most of those that have been carefully studied are selective, favoring certain species or materials derived from phytoplankton and rejecting others. The nutritional welfare, composition, and productivity of the zooplankton, therefore, very strongly reflect quality as well as quantity of photoplankton food, and respond strikingly and quickly to environmental changes that affect the composition and abundance of their food (see, for example, Pacaud, 1939; Lowndes, 1935; Fryer, 1954).

Species composition of zooplankton of Lake Michigan and seasonal changes are imperfectly known, and it is difficult to

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[1] The term "secondary productivity" will be used throughout this section to refer to productivity of all heterotrophs, without making distinctions among the so-called primary, secondary, tertiary, . . . consumers. Such distinctions are useful in certain contexts, but not here.

separate natural changes in the character of the community from those resulting from human alteration of the Lake's environment. There is some indication that "native" oligothermal species, such as Diaptomus (Leptodiaptomus) minutus, are being replaced by more euthermal ones, such as Diaptomus (Skistodiaptomus) oregonensis, and that certain species characteristic of oligotrophic waters, such as Eubosmina (Bosmina) coregoni, are being replaced by those characteristic of more eutrophic waters (not necessarily because of temperature, but for reasons at present unknown), such as Bosmina longirostris (Beeton, 1965, 1966, 1969). Such changes, if permanent, may reflect quality of the food supply or changes in water chemistry. The composition of the rotifer component of the zooplankton is, with the exception of a few large or prominent forms, almost entirely unknown.

Studies of species-composition and abundance of zooplankton are complicated by annual and diel cycles of abundance. Annual cycles of abundance appear to be correlated with factors such as temperature, food supply, and predation (as the spring-fall pulses of Daphnia in many inland lakes), diel cycles (as in 24-hour changes in depth-distribution of populations of Daphnia) with changes in light intensity or quality. Whatever the cause, cycles are well known and sampling programs should take them into account (Wells, 1960; Cushing, 1951).

The importance of zooplankton for monitoring cooling water effects follows from two characteristics of the community:

1. Ecological status. It is a central trophic element and quantitatively significant factor in the Lake ecosystem. If

affected directly, secondary effects will ramify in two directions, upwards, toward the primary productivity of the phytoplankton, on which it exerts a complex regulatory effect through grazing, and downwards, toward fish and other animals and the secondary productivity of the entire ecosystem.

2. Sensitivity results from small size and high reproductive potential. (High reproductive potential may also negate sensitivity by permitting rapid replacement of individuals destroyed by condenser passage.)

On the other hand, it is not an easy community to study because of taxonomic confusion in some of the groups, because of the difficulty of maintaining most species under laboratory conditions, and because of numerous problems in estimating abundance in field.

Environmental changes affect zooplankton by altering certain physiological rates: of respiration, digestion, reproduction, and other similar processes, probably in age-specific ways. These changes are then reflected in properties of the entire community, such as total respiration, total productivity, rate of change in biomass, and species composition. Individuals are suitably studied primarily under laboratory conditions; communities primarily in the field.

Field Studies: Questions

The following general questions should guide field studies of the effects of thermal discharges on zooplankton populations:

1. What changes have occurred in the species composition of the affected community?

a. In the relative biomasses of the various species composing it?

b. In the patterns of seasonal change that characterize its species composition?

2. What changes have occurred in the productivity of the affected community? What changes in fractional units of productivity furnished by the major components? What changes in the seasonal distribution of productivity?

3. How are the above changes related to changes in the character or behavior of the phytoplankton community? How, for example, has the food supply of major elements in the zooplankton community been affected?

4. What is the character and behavior of the zooplankton community in the Lake as unaffected by man, or, what was the condition of that part of the Lake prior to thermal discharge? Two subsidiary questions are implied here:

   a. Is the discharge a factor that disturbs the stabilized state of the Lake, if indeed its state is stabilized?

   b. How does the discharge interact with other controllable impacts, such as chemical pollution, to modify or amplify the effects?

Field Studies: Implementation

1. Standard Samples

   a. Location and number of samples (see sections on phytoplankton).

   b. Collection and treatment of samples

      1) For species determination and enumeration, evaluation of

biomass by dry weight, settled volume, total carbon, total nitrogen, or any other destructive analysis, samples are best collected with a metered townet (or isokinetic pumping of water[1]) to obtain an integrated sample from the top to the bottom of the water column (except where vertical distribution is the subject of study) so that results can be expressed as quantity per unit area of lake surface. If several kinds of gear are used, they should be standardized by comparison at a given location and time.

2) Townets (or strainers for pumped samples) have a mesh size too coarse to capture smaller zooplankton, such as most of the rotifers, copepod nauplii, and smaller cladocera. Smaller forms are probably best studied quantitatively in whole water samples; zooplankton may range down to diameters of the order of 50 micrometers, as noted above.

3) For specific analyses, the catch should be subsampled. The best technique for handling standard zooplankton samples is to preserve the entire sample so as to maintain the identity of all animals. This may be a two-step

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[1]A properly used townet may come close to being isokinetic at the orifice, although it probably will never achieve that ideal; a townet often results in damage to the organisms. Volumes can be controlled better with pumped samples, but the apparatus is more complicated, subject to malfunction, and intake avoidance may still be a significant problem.

process (anesthesia plus fixation) and varies depending upon the kind of zooplankters in the sample. This is followed by a preliminary concentration of the catch and removal of a true aliquot for species determination and enumeration (by age-class if possible: see below). Removal of material from this aliquot (for counting, for diagnostic purposes---dissection, making mounts for microscopic examination, etc.) must not change its composition, because the residue is preserved as a voucher. Correct determination of field abundance and composition of zooplankton may require additional collection of specimens at the same locality, based on data from the aliquot (some organisms require examination in the living condition, and some require fixing or preservation with special precautions for competent determination).

After removal of the aliquot, the residue of the sample should be dried at low temperature or under vacuum, and pulverized for storage and destructive analyses. Data should be accumulated for eventual calculation of conversion factors (and their variances) relating total carbon, total nitrogen, total dry weight, and counts by species, to save effort in later similar studies.

Dry material retained will be useful for additional destructive analysis, for example, for radioactivity, heavy metal content, or chlorinated hydrocarbon content. Usefulness will be maximized if careful attention is given to conditions of preparation and storage.

4) Sampling errors. When developing data over areas using large integrated samples (hundreds of liters), replication at a station is probably unnecessary because:

   a) true errors of sampling for large samples will be insignificant;

   b) errors due to horizontal nonhomogeneous plankton distribution ("patchiness") will not be correctly estimated by simple replication of long tows or pumping runs. Major sampling errors in counts, determinations of dry weight, carbon content, etc., will originate primarily in aliquotting or subsampling, and here replication is required. The degree of replication is determined by variation in the samples and by rigorous testing of the subsampling procedures;

   c) other errors will originate in poor calibration of the sampling equipment as it measures sample volume. Calibration should be performed regularly to insure a high level of precision;

   d) 95 percent confidence limits for means, based on subsampling replication should be presented with all results. However, if stations are to be compared to stations in order to detect changes which may have occurred over a more limited geographic distance, or to substantiate possible vertical variation, replication at sampling stations may be required, depending upon the sizes and nature of the samples.

c. As soon as possible, the above scheme should be implemented with regular sampling along 16-mile transects in unaffected areas in each of the geographic regions of the Lake (as listed in the section on phytoplankton) on a regular monthly schedule and maintained indefinitely to provide a baseline for evaluation of future conditions.

d. Such techniques should generally apply to on-site studies and monitoring programs.

2. Productivity.

No single measure equivalent to ^{14}C-uptake (primary productivity) is currently available to provide information on productivity in a population of consumers. Techniques involving use of ATP (adenosine triphosphate) are currently under development to provide this important information.

Secondary productivity of a single-species population can be laboriously computed through data on birthrates, mortality rates, growth rates, respiratory rates, age-structures, etc. in various combinations. Most of these data are exceedingly difficult to obtain. In the absence of direct determination of secondary productivity, indices from standard samples will provide some information on some of the components of the zooplankton.

Faithfully through time, at all stations on the Lake, a picture of the normal seasonal pattern of zooplankton productivity characteristic of each of the various geographic regions will be obtained, which will serve as background or standard of comparison against which changes produced by thermal discharges can be evaluated.

These indices are ratios of numbers of individuals at two different stages of the life cycle (thus at two different ages). They are related to rates of change in population size, or to turnover rates. In conjunction with information on absolute population size, and compared within a species through space and through time, the following routine measurements may shed light on zooplankton productivity:

a. Average number of broodpouch eggs per parthenogenetic female in many cladocerans (especially species of Daphnia). In most cladocerans, there are no strikingly distinct juvenile stages, and ages can only imperfectly be inferred from size. The broodpouch egg, however, is a well-defined age category, and the number of eggs carried is related to the rate of addition of new individuals to the population.

b. Proportions of adult females (or of all females) carrying ephippial eggs (agains, in Cladocera, especially Daphnia). The significance of production of ephippial eggs in cladocerans is not well understood. Poor nutrition is thought to stimulate production, and appearance of ephippial eggs is thought to be an indication of overcrowding and incipient population decline (Hutchinson, 1967, p. 597 ff.).

c. Relative number of female (copepods) carrying egg sacs. As in a., this is a measure of the rate of addition of new individuals to the population.

d. Average number of eggs per sac(female copepods). There is little information on the significance of the number of eggs per sac, but along with the frequency of gravid females in the population, it is a measure of the potential rate of increase.

e. Ratio of copepodites to numbers of adults in a copepod population. This is related to mortality rate between the average copepodite and average adult age, and may provide insight into the rate of predation on the population.

Ratios of numbers of nauplii to copepodites to adults serve a similar purpose, except that, at present, it is not generally possible to identify copepod nauplii to species; it is necessary to work with the entire population of copepods without regard to possible specific variation. Wherever the population consists of more than one dominant species, unambiguous interpretation of changes in ratios of nauplii to later stages of the reproductive cycle will be impossible.

f. Similar indices should be developed for populations of planktonic rotifers; rotifers, depending on species, produce both parthenogenetic and sexual eggs, which are often distinguishable and countable.

Laboratory Studies: Questions

The principal objectives of a program of laboratory investigations of zooplankton are to improve understanding of the responses of the organisms to unnatural patterns of temperature elevation, both the momentary ones of relatively great magnitude, such as are experienced by organisms passing through the condensers of a plant, and those more prolonged but of lesser magnitude, as may be experienced by organisms entrained in a discharge plume. Study of entrainment effects is discussed in another section.

Aside from injury from direct exposure to heat, a variety of indirect effects might be expected on zooplankton, such as those that would follow from direct effects on the phytoplankton, affecting the source of food. Until the effects of thermal discharges on phytoplankton are more clearly understood, it is not possible to propose specific guidelines for laboratory investigations of the responses of zooplankton to changes in the quality of food.

1. Food Preference

   a. What is the principal food for zooplankton species seasonally and throughout development? What preferences or requirements are revealed by differences in the composition of the zooplankton species?

   b. What replacements among species, or shifts in dominance, are likely to follow changes in the composition of the phytoplankton (such as a shift from dominance by one species of diatom to dominance by another)?

Microbenthos

Introduction

This term is applied to communities of microscopic organisms which exist on the lake bottom or at the interface between the lake and land. Such communities are complex and composed of primary producers belonging to several major algal divisions and consumer organisms including Protozoa and representatives of several invertebrate groups. Characteristic communities tend to develop on substrate types and are often designated as: epiphytic (occurring on plants), epilithic (on rocks), epipelic (on soils), psammonic (among sand grains). The general term periphyton is often applied to coarser, more obvious forms.

Due to difficulties in quantitatively sampling these communities, they have remained rather poorly known with the exception of nuisance causing periphyton growths. Limited observations indicate that such communities occur to depths of at least 30 m in Lake Michigan. Many species are present which are apparently obligate cold stenotherms (Stoermer, *in press*). Certain elements of this "glacial relict" flora and fauna apparently find refuge in Lake Michigan below the level of the thermocline during the summer months.

Because the primary producer component of these communities is much more concentrated than the plankton, they provide a rich food source for invertebrate animals. The importance of these communities to the total ecology of the Lake has not been adequately investigated. Observations, however, indicate that areas of benthic algal growth are favored feeding regions for adult fish of many species, furnish a place of refuge for the young of some species, and are nesting grounds for others.

Primary concerns regarding thermal effects are damage to indigenous stenothermal communities by plume impingement and facilitation of growth of nuisance periphyton, *Cladophora* in particular, in the eutrophied nearshore zone (Neil, 1974; Griffiths, 1974).

Approaches

Because of the present inadequate state of knowledge, extensive preliminary reconnaissance is necessary followed by detailed observation of characteristic community types. Suggested phases of this process include:

1. An intensive visual survey should be made of the region which could conceivably come under the influence of heated plumes. This survey should include shoreline, and bottom to a depth of at least 20 m. Sampling of communities should be accomplished at this time. It is imperative that personnel sampling are thoroughly familiar with community types and appropriate sampling methods. At most sites, work will be accomplished by SCUBA divers. Output should be detailed maps of substrate types and comprehensive lists of the fauna and flora characteristic of substrate types and depths.
2. On the basis of this information, a detailed study plan should be designed and submitted to appropriate agencies for review. A study plan should demonstrate adequate sampling of community types with depth and distance from the effluent. Sampling interval should be not less than monthly. Certain habitats may be closed to sampling by ice during the late winter season.

Parameters should include:

a. Population abundance and community structure estimates similar to those developed for plankton communities.

b. Standing stock biomass estimates.

c. Productivity and growth rate estimates.

It is suggested that measurements of biomass and productivity be obtained from naturally occurring communities rather than from those developed on artificial substrates. Such estimates require innovative sampling techniques and the use of *in situ* enclosure experiments best accomplished by SCUBA divers. Artificial substrates may be used as a measure of trends, but should not be regarded as quantitative or representing natural conditions in the Lake.

Another problem is transfer of materials from the plankton to benthic habitats. This problem is also important to investigations on macro-invertebrates and fish as well as microbiological communities. Since certain of the studies are best accomplished with the work outlined above, they are discussed in the following sections.

Particulate Fallout

Planktonic organisms which pass through or are influenced by the thermal effluent from a power plant eventually die and sink to the bottom of the Lake as do plankters in undisturbed areas of the Lake. Many of these organisms are consumed or decomposed during their descent while others complete the fall to the bottom and become part of the sediments. If the effects of a power plant effluent result in death of planktonic organisms, one might expect dead organisms to rain down from the plume in greater numbers in the vicinity of the plant, than in undisturbed areas. This could result in an accumulation of organic matter on the bottom which could either enhance the bottom fauna or create an oxygen demand and subsequent depletion, limiting bottom organisms. If the production of planktonic forms is stimulated by the effluent, deposition might not occur in the immediate vicinity of the plant, but may be shifted further downstream. In either case, measurement of the fallout of particulate matter from the water column would provide useful information concerning the influence of the power plant on the planktonic community and, in turn, its influence on the benthic community.

It is suggested that a series of sediment collectors be deployed to measure the rate of particulate fall from the water column. Collectors could be placed at the ten stations proposed above for detailed study of phytoplanktonic productivity and, should also be near stations sampled for benthic organisms. Sediment collectors could be deployed and retrieved on a regular basis coincident with monthly plankton sampling. Analyses should be performed on the particulate material to determine the substance collected and organic carbon content.

Benthic Respiration

Another measurement closely allied with particulate fallout is rate of oxygen consumption in bottom sediments. Whether the oxygen is consumed by macrobenthic forms or by microbial organisms is of minor concern. What is important is a comparison of the rate of consumption to re-oxygenation. In areas that have been organically enriched, oxygen consumption generally occurs at a rate greater than in an unenriched area. Furthermore, in an area organically enriched either naturally or from power plant stimulated fallout, and, warmed by a thermal effluent, oxygen consumption may be increased as a result of both stimuli.

Measurement of benthic respiration yields information on the problems discussed above. Technique for <u>in situ</u> respiration appropriate for this study have been described in the scientific literature. The apparatus could be set out with the sediment traps and retrieved after appropriate incubation. Respiration rates combined with the particulate fallout data would yield valuable information to evaluate effects of a power plant on the benthic ecology of Lake Michigan.

<u>Priority Research</u>

This subcommittee has expressed its ideas regarding research necessary to understanding the effects of thermal introduction into Lake Michigan in the preceeding sections. From their knowledge, they do not believe that existing data will get at some of the more serious fundamental problems in this area. They therefore suggest that the following research be strongly considered and that it be categorized as follows:

<u>Category 1</u>. Basic research necessary to implement or fortify ongoing and/or essential studies.

1. To develop standard reference works in English which address the taxonomic aspects of algal communities.
2. To develop quantitative knowledge of the physiological requirements of planktonic species native to Lake Michigan.

Category II. Basic research necessary to interpretation of results of ongoing and/or essential studies.

To develop, from historical collections and from paleo-limnological studies, temporal and spatial trends of populations of plankton which existed in Lake Michigan.

Category III. Special interest questions answerable by further treatment of existing data or by minor modifications of presently planned programs.

To develop, through proposed environmental monitoring programs and through the generation of special field measurements, information on planktonic populations of the following nature:

a. mass transport of biomass,

b. food chain perturbations.

Category IV. General regional support items necessary to facilitate cooling water studies.

To develop basic facilities support (ships, buoys, computer systems, etc.,) for the collection, identification and analysis of planktonic populations, especially platform and large instrument package support.

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SECTION VI

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON MACROZOOBENTHOS

Section VI. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON MACROZOOBENTHOS

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Section VI. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON MACROZOOBENTHOS

Foreword

All comments received regarding this paper during the period of solicited review have been incorporated into the text.

Introduction

In some lakes zoobenthos is sparse and therefore its role in the lake's ecosystem appears insignificant. However, the zoobenthic standing crop of Lake Michigan is extraordinarily large (179 kg/ha) compared with other large and deep lakes in North America (Alley and Powers, 1970) or with lakes all over the world (Hayes, 1957). Zoobenthos are important in energy transfer and serve two major functions: food conversion and nutrient recycling.

Macrozoobenthic organisms are characteristically less mobile than many aquatic organisms and therefore integrate environmental stress over time. Their relative abundance and community structure are indications of the quality of their environment: water and sediments. Changes in benthic communities often are more easily measured than in communities or populations of other aquatic organisms.

Macrozoobenthos of Lake Michigan

The profundal macrozoobenthos of Lake Michigan is made up largely by members of five taxonomic groups:

1. Amphipods (Amphipoda)
2. Segmented worms (Oligochaeta)
3. Midge larvae (Chironomidae)
4. Fingernail clams (Sphaeriidae)
5. Opossum shrimp (Mysidacea)

These groups are also dominant in the sublittoral zone, but other taxa are found with them. These five groups are of greatest importance in the benthos because the largest area of the lake is the profundal zone. The oligochaete, midge and sphaeriid fauna include several species, but Pontoporeia affinis is the overwhelmingly important amphipod and Mysis relicta is the only representative of the Mysidacea found in the lake. These two species, which occur naturally in relatively few lakes in North America and are relicts of the glaciation which formed Lake Michigan, are very important to the support of fish fauna of the lake.

The littoral areas in general, and especially rocky shorelines, embayments, island areas, river mouths and unusual structures, provide habitats for many other animals such as crayfish, snails, and the immature forms of mayflies, stonefiles, and caddisflies. Since cooling water is usually withdrawn and discharged into the littoral zone, inhabitants of these areas are most likely to be affected. Littoral zone benthos is often locally important to adult spiny-rayed fish and may be especially important to the juveniles of many fish species which frequent shallow water. The contribution of the littoral zone to the lakewide benthic biomass is far overshadowed by that of the sublittoral and profundal zones.

A perspective on the abundance, depth distribution and dominance of amphipods and oligochaetes in Lake Michigan is provided by Mozley and Alley (1973), who report these animals made up over 80 percent by number of those collected in extensive surveys of the central and southern basins during 1964-67 (Table VI-1.)

Biology of Selected Lake Michigan Benthos

Pontoporeia affinis

Adult Pontoporeia range from 6 to 9 mm in size in Lake Michigan (Alley, 1968). Peak mating occurs in mid-winter and the female carries the fertilized eggs and embryos within a marsupial pouch beneath her abdomen. When released, the young are slightly less than 2 mm long. Just after the young are released, the population reaches a maximum (Mozley and Alley, 1973). Newly released amphipods can pass through screening devices which retain adults.

Size frequency histograms indicate that Pontoporeia living at a depth of 10 m in Lake Michigan mature in one year; those living between 20 - 35 m require two years to mature; and those living at depths greater than 35 m possibly require three years or more to mature (Alley, 1968). Amphipods at 10-35 m depths reproduce in the spring, while those living at greater depths reproduce intermittently throughout the year.

While Pontoporeia frequently inhabit depths less than 8 meters, large populations are not normally found there. Populations generally increase with depth to the 35 m contour where populations average 8,500/m^2 (or more) and then taper gradually to populations of 1,000 or less/m^2 at depths exceeding 180 m (Powers and Alley, 1967).

Table VI - 1. Estimates of abundance (number/m^2), by depth, of two benthic taxa from the central and southern regions of Lake Michigan. 1964 - 67.[1]

Taxon	Depth m	Central Basin Mean Number of Animals	Central Basin Number of Grap Samples	Southern Basin Mean Number of Animals	Southern Basin Number of Grap Samples
Amphipoda	0- 20	6,380	12	2,544	235
	21- 40	8,477	199	4,264	160
	41- 60	6,876	116	4,858	164
	61-140	3,353	286	3.137	250
Oligochaeta	0- 20	1,389	10	2,898	229
	21- 40	1,460	196	3,411	157
	41- 60	2,509	91	2,171	163
	61-140	520	227	720	248

[1] After: Mozley and Alley, 1973.

Pontoporeia occur over a wide range of sediment types, but largest populations are found in silty-sand sediments that permit easy burrowing and access to organic detritus. Marzolf (1963) demonstrated a correlation between numbers of amphipods and numbers of bacteria contained on detrital organic substrate. Several investigators theorize that the major nutritional source is bacteria which decompose detritus, rather than detritus itself. Vertical migrations of several meters into the water column are common for a small percentage of the *Pontoporeia* population during hours of darkness and to a lesser extent during the daylight hours (Marzolf, 1965; and Wells, 1968).

Oligochaeta

Several species of segmented worms are abundant in Lake Michigan. In general, the ratio of amphipods to oligochaetes shows a north to south gradient, with oligochaetes more abundant to the south. The dominant oligochaete of Lake Michigan is *Stylodrilus heringianus* in the profundal and transitional zones (Howmiller, 1972 a). *Limnodrilus hoffmeisteri* is most abundant in river mouths, deltas, and shallow water areas (Hiltunen, 1967: and Howmiller and Beeton, 1970). Moderate numbers of *Potamothrix moldaviensis*, *P. vejdovskyi* and *Peloscolex freyi* occur in shallow water and transitional areas and *Tubifex tubifex* are often rather common lakewide at a depth of 40 m (Hiltunen, 1967). Brinkhurst (1969) points out that distribution maps for the pollution tolerant tubificids, *Peloscolex multisetosus*, *Limnodrilus cervix*, and *L.*

maumeensis essentially correspond to the locations of the largest cities on the Great Lakes with the exception of Chicago. In Chicago, sewage is discharged to the Illinois River and is diverted away from Lake Michigan. Other oligochaetes locally important in Lake Michigan are *Limnodrilus spiralis*, *Aulodrilus pluriseta*, *Limnodrilus claparedeianus*, *Peloscolex variegatus* and *P. superiorensis* (Mozley, 1974). Forty species of microdrile Oligochaeta are known from Lake Michigan (Hiltunen, 1967). Eleven of these species were not found in Green Bay by Howmiller and Beeton (1970). They found two species not reported by Hiltunen.

Many species of oligochaetes breed over a wide seasonal range with a peak in the summer months. Fertilized eggs are deposited in cocoons in the sediments and a life cycle is complete in 12 to 18 months. This pattern can be modified by local conditions (Kennedy, 1966), hence time of recruitment will vary from place to place.

Recent Russian work (mentioned in Mozley, 1974) indicates possible generation times of two months for *Tubifex tubifex* and *Limnodrilus hoffmeisteri*, while other tubificid species require more than one year for sexual maturation. Peak numerical populations undoubtedly occur in different months and there is a lag between emergence of the embryos and growth to sizes retained on screening devices. Various investigators have reported peak counts from February to October. Oligochaete biomass in Saginaw Bay of Lake Huron fluctuated from 3.0 g/m^2 in June to 8.4 g/m^2 in August, to 0.5 g/m^2 in October of 1969 (Schneider et al., 1969). To date, the data on seasonal oligochaete population fluctuations do not lend themselves to generalization, e.g., a fall maximum has been reported in Lake Michigan littoral zones while November minima have been reported for S. heringianus.

Attempts to correlate oligochaete populations with sediments on the basis of particle size alone have usually failed. Organic content may be more important than particle size and the incompletely understood relationship between the tubificid species and the microbial flora of the organic material may be the key to distribution and abundance.

Chironomids

Heterotrissocladius and Procladius are the only midges found in important numbers in the profundal zone of Lake Michigan. They are also found in the sublittoral zone where Heterotrissocladius is represented by at least two species. In the littoral zone and areas to 20 m depth the midge fauna is dominated by Potthastia, Cryptochironomus, Monodiamesa tuberculata, Paracladopelma, Procladius, Tanytarsini, Chironomous attenuatus, C. antharacinus and other Chironomus. Polypedilum and Parachironomous can be important locally. Generally, members of the Orthocladiinae become more numerous in the northern part of the lake, but Psectrocladius cf. simulans is numerous in the southern part. Procladius and other predaceous midges often occur in company with large oligochaete populations.

According to species preference and water temperature, midges emerge as adults to mate from very early spring to as late as October for Heterotrissocladius. Midges of the deeper waters are most probably limited to one cycle or less a year, while those in the shallows may go through more than one cycle. Most commonly, eggs are laid in gelatinous masses which sink to the bottom. The first larval instar is usually planktonic and later instars occasionally leave the sediments or substrate to swim above the bottom, especially at night.

Considering Lake Michigan as a whole, midges are far less numerous than amphipods and oligochaetes and make up a small part of the biomass. However, at depths less than 10 m, chironomid larvae may be the dominant macrobenthic animals. Heterotrissocladius may be 100 to 300 times less abundant than amphipods and oligochaetes in an average sample taken from the profundal zone.

The Chironomidae exhibit the most pronounced seasonal abundance of the major taxa. The times of emergence of each species and recruitment of early instars into the size retained in sieving devices are variable and little information is available. A July maximum has been reported in littoral areas, probably because several small species reach screenable size only just before summer metamorphosis.

Fingernail Clams

Twenty species of Sphaeriidae are known from Lake Michigan (Heard, 1962). Generally, Pisidium numerically dominate the sphaeriid fauna at all depths. Sphaerium nitidum and S. striatinum forma acuminatum occur with Pisidium, but only in local areas do the numbers of Spharerium exceed the numbers of Pisidium in any sample.[1] Maximum spaeriid populations are found between 30 and 60 m. Pisidium is commonly observed carrying its young in the mantle cavity during late summer, but there is no firm information on population fluctuations with season (Heard, 1960). If the young were released concurrently, large increases in numbers should occur over short periods because the young are large enough to be retained in the most commonly used sieve sizes.

Opossum Shrimp (Mysis relicta)

Mysids are considered epibenthic. In shallow and intermediate depths they spend daylight hours on or just above the sediments and in deep water some of the animals may be considerably above the sediments. At night large numbers (probably all) move upward into the plankton.[2] Apparently their sensitive eyes and backward-darting escape reaction enable the animal to elude capture by benthic grabs most of the time. Because of their habits and mobility, methods to determine the effects of pump entrainment on the populations would be similar to methods suggested in Section VIII, Entrapped and Entrained Organisms.

Reynolds and DeGraeve (1972) reported monthly estimates of mysid density in southeastern Lake Michigan. Using a plankton net attached to a benthic sled, animals were not captured at depths of 9 m. Density was usually low at depths between 18-37 m, moderate between 46-55 m and relatively high at 64 m and deeper. Average population density at depths from 18-73 m ranged from

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[1] Hiltunen, J., 1974. Personal Comm. Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor, Michigan.

[2] Beeton, A.M., 1975. Personal Comm. University of Wisconsin, Milwaukee, Wisconsin.

0.3/m^2 in December to 64.2/m^2 in August. Maximum density was 228/m^2. These estimates are most likely too small as the water stratum from the bottom to a height of 10-15 cm was not sampled. Reynolds and DeGraeve (1972) also suggest that sizeable numbers of adults apparently move from the deep water areas to relatively shallower water (18-64 m) in winter where they breed and subsequently release their young in April and May. At greater depths there appears to be some breeding and recruitment throughout the year. General population abundance was lowest in December and highest in mid-summer.

Mysis from Lake Michigan range in length from about 3 to 27 mm. Incubation time of the young in the marsupium may be no longer than 2 or 3 months. Brood size declines with development from egg (mean, 14.1/female). At release, young are 2-3 mm in length.

Mysids are reported to feed on organic detritus and pelagic diatoms in Lake Michigan (McWilliam, 1970). This differs in part with observations from Char Lake, N. W. Territories, where feeding on inorganic particles and diatoms on a moss substrate was reported by Lasenby and Langford (1973). Apparently the microbiota or absorbed film of colloidal organic matter attached to the inorganic particles are gleaned in the gut. The authors reported that mysids feed on Daphnia, other cladocerans, and components of plankton while in the water column at night.

Role of Zoobenthos In The Ecosystem

The macrobenthic invertebrates of Lake Michigan are part of the energy transfer system and serve two major functions: recycling nutrients from the sediments and deep water areas into the phototrophic zone, and converting lower organisms into a food form available to higher organisms.

Oligochaetes (and other invertebrates), burrowing and feeding in sludges and sediments, pass the converted materials upward to the sediment-water interface where they are more susceptible to breakdown and assimilation by other processes. Without such recycling, nutrients and other chemical elements deep in the sediments would be essentially unavailable.

Mysids remain on or near the bottom part of the time and at other times migrate vertically many meters into the water column. During migration their fecal pellets redistribute minerals derived from the bottom materials. To a more limited extent this same phenomenon occurs with Pontoporeia and some midge larvae. Fish, feeding on these migrating organisms, contribute to the same cycling phenomenon.

The more obvious energy transfer role is that of converting organic detritus (or the microflora and fauna associated with it) into a form directly available to fish of recreational and commercial importance, or for smaller fish which in turn are food for the larger species of value to man.

Oligochaetes are rarely reported as important fish food, but because these animals breakdown rapidly during digestion, their importance may have been overlooked. Midges are well recognized as food for small fish and have been reported by Rolan (1972) as food for at least 19 species of fish found in Lake Michigan. His listing did not include many species of Lake Michigan fish known to consume midges. Rolan also reported six species of Lake Michigan fish as known sphaeriid feeders; his list did not include spottail shiners, alewives, deepwater and slimy sculpins, or Catastomidae, all known sphaeriid feeders. Wells and Beeton (1963) recorded fingernail clams (Sphaerium nitidum) in the stomach of Lake Michigan bloaters (Hiltunen, J. K. 1975, Personal Communication).

Pontoporeia affinis and Mysis relicta are, for several reasons, the most important macroinvertebrate food for fishes of commercial and recreational value in Lake Michigan: their abundance, wide distribution, high percentage of benthic biomass, availability to fish, and the preference of many fish species for these organisms at some stage of the fish's development.

Henson et al., (1973) summarized much of the literature dealing with the food habits of the important fish in Lake Michigan. Important forage species such as smelt and sculpin depend heavily on Pontoporeia. The diet of longnose suckers can be as high as 63 percent Pontoporeia and the intake of the white sucker is about 30 percent Pontoporeia. Both fishes are commercially important. Young lake trout and burbot feed on this amphipod as do the deep water chubs which are in turn eaten by the larger trout. The diet of whitefish is comprised of as much as 63 percent Pontoporeia.

Mysis relicta is the dominant food organism for the deep-water bloater chub and the average occurrence in stomach was 48.2 percent. *Mysis* is important in the diet of smelt and whitefish and ranks first in volume of food for young lake trout (28-30 cm) in Lake Superior. Mysids are eaten also by burbot.

Sphaeriid clams have been reported by several investigators as important in the diet of migrating waterfowl, particularly scaup. Over-wintering old squaw ducks on Lake Michigan feed heavily on *Pontoporeia* to depths of 20 m.

The two major benthic energy pathways in Lake Michigan involve *Pontoporeia* and *Mysis*. The first pathway, based on nutrient input, goes through the phytoplankton, the zooplankton, *Mysis*, the chubs and other forage fish, to the large salmonids. Because of the current abundance of alewives in Lake Michigan and the lesser importance of *Mysis* in their diets, *Mysis* is partially bypassed in this energy transfer. The second pathway begins with energy derived from the organic matter and microbenthos, leads through *Pontoporeia*, the chubs, and numerous other forage fish including the alewife, to the large salmonids. Collapse of either the *Pontoporeia* or *Mysis* populations would result in an energy shunt with added stress on the remaining cornerstone. The ecological outcome would be difficult to predict. Current information and knowledge of cooling water use on Lake Michigan does not suggest that such use has affected populations of these organisms.

Benthos As Indicators of Environmental Quality

The relative abundance, species composition and community structure of benthos are reflections of the quality of their environment as characterized by chemical, biological, substrate, and other physical conditions. Benthic animals are characteristically less mobile and therefore are better indicators of stresses over time than pelagic organisms. Environmental stresses are often reflected in changes in benthic assemblages. These changes are often more easily measured than in communities or populations of other aquatic organisms.

Oligochaetes have perhaps been more misused as indicators of aquatic environmental quality than any other single group. Upon discovery of very abundant populations of oligochaetes, various investigators, especially those representing enforcement agencies, have proposed over-simplified and perhaps naive schemes of population detection and assessment. An eminent authority on North American oligochaetes, Dr. Ralph Brinkhurst (1965), has stated categorically, "there is no simple numerical relationship between the numbers of unidentified worm species, or the proportion of all worms in the fauna, and pollution of any but the most obvious, and demonstrably extreme types." Identification of the worms is essential because the presence of a particular species and community structure reflect environmental conditions much more accurately than simply the presence of "oligochaetes" alone.

Brinkhurst, et al. (1968) suggest the indicator value of some oligochaetes in the Great Lakes based on many years of observations and taxonomic work:

1. Species restricted to grossly polluted areas: Limodrilus hoffmeisteri, L. cervix, and Peloscolex multisetosus.
2. Species often present in grossly polluted areas: Branchiura sowerbyi, L. maumeensis, and L. claparedianus.
3. Present in mesotrophic or eutrophic areas (in the classical sense): Aulodrilus, Potamothrix, and Peloscolex ferox.
4. Characteristic of oligotrophic areas: Rhyacodrilus, Tubifex kessleri americanus, Peloscolex variegatus, and Stylodrilus heringianus.

The problem with such lists is that contradictory opinions or modifications continually emerge. This subcommittee feels the categorization "restricted to grossly polluted areas" is too rigid[1] and a more appropriate category would be "present in a wide range of environments, but not abundant outside polluted areas". Tubifex tubifex, Limnodrilus hoffmeisteri and Peloscolex multisetosus for example, could be included in that category.

Brinkhurst, et al. (1968) also suggest the use of some species of chironomid larvae as indicators of trophic conditions in lakes, as have other scientists. The subcommittee endorses efforts to

[1]See also Howmiller and Beeton (1971); Hiltunen (1967, 1969), and Kinney (1972).

develop this concept further, especially as it would refer to specific sites and stresses. However, local conditions do not often reflect lakewide conditions in large bodies of water.

There is universal agreement that such animals as Pontoporeia, Mysis, Heterotrissocladius and Stylodrilus heringianus are indicative of oligotrophic situations. On the other hand populations of oligochaetes composed of Limodrilus cervix, L. maumeensis, and high numbers of L. hoffmeisteri, indicate saprobic conditions. Generalizing on the significance of the presence of species where preference is less clear meets with disagreement. Similar relationships are recognized for many other benthic organisms. It is acknowledged that the presence or absence of certain species and population trends of certain species can be meaningful information on environmental quality, provided such information is interpreted by an expert thoroughly familiar with the ecosystem.

Total numbers of individuals or biomass of benthic populations or communities have also been used as evidence of organic enrichment of lakes (Alley and Powers, 1970, and Robertson and Alley, 1966). Biomass measurements should be employed only with careful attention to technique since preservation of animals and measurement of weight have been so varied that comparison of results with other studies may be misleading (Howmiller, 1972b).

In summary, at the present time the use of all macrozoobenthic information in Lake Michigan as an indication of environmental quality is not an exact science. However, reproducible results and reliable, generalized judgments are often possible. While controversy exists over which populations or assemblages indicate what environmental conditions, there is much agreement on most worm species-communities as well as on Pontoporeia relationships.

Response of Benthic Animals to Environmental Stimuli

Physical Factors

Depth

Most benthic species in Lake Michigan do not thrive in the shallowest water areas or deepest areas of the profundal zone, but between those two extremes their depth distribution is not sharply limited. There is general agreement as to whether a species is typically shallow water, transitional, or deep water in habit, but depth range is normally broad. Rolan (1972) reviewed the work of several investigators and combined their information into graphs clearly illustrating these generalizations.

Such depth-related factors as temperature, light intensity, chemistry, turbulence, sediment composition and availability of food appear to be more important than hydrostatic pressure. Certain chironomids, dependent on ability to secrete gas for buoyancy before emerging, may be limited by hydrostatic pressure.

Shallow areas of unstable sediments subject to wave action and turbulence generally have low macrozoobenthos populations. However, recent work (Mosley, S.C. 1974. Personal communication) using a #10 net indicates that, at least in midsummer, extremely large populations of meiobenthos (>micro- and <macrobenthos), e.g. Naididae, Nematoda, Turbellaria, Entomostraca, and small species and early instars of Chironomidae, may occur in shifting sandy sediments at depths less than 10 meters. Stable sediments or solid substrates

collected greater numbers ...

been thought to inhabit such areas.

The data of Mozley and Alley (1973) showing depth distributions of Amphipoda and Oligochaeta (which made up over 80 percent of the organisms captured) appear to be representative of the depth distribution of a number of benthic organisms in Lake Michigan. Other investigators (Cook, et al., 1965; Schuytema and Powers, 1966) have reported peak numerical populations in Lakes Michigan and Huron occurring at depths less than 10 m. These data include samples from bay and harbor areas not typical of exposed shorelines and open waters. Their data for depths $\geq$20 m are representative and show numbers peaking at about 35 m, dropping rapidly to depths of 80 m, and then leveling off.

On the sandy, exposed shorelines of eastern Lake Michigan populations of macrobenthic animals are comparatively sparse at depths less than 7 m, however chironomids are most abundant there. Amphipods, sphaeriids and oligochaetes increase between 7 and 13 m and amphipods and oligochaetes increase further between 22 and 25 meters. These changes correspond to changes in sediment type and, most likely, to accompanying changes in organic content.

Substrate

Substrate is one of the most important factors influencing distribution and abundance of benthic fauna. Changes in type and abundance of benthos with depth, as described previously for a sandy exposed shore, corresponded with changes in sediment type. At depths less than 7 m, coarse and medium sands predominate; between 8 and 22 m, fine sands with some silt are most frequent; and between 22 and 25 m, gelatinous silt and clay generally become dominant. Underwater observations show that sediment types do not change smoothly with increasing depth. Patches of silt and muck occur in zones where clean fine sand predominates (Mozley and Alley 1973).

Many species occur over a broad range of sediment types and substrates. Laboratory experiments have determined a preferred substrate composition for some species. Other factors equal, the species will be found in greater numbers in association with their preferred substrate in a natural situation.

Median particle size is often reported in benthic studies (See section following on "Sediments and Sediment Chemistry"). Brinkhurst (1967) feels that such studies have not been helpful in explaining the occurrence of oligochaete species. However, Henson (1962) found that the abundance of oligochaetes in the Straits of Mackinac region, when plotted against median particle size, was nearly a normal curve with the mean ($\emptyset_{50}$) at 3.9, which is fine to very fine sand. Several authors have generalized that oligochaetes prefer finer sediments to coarse ones. Henson and Herrington (1965) plotted the distributions of 25 species of fingernail clams in the Straits region against depth and particle size. They established the preference of several species for median particle sizes.

Evidence from a number of recent studies supports the contention that organic content of sediments may have more influence on benthic distribution than sediment size. Brinkhurst (1967) has found *Ilyodrilus templetoni* positively correlated with organic content of sediments, while *Peloscolex ferox*, another oligochaete species, is negatively correlated. Schneider et al. (1969) found that *Hexagenia* sp. and *Chironomus plumosus* are positively correlated and *Cryptochironomus* and *Pseudochironomus* negatively correlated with organic content of sediments in Saginaw Bay of Lake Huron. Fenchel (1972) provides insight into the relationship of interstitial bacterial populations to sediment particle size and nutrient content of water.

In general, sorting of the lighter organic sediments following resuspension by a variety of factors tends to keep the littoral sediments low in organic content, while sublittoral and profundal sediments are higher. Organic content and the associated microbial fauna may be more important than particle size or other factors such as depth in governing the distribution and abundance of macrozoobenthos.

Water Movement

A few benthic species whose usual habitat is quiet water can adapt to turbulent conditions provided a stable substrate to burrow into or cling to is available. Amphipods, certain midge larvae and snails have such adaptive ability since they can be found, along with immature stoneflies and certain mayflies and caddisflies, in shallow areas subject to great turbulence, such as exposed rocky shore or breakwaters. Rheophilic organisms adapted to life in flowing streams, such as caddisflies (Hydropsyche), may colonize the riprap of power plant intake and discharge areas in the lake. Currents have a role in bringing food to sessile filter feeders and also in distributing the eggs and early instars of several benthic insects.

Movement of unstable sediments appear to limit the shoreward distribution of many species. Grinding action may limit microbiological and diatom development on such sediments, eliminating a food source. Such action can also injure the animal directly. Resuspensions of sediments by wave action and redistribution of the lighter organic fractions to deeper water also deprives organisms living in the shallows of this food source.

Discharge of cooling water may produce a scouring action on the bottom precluding benthos colonization around the discharge structure. Farther from the discharge, populations of lacustrine benthic organisms will increase. These animals may benefit from fallout of crippled or dead zooplankton and broken algal cells caused by passage through the pumps, condensers and discharge structure.

Temperature

The species composition of aquatic communities at all trophic levels depends in part on the temperature characteristics of their environment. Each species has upper and lower thermal limits (both short and long-term), optimum temperatures for growth, preferred temperatures in thermal gradients, normal temperature ranges, and temperature limits for various activities such as mating, ovipositing, egg incubation, hatching, pupating and emerging. Aquatic invertebrates are without internal mechanisms for thermal regulation and, since their surface area is large in proportion to their mass, their body temperature quickly conforms to the temperature of the surrounding water. Thermal conditions are rarely optimal, as natural variations create conditions either above or below optimum within a tolerable range.

Lake Michigan is one of the southernmost lakes possessing an oligothermic fauna characteristic of colder lakes. This is possible since the hypolimnion is insulated from surface warming by a well-marked thermocline and remains cold and well-oxygenated at temperatures near 5C throughout the summer, although surface layers may warm up to 20C or more. The warming of the main water mass in spring and early summer lags the air and watershed temperature to such an extent that warm water rivers entering the lake may be 10 - 15C warmer than the lake surface waters.

The glacial marine relicts Pontoporeia affinis, Mysis relicta, Heterotrissocladius subpilosus Kieffer (Henson et al., 1973); a possible glacial marine relict, Pisidium conventus (Henson, 1966); and other oligothermic fauna thrive in the thermal regime of the hypolimnion and thermocline.

The southern half of Lake Michigan is generally warmer than the northern half and because prevailing winds from the sector south to west produce more frequent upwellings along the western shore than on the eastern shore, surface temperatures are generally higher on the eastern side. During the spring warming phase previously described, the region of nearshore thermal stratification with surface temperatures rising above 4C is separated from offshore homothermal water at temperatures below 4C by a narrow outward-moving transition zone (the thermal bar) in which water at maximum density is actively sinking (vertical 4C isotherms). The offshore transport of heat therefore takes place not only at the surface as the thermal bar moves outwards but also in the form of heat addition to deeper layers, gradually warming the hypolimnion from its March minimum near 2C to its summer value near 4C.

These several phenomena influence the lake's thermal regime and thus determine in part the species present, their abundance, distribution, reproductive activities and productivity.

The addition of heat to Lake Michigan by cooling water discharges has the potential for changing the structure and metabolism of aquatic biological communities. Such changes may be detrimental or beneficial. While the great majority of published investigations on effects of thermal discharges to the Great Lakes, and Lake Michigan in particular, demonstrate negligible environmental effects, especially for the benthos, scientific prudence dictates caution in presuming that the effects of all current and proposed thermal discharges to Lake Michigan will be negligible.

Light

Cooling water discharges may scour bottom sediments and create increased turbidity locally. Littoral currents transporting sediment can provide fresh materials for resuspension by scour. The extent to which the resulting decreased light transmission influences benthos has not been reported. Light intensity influences the distribution of some benthic species directly, regulates the vertical migrations of Pontoporeia (Marzolf, 1965) and Mysis (Beeton, 1959) and limits the water depth to which benthic flora, a food source, can grow. Segerstrale (1971) demonstrated photoregulatory dominance over thermoregulation in maturation of Baltic populations of Pontoporeia.

Chemical Factors

Few investigations have been conducted to quantify the influence of chemical contaminants in the sediments on benthic macroinvertebrates. Gannon and Beeton (1969, 1971) carried out a series of laboratory tests with benthic animals using sediments from nine Great Lakes harbors. Sediments from five harbors were toxic to Ponotoporeia. Test animals displayed selectivity for the less contaminated sediments when offered choices. The U.S. EPA used data from these tests to establish criteria for identification of sediments which should be dumped only in confined areas (U.S. Army, 1971). Contaminants of general concern are volatile solids, phosphorus, ammonia, organic nitrogen, chemical oxygen demand, oil and grease, iron, lead and zinc. Oily sediments have been identified by many authors as influencing benthic communities.

Johnson and Matheson (1968) associated direct iron toxicity, or COD associated with iron oxidation, with a lack of tubificid worms in Hamilton Bay in the vicinity of steel mill discharges.

Changes in dissolved gases caused by heated discharges may be more important than currently recognized. There are documented incidents of gas bubble disease of fish in heated effluents (Demont and Miller, 1972) and the laboratory occurrence of gas bubble disease in three species of bivalve mollusks held in heated running seawater during the winter (Malouf et al., 1972). Any effects on benthos would probably be limited to the immediate vicinity of the discharge.

Biocides, such as chlorine used to prevent fouling in condenser tubing are known to kill fish (Truchan and Basch, 1974). Benthos can be similarly affected when they are resident in the zone of residual biocides and time-toxicity relationships exceed their tolerance.

Concerns For The Macrozoobenthos As Related To Cooling Water Use

Mechanisms by which cooling water use causes significant effects on the Lake Michigan macrozoobenthos community have not as yet been demonstrated unequivocally. The possible potential effects of use of Lake Michigan waters for cooling lead to the primary concern that the macrozoobenthos may be so altered, reduced or eliminated that an energy shunt is created which would result in lower production of desirable forage, game and commercial fish or increased production of undesirable fauna and flora, or both.

Mechanisms which could contribute to this primary concern are:

A. Thermal

1. Shortened incubation periods resulting in a reduced hatch of smaller and less physically-capable animals,
2. Premature hatching when food sources are not available,
3. Premature emergence into unfavorable climatological conditions,
4. Chronic conditions exceeding temperature tolerances of desirable organisms,
5. Conditions favorable to organisms of less value as food to macrozoobenthos and higher trophic levels,

6. Conditions favorable to parasitic or disease organisms,
7. Conditions favoring abnormally high predation, and
8. Stress induced by intermittent thermal shocks as plumes shift or units go on and off line.

B. Physical, other than thermal
1. Substrate alteration during construction,
2. Substrate alteration by physical interruption of littoral drift,
3. Creation of uninhabitable environment due to velocity of discharge, and
4. Increased turbidity by scour.

C. Chemical
1. Direct toxicity by chlorine,
2. Direct toxicity by discharge of boiler cleaning materials,
3. Direct toxicity by cooling tower maintenance materials, and
4. Accumulation of toxic metals in sublethal concentrations.

D. Intake
1. Impingement of large organisms such as crayfish on screens,
2. Pump entrainment and condenser passage, and
3. Deposition of organisms killed or crippled by entrainment.

Experimental Questions

In response to the concerns enumerated above there are experimental questions to be answered or addressed during investigations into effects of cooling water use on macrozoobenthos. The questions are grouped into on-site preoperational, on-site operational, and off-site lakewide studies. While this encourages redundancy, there are advantages to the reader. There is an inherent responsibility in planning or evaluating any study to be sure investigative resources are allocated wisely so that the aspects which have the greatest potential for impact at the specific study site receive an appropriate share of the effort. Thus some aspects may be addressed only through literature search while others should be investigated in minute detail.

In responding to these questions, the investigator should establish the relationship to the macrozoobenthos. The questions are not all-inclusive, nor exclusive of site-specific considerations.

On-site Pre-operational Studies

1. What are the bottom contours within the study area prior to construction or operation?
2. What are the substrate types within the study area prior to construction or operation?
3. Are the contours and substrates known to an extent which would permit detection of changes caused by construction or operation?
4. Are the substrates unique to the site or critical to the survival and well-being of important indigenous macrozoobenthos?

5. Is the littoral drift known?
6. Will the littoral drift be physically altered by construction or operation?
7. Were the littoral drift, bottom contours, and substrate types altered by construction?
8. What are the preconstruction or preoperation macrozoobenthic populations and communities in the study area? Species? Densities? Diversity? Community biomass? Important species biomass?
9. Are the macrozoobenthos communities known to an extent which would permit detection of change? Were they altered by construction?
10. Are the macrozoobenthic organisms of importance in the diet of local fishes?
11. Are the local macrozoobenthos unique or critical to the ecosystem of the water body segment or lake?
12. Are any of the macrozoobenthos present in nuisance quantities?
13. Are the seasonal behavior patterns and life cycle activities of the important animals known?
14. What food sources are important to the macrozoobenthos?
15. Based on plume modeling and anticipated operational modes, what macrozoobenthic organisms will be impacted and over what area?

On-site Operational Studies

1. What changes have occurred in the bottom contours due to construction and operation? Are the changes important to the macrozoobenthos?
2. What changes have occurred in the littoral drift due to construction and operation? Are the changes important to the macrozoobenthos?
3. What changes have occurred in the substrate type due to construction and operation? Areal extent? Are the changes important to the macrozoobenthos?
4. What are the post-operation macrozoobenthos populations and communities?
5. What changes have occurred in the macrozoobenthos due to construction and operation? Were the changes statistically significant? Areal extent? Are the changes ecologically significant to higher trophic levels?
6. Are any of the macrozoobenthos present in nuisance quantities?
7. Are macrozoobenthic organisms impinged or pump-entrained? In sufficient numbers to threaten appreciable harm to populations or communities? If so, what is fate of entrained organisms?
8. What is reaction of macrozoobenthos to biocide applications? To other chemicals associated with plant operation? Is reaction sufficient to threaten appreciable harm?

9. Do macrozoobenthos accumulate toxic materials for potential transfer to higher trophic levels?

10. Are there indications of gas-bubble disease in the discharge area?

11. If changes have occurred in the macrozoobenthic community what mechanism or combination was responsible? Pump-entrainment? Biocide reaction? Reproductive synchrony? Velocity? Scour? Substrate shifts? Littoral drift shifts? Food source? Predation? Parasitism? Disease? Intermittent thermal excusions? Chronic thermal conditions?

Off-site (Lakewide) Studies Related to Macrozoobenthos

It should be noted that investigation of lakewide effects are not the responsibility of a single user, or group. There are many stresses on the waters of Lake Michigan and separation of those caused by cooling water use is difficult.

1. What are the substrate types and their areal extent?
2. What are the habitat types and their extent?
3. What benthic fauna occupy these substrates and habitats? In what densities? Community biomass? Important species biomass? Can these be generalized?
4. What roles do the benthic animals have in the lake's ecosystem?
5. Which benthic animals are of primary importance to this system and why?

6. To what extent would elimination (destruction) of a habitat type (or portion of a type) and its associated biota affect the lakewide ecosystem?
7. What is the effect, real or potential, of local effects at one site or all combined local effects on the lakewide ecosystem?
8. Can long-term chemical changes in the lake have an effect on benthic animals and to what extent will the chemical additives from a number of power plants amplify this effect?

Major investigative effort should be directed toward field studies at present. Clearly, many of the experimental questions posed are more research than baseline surveys. However, it should be obvious to the investigators that when perturbations occur in the field, the causative factors can often be isolated only in the laboratory. Controlled experiments and research needs are discussed later in this chapter.

Principal Problem Areas In Understanding Effects of Cooling Water Use on Benthos

The problems associated with understanding the results of benthos investigations as a part of studies of cooling water use fall into four categories: a) regulation of benthos abundance and community structure by natural environmental factors, b) separation of the effects due to other water uses from the effects of cooling water use, c) obtaining precise estimates of abundance and community structure, and d) demonstration of the significance of the benthos in the over-all lake ecosystem.

Natural Environmental Factors

From previous investigations it seems reasonable to assume that the off-shore benthos community of Lake Michigan (exclusive of Green Bay and many near-shore areas) is essentially a single community. However, it has been found that abundance and community structure of the benthos change with certain natural environmental factors, chiefly depth and sediment composition. Macrozoobenthos abundance is usually very low at depths less than five meters and increases with depth to a maximum at a depth of 30 to 60 meters. At depths greater than 60 meters, benthos abundance decreases. Near-shore sediments with a high percentage of small particles and/or a high organic content support large populations of tubificid worms which are less abundant in other types of sediments.

Normal turbulence due to wave action can move bottom sediments in areas shallower than about 15 meters and redistribute the benthos and small particle size material. This material settles in depths ranging from 15 to 60 meters with the heaviest deposition of organic matter derived from the disturbed sediments occurring between 15 to 25 meters.

Condenser cooling water intakes and discharges usually are located in water less than 15 meters deep. This is not the region of maximum macrozoobenthos abundance but is the region in which the abundance and composition of the benthos may change quite significantly due to natural factors: depth, sediment composition, and perhaps others. These natural variations in benthos compound the problem of demonstrating effects of cooling water use.

Careful selection of areas for sampling will avoid this problem. Test areas in which cooling water use effects might be observed should be selected with adequate consideration of the natural effects of lake currents and wave action. Reference areas should be selected to permit comparison with the test areas in depths, sediment types, and as many other environmental factors as possible.

The benthic community in any given area changes seasonally and annually. Due to these changes comparison of preoperational data from a test area only may not provide a very clear picture of the effects of cooling water use. Comparisons of changes in the benthic community of the test area with changes in the reference area(s) provide the best approach for measuring effects. Such comparisons will be of greatest value when preconstruction and preoperational data from test and reference areas are available.

Effects of Other Discharges

Discharges of waste materials to Lake Michigan have caused changes in the benthic community in some areas. Some of these changes are obvious and highly localized such as the increased abundance of leeches and reduced abundance of other benthos near the discharge from a steel mill. Some changes are more widespread, such as the increases in tubificid populations in the 15 to 25 meter depth range in association with inputs of organic wastes at several points around the lake. When changes in the benthos in areas of cooling water use are found, it must be determined whether the changes are due to cooling water use or to inputs of waste materials.

The best approach to this problem which can be suggested at present is again careful selection of test and reference areas. Particular attention should be given to distance from influential discharges such as municipal wastewater treatment plants and mouths of large rivers. Selection also involves knowledge of prevailing currents. If both the reference and test areas are subjected to the same environmental influences except for the single factor of cooling water use, the differences in changes between the test and reference areas should be due to the cooling water use.

Once a difference in the changes in benthos occurring in the test area is found, this should provide verification for one of the concerns expressed previously. If it appears that one of the mechanisms is actually operating in the lake, it should be further tested by laboratory experiment. Data from the laboratory experiments, if properly designed and conducted, should be quite helpful in separating the effects of cooling water use from the effects of the input of waste materials. Further information on the response of benthos to various stresses should also be quite helpful for sorting out effects.

Sampling Problems

An objective of any program of benthos sampling is to obtain samples giving a quantitative estimate of the abundance and species composition of the benthic community or a representative fraction thereof. In any area the faunal assemblage is likely to vary considerably from one sample to the next. Thus replicate samples are needed to estimate the mean and variability of individual samples. Samples from test and reference areas must be collected in a manner so that they provide comparable data. Each replicate sample in both areas should consist of organisms collected over an equal area and occupying an equal volume of sediment. Since sampling devices are imperfect (i.e., any sampler is somewhat selective) and do not collect equal volumes from different sediment types, each sample should be examined immediately after collection and rejected if the sampler does not contain an appropriate volume or if there is evidence that the sampler is not functioning properly.

Benthos tend to have different distributional patterns at different depths. While the expected distribution is random in areas where sediments are disturbed by wave action and aggregated in deeper areas, the benthos of some nearshore areas may contradict this by exhibiting strong aggregation. In cases of animals with territorial behavior (e.g., crayfish) the distributional pattern may be regular. Statistical distributions which may correspond to the various patterns of benthos dispersion are Poisson for random, negative binomial for clumped, and positive binomial for regular. Sampling an area to fully document patterns of dispersion may require a prohibitive number of samples. For statistical treatment, mathematical transformations of the data should be used only where there is valid justification. The normal distribution should be assumed only when it can be shown that the data fit. When the data are inadequate either to demonstrate the distribution or to provide precise estimation of the parameters of the distribution, non-parametric procedures should be used, as for data from different areas.

Determination of the Role of Benthos at Study Sites

As previously indicated, the benthic community is of major importance to the lake ecosystem as a source of fish food. Since it is important to design a benthic sampling program which defines the role of the benthic community in the study area, stomach contents of fish of a variety of species and ages should be analyzed to determine the importance of benthic organisms in their diet. Such analysis should be related to the seasonal benthos communities.

Objectives Of Measuring Environmental Conditions and Responses

In general terms, the objectives of site-specific benthos investigations are to quantify the on-site effects of cooling water use, to establish the spatial limits of benthic effects, to determine the extent to which such effects are cause for concern, and to relate measurable perturbations to the water body segment or the Lake Michigan system as a whole.

Some specific objectives of preconstruction or preoperational studies are establishment of the baseline environment for comparison with conditions during operation. For comparison of macrozoobenthos, the bottom contours, sediment types, normal seasonal benthos abundance, distribution and community structure should be determined. Knowledge of the important species (e.g. reproductive behavior and time, migration, thermal tolerance) and their role in the system is highly desirable.

Some specific objectives of operational studies are to determine changes in bottom contours, sediment type and benthos distribution, abundance, community structure and behavior (as distinguished from normal changes) caused by construction and operation of cooling water intake and discharge. If changes in benthic populations are observed, the question of the significance of these changes to higher trophic levels should be addressed.

Benthic Study Field Methods

Collection

Benthic samples should be collected using appropriate and recognized sampling devices and methods. The choice of sampler is dictated in part by the substrate, depth, and organisms. When various techniques are employed at one study site, a mechanism should be adopted to compare techniques on a quantitative basis after careful consideration. There are great differences in sampling efficiencies among grabs. In granular substrates the following devices may be used:[1]

1. Grab samplers (Ponar, Petersen, Ekman, Smith-McIntyre)
2. Core samplers (single and multiple)
3. Sleds and dredge nets

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[1] For discussion of relative sampling efficiencies and appropriateness see Powers and Robertson, 1967; Mozley and Chapelsky, 1973; Beeton, Carr and Hiltunen, 1965; Flannagan, 1970, and Howmiller, 1972.

In areas of rock outcrops, large rocks and gravel, or hard packed clay, the following sampling devices may be used:

1. Pumps
2. Scuba divers (direct observation, *in situ* collecting, or photography)
3. Artificial substrates approximating natural substrates
4. Sleds

Separation

Organisms should be separated from the sediment by sieving or elutriation or both. Meshes should not be larger than those of a U.S. Standard No. 30 sieve (589 microns). Samples should be placed in labeled containers and preserved with 10 percent buffered formalin or 70 percent ethanol.

A U.S. Standard No. 60 sieve (246 microns) may be used when the substrate allows. This size is more efficient at retaining smaller macroinvertebrates such as early instar chironomids and minute oligochaetes. Varying sieve sizes affects comparability of the stations and the advantages of sieve sizes must be considered against the effort of extracting and identifying these small animals. There is a possibility that samples of larger animals from a larger surface area may be more valid statistically. For more complete community estimates, two sample sizes and sieve meshes might be used together.

If organisms are not separated from the substrate in the field, the entire sample can be placed in a labeled container and kept cool and unpreserved until it is separated, preferably the same day. However, the organisms are subject to predation and also to death from anoxia or abrasion (followed by decomposition). Since differences in numbers and sizes of animals recovered could result from inconsistent methodology, trials should be conducted with known numbers of live animals to determine (a) the relationship of holding time to percentage recovery and (b) the numbers and sizes of animals recovered by field separation techniques compared with laboratory techniques. It is preferable not to vary collection and separation techniques on a study area.

Sediments

Although bedrock exposures are found in Lake Michigan, most of the bottom is covered with glacial deposits overlain by more recent sedimentary materials. Descriptions are provided by Hough, 1935; Ayers and Hough, 1965; Ayers, 1967; Powers and Robertson, 1968; Somers and Josephson, 1968; and Mozley and Alley, 1973. These sediments play an important role in abundance and composition of the benthos since they provide the physical habitat for all and the food supply for many. Variations in the benthic community with sediment type and composition must be known in detail before it is possible to ascertain the effects of other environmental variables (such as temperature). Some of the possible effects of cooling water use upon the Lake Michigan ecosystem are related to possible changes in the sediment such as the patterns of sediment erosion and deposition near discharges, or increased organic content in the sediments due to "fall-out" of plankton killed during condenser passage.

Mapping of Sediments

Sediments in the areas of actual or potential cooling water use should be mapped for selection of sampling sites for field studies of the benthic community and for estimating potential effects on the habitat. Five methods used for sediment mapping are applicable to benthos work: grab samples, core samples, use of divers, underwater television or photography, and seismic profiles.

1. Grab samples are useful since the surface layer inhabitated by most of the benthos makes up a large portion of the sample. However, the layered characteristics are often disturbed by the action of the grab. When grab sampling an area of approximately 500 cm^2, the volume of each sample should be at least one-half liter to assure adequate representation. If this amount cannot be collected by a single grab, a core sampler should be used. However, in well-sorted, fine sand some grabs are inefficient and core samplers do not retain the sample.
2. Core samplers penetrate deeper, but usually cover less surface area than grabs. They collect a smaller amount per sample of the critical upper layer mainly inhabited

by benthos, but the sample is relatively undisturbed. Core samplers are particularly useful in areas of hard clay where a grab will not penetrate to collect an adequate sample. Examination of the sediment from a core sampler may be confined to the upper 2 cm for surficial sediment mapping, although the deeper sediments may be important to certain benthic animals.

3. Divers trained in scientific observation and using techniques for random or design sampling can be useful in mapping sediment characteristics. Divers are especially valuable for locating such features as rock outcrops, patches of silty or organic sediments, or areas of macrophyte growth missed by other sampling techniques.
4. Underwater television or photography are alternatives to the visual observations supplied by divers.
5. Seismic profiles provide data on gross distribution of sediments over large areas but cannot provide the detailed information on the upper layer of sediment over a small area needed for evaluation of benthic habitats. Sediment profiles based on seismic data and some core samples are available from the Illinois Geological Survey for the entire southern basin of Lake Michigan.

Sediment mapping should extend at least 2 kilometers along the shore in either direction from the point of discharge and at least 2 kilometers away from shore. These distances vary with the site and size of the anticipated area of influence. For initial mapping, at least 10 samples should be collected over each km^2. These could be supplemented by visual surveys by trained divers to identify significant features of the bottom which may be missed by random sampling. Sediment mapping should also be involved in selection of reference areas to insure comparability.

Laboratory Analysis of Sediment

Sediment type is identified by laboratory analysis. Since there is no way at present to relate sediment mineralogy to benthic communities, mineralogical analyses are not recommended. However, it is highly important to have information on organic content and the particle size distribution. See Substrate Section, page 188, for comments on quality of sediments.

1. Organic content should be measured by total organic carbon determination (TOC) and reported as percent dry weight (± 1 percent).
2. The particle size distribution of dry sediment should be determined by shaking it through a series of 7 sieves with the following separation sizes (Inman, 1952):

Separation size (mm)	Phi ($-\log^2 d$)	Class
2.00	-1.0	very coarse sand
1.00	0.0	coarse sand
0.5	1.0	medium sand
0.25	2.0	fine sand
0.125	3.0	very fine sand
0.0625	4.0	silt
0.0039	8.0	clay

The Phi number ($-\log^2$ diameter in mm) of the mean particle size and the standard deviation in Phi values should be reported. It is also useful to report the percent (by weight) of particles less than 0.0625 mm in diameter.

Sediment Chemistry

Sediment chemistry of particular interest in evaluating cooling water use describes the exchange of materials between the sediments and water of the lake. Specific elements often are, or become, insoluble and are deposited in the sediments. If toxic, and biologically available, they may reach concentrations high enough to alter composition of the benthic community. It is also significant that benthic organisms sometimes recycle nutrients and other materials from the sediments into the water and back into other trophic levels.

Where cooling towers are used, evaporation increases chemical concentrations in the blowdown. Toxic materials may be used in cooling tower maintenance. Therefore, materials in blowdown discharged into the lake have potential for accumulating in sediments over a relatively small area. In view of the wide range of blowdown contaminants, it is not possible to make general recommendations on the types of analyses which should be performed, however, investigators should be alert to the possibility that changes in benthic communities may be due to changes in sediment chemistry.

Corrosion or erosion in circulating water systems may contribute toxic metals to once-through cooling water discharges or to cooling tower blowdown. Metals of concern include copper, zinc, and chromium. Concentrations of these materials in the discharge and physical models of their distribution over the receiving area are needed before it is possible to specify the analyses and precision.

Supporting Information

The following information should be collected (concurrently, and with appropriate periodicity) to assist in interpretation of benthic ecological patterns which may emerge from the survey:

1. Water Chemistry
    a. dissolved oxygen immediately above or in sediments
    b. suspended organic matter
    c. C:P:N ratio
2. Water depth (in meters)
3. Date and standard time
4. Temperature (Celsius) of bottom waters. The relationship to overlying temperatures may be of value, as would be the temperature at the sediment-water interface or in the sediments at critical sites. If the area of the bottom impacted by increased temperatures and the frequency

and amplitude of such increase is not well known, interpretation of direct thermal effects will be difficult at best.

5. Transparency, by photometer or Secchi disc
6. Visual examination and description of the sediment at the time of sampling. The sediment type or combination of layered sediments may be encoded by a single number or combination of numbers. Example: medium sand layered over hard clay - 10, 2/6, or silty fine sand = 5, 4/3.

1 - Coarse sand	7 - Clay-soft
2 - Medium sand	8 - Gravel
3 - Fine sand	9 - Rock
4 - Silt	10 - Layered sediments
5 - Mixed	11 - Gelatinous
6 - Clay-hard	

Sampling Design

A statistician familiar with environmental sampling should be consulted during the design stages of the program.

Establishing Stations

Sampling stations in the test and reference areas should be established in a similar manner, either in a grid system or by random selection along transects. The number of stations and number of replicate samples depends on the degree of variability in the habitats. To determine the extent and detail of the program, preliminary sampling should be done to evaluate variability in depths, sediments, water quality and benthos. For statistical analysis of areal differences, stations from similar habitats may be grouped.

Fixed Grid

Areal extent of the grid and proximity of the stations should fit the size and the expected area of influence. The grid should be modified to account for special situations as outlined below.

Selection of Reference Area(s)

The reference area(s) should be sufficiently remote from the test area to be unaffected by the plant operation. They should be as similar as possible to the test area in topography, sediment types, distribution of sediments, and water quality. Differences will create difficulties in interpretation of results and identification of changes in the test area. Considerable effort should be expended in making as careful and knowledgeable choice as possible. (See Principal Problem Areas in Understanding Effects of Cooling Water Use on Benthos, page 201.)

Station Identification

Stations should be located with precision and either marked by a buoy or located using a transit with fixed shore points or distance measuring equipment. Far field or open lake stations can be accurately established and relocated with ships' radar and other navigational aids.

Station Distribution and Spatial Interval

Stations should be distributed so results of sampling can be related to the frequency of occurrence of the discharge plume in the test area. Spatial interval depends upon the extent and homogeneity of the area over which the target effects are to be evaluated. Establishment of stations in the area where heated water will contact the bottom is important. Additional stations, if necessary, should be located to measure and evaluate: 1) erosion by disturbance of bottom sediments; 2) winter sinking plume; 3) areas of increased fish predation; 4) areas of "fall-out" of organisms killed by condenser passage. Additional sampling sites may be needed to document special situations.

Sampling Frequency

Ideally, sampling should be done every other month (six times per year) for the calendar year and more often during periods of rapid change such as late spring or summer at a critical site. Minimum sampling frequency should be four times per year, seasonal.

Number of Samples

The number of replicates collected at each sample site in the test and reference area on each sampling date should be adequate for statistical treatment as discussed in the Date Requirement Section (page 47) and Sampling Problems, page 204. Generally, at least three replicates should be collected each time and at least four replicates may be required if non-parametric statistical tests are used. The number of replicates required may be much, much greater than three or four if it is desirable to detect significant differences in species abundance in the presence of the variability usually found in benthic populations. A key to the amount of benthos sampling and detail desirable is associated with the severity of impact experienced at the site and importance of the site specific and water body segment of the benthic community.

An approach to detect differences in abundance which is not generally satisfactory is to assume that the Poisson distribution (random distribution) model can be used to describe the data. The square root transformation is used to "stabilize the variance" and analysis of variance is applied to the transformed data.

There are good biological reasons to believe that benthic population data should fit distributional models other than the Poisson, such as the binomial or negative binomial. If the incorrect distributional model is used, then the incorrect data transformation is used and analysis of variance will be less likely to detect differences. However, the number of replicates required to examine detailed distributional properties of the data may be beyond the resources of any particular study group.

There should be a special study to determine the appropriate distributional models for analysis of benthos data. Until such a study is carried out, non-parametric tests are recommended. When data distributions are not known, non-parametric tests often have greater sensitivity to detect differences than analysis of variance. Design of sampling should be decided with the advice of a statistician.

Laboratory Techniques

Sorting, identification and enumeration of benthic samples should be performed using standard laboratory equipment, procedures, and techniques. All identifications should be performed with appropriate magnifiers and microscopes using recognized taxonomic keys or publications.

Data Presentation

Generic and Specific Identification

In general, dominant organisms should be identified to species if possible and all other organisms should be identified at least to genus, counted and quantified in units/m^2. Following this guideline, mysids, decapods, amphipods, and most oligochaetes should be identified to species. Sphaeriidae should be identified at least to the two Great Lakes genera, Sphaerium and Pisidium, and preferably to species. Chironomidae, other aquatic insects, and gastropods should be identified at least to genus.

The presence of parasitic Cestoda in Oligochaeta; Nematoda, viruses, bacteria and protozoans in Chironomidae; and acanthocephalans in Amphipoda should be determined at selected stations.

The following literature is not meant to be inclusive or exclusive, but simply helpful suggestions from some workers in the field. Chironomids should be named according to Hamilton, Saether, and Oliver (1969) (allowance is made for periodic updating, e.g., Saether's 1973 paper on Monodiamesa). Other useful texts on midges are Beck and Beck (1969), Roback (1957), Cernovskii (1949), and Mason (1973). Tubificidae and Naididae keys are available from J. Hiltunen (1973). Several keys to various groups recently published by U.S. EPA in the Smithsonian Biota of Freshwater Ecosystem Series are recommended. This series is listed separately at the end of the References and Literature Cited section. Gastropoda genera may be identified using Harman and Berg (1971), or Walter and Burch (1957). Ward and Whipple (1959) is useful for other forms.

Since use of the recommended sieve mesh size (589 microns) will probably result in escape of the majority of Nematoda, Ostracoda, Harpacticoidea, Platyhelminthes and benthic Cladocera, identifying representatives of these groups to specific levels is of little quantitative value. Identification becomes important when refined collection and separation techniques are used and greater community description is desired.

Biomass

1. Dry weight determinations should be made on unpreserved organisms since preservatives cause weight loss (Howmiller, 1972b). Organisms should be oven dried at 60C for 24 hours and weighed.
2. For ash free determinations, dried organisms should be placed in a muffle furnace at 600C for 30 minutes. Ash free weight equals oven dry weight less final weight after ashing.

Diversity Indices

Depending on the level to which the organisms have been identified, species diversity analysis may be conducted. The usefulness of species diversity indices with Lake Michigan zoobenthos is questionable (See Mozley, 1973). Species "richness" and "evenness" are of interest, but sampling and taxonomic problems severely limit their use. They are an optional means of presenting data, if justifiable.

Research Needs and Controlled Experiments

Although this chapter focuses on a very practical field problem, the evaluation of the effects of cooling water use on Lake Michigan macrozoobenthos, solutions to the mechanisms which control the undesirable effects may be most efficiently provided by basic research. Field studies provide estimates of effect, but often do not bear on causative mechanisms. While no attempt will be made to provide an endless list of laboratory studies, carefully chosen laboratory research projects can provide guidance for operational protocols that could minimize environmental impact. It is possible to identify areas of laboratory investigation on benthic organisms of immediate practical use. One of the first questions concerns the simple effect of heat on the benthos, that is, temperature bioassays of ecologically important benthic species to provide estimates of effects of chronic and acute exposure to heat.

Laboratory bioassays have been justifiably criticized for the following reasons:

1. Such studies may have limited transfer value.
2. Test conditions in the laboratory may not adequately simulate simple field situations.
3. Bioassays tend to treat a single factor at a time, making it difficult to predict multiple effects, synergisms, or modifications that might occur under natural conditions.
4. More complex field situations are difficult and expensive to simulate in the laboratory.

In view of the foregoing, laboratory studies should consider the following factors and their interactions: temperature, biocides, cooling tower blowdown products, dissolved gases.

In general, the physiological requirements of most species of lake macrozoobenthos are poorly known, including even their basic temperature and dissolved oxygen requirements. Bioassay and characterization of toxicity should characterize normal requirements and develop criteria to identify responses to changes from normal. This knowledge is fundamental to understanding the results of environmental change. As a partial remedy, the following steps are proposed:

1. Have competent specialists sèlect key, dominant, or representative species, both site specific and water body segment specific;
2. Subject selected species to intensive laboratory study to determine oxygen and temperature tolerances at various life history stages;
3. Standardize procedures, design variables, and reporting procedures for the testing; and
4. Perform toxicity and uptake tests for biocides and heavy metals only on species for which oxygen and temperature tolerances have been developed.

By standardizing bioassay protocols, information developed for one site is more applicable to work related to other sites.

The effect of intermittent heat or discontinuous generation on benthic organisms is a second area of concern which can be profitably studied in the laboratory. Irregular generation and shifting plumes can cause unseasonal thermal environments which may have significant ecological effects even though absolute temperature differences created may be small. Many physiological and behavioral activities, such as reproduction and migration are keyed to normal seasonal and daily temperature patterns.

Priority Needs and Research

Relatively immobile benthic and sessile organisms may be subject to continuous or intermittent stress in the vicinity of facilities using Lake Michigan as a source of cooling water. Stress may be caused by discharge velocity, thermal differences or exposure to chemicals used in plant operation. This may result in a difference in benthic communities in the vicinity of such facilities from those remote from the facility.

Minimum stress to benthic organisms is achieved by minimizing the bottom area exposed to harmful conditions. This may be accomplished by careful discharge location and design, and by cooling water and wastewater treatment before discharge. Such measures may entail additional use of other resources and an economic penalty to the discharger, which is ultimately passed to the consumer. Therefore, a decision should be made on a case-by-case basis as to how the benthos are to be protected. The bottom area in the vicinity of thermal discharges may represent a living space denied to benthic organisms and this space may or may not be of significance to the biological community.

The need for biological judgment requires that this subcommittee recommend some general and specific studies which would compare the effect of environmental alteration to natural situations. Since some of these studies take precedent over others, a system of priority has been established based on need, and categorization has been accomplished based on the availability state of the data, as follows:

Priority - 1 - Highest priority consistent with achieving primary goals of Panel;

2 - High priority item directly supporting priority 1 items;

3 - Intermediate priority.

Category - 1 - Solution available from existing data;

2 - Solution available from ongoing studies;

3 - Solution requires additional research.

(A) The discussion introducing this section identifies high priority need for biological information applicable to the regulation and/or modification of thermal discharges: determination of the importance of macrozoobenthos in the vicinity of the discharge to the biological community of the receiving system. The most obvious approach is through field food chain studies on site to aid in answering the question of whether elimination or alteration of macrozoobenthos in areas of varying size would affect fish or their populations.

Priority 1, Category 3.

(B) The second high priority information need is the ability to distinguish the effects of cooling water use on macrozoobenthos from contemporaneous changes due to other causes.
Priority 1, Categories 1 and 2.

(C) Because cooling water use represents only one of a number of stresses on the Lake Michigan ecosystem and because the macrozoobenthos of the vast profundal and sublittoral areas are of established importance to the biological community, baseline measurements of lakewide zoobenthos populations are needed in sufficient detail that trends may be recognized at an early date. These baseline measurements should be accompanied by a seasonal biological map incorporating activities of important species.
Priority 1, Categories 1, 2 and 3.

To provide the above three information needs, other studies and activities of a supportive nature should be initiated.

(D) Macrozoobenthos species lists with synonyms and known spatial and geographic distribution.
Priority 2, Category 1 and 2.

(E) Determine and list species of special significance and specify reasons for significance, i.e.:

a. Benthic environmental quality indicators

b. Energy transfer in food chains

c. Recycling of nutrients, toxins and radioactive materials

d. Accumulators of materials of concern (metals, organics, and radioactivity)

e. Nuisance producers

Priority 2, Category 1 and 2.

(F) Determine sampling design and sampling devices necessary to ensure minimum capability for identification of change. Intensive review of exiting data should yield conclusions on such factors as:

a. Replication and limits of statistical error

b. Spatial distribution of sampling efforts

c. Criteria to establish reference locations

d. Seasonal distribution of sampling effort

e. Data reporting criteria and format

f. Sampling devices

Priority 2, Categories 1 and 2.

(G) Identification of the degree of influence on benthic populations by such factors as:

a. Chemicals (algacides, cleaning agents, chlorine blow-down products)

b. Thermal effects (intermittent, acute and chronic exposures, sinking plumes)

c. Riprap

d. Fish predation

e. Scour and velocity

f. Enrichment (organism "fall-out" from plumes)

Priority 1, Categories 1, 2 and 3.

Items D, E, and F above relate to the basic problem of benthos investigation on any body of water on which several academic, enforcement, industry, and consultive entities are working: non-uniformity of methods. This leads to a low degree of data comparability. Utility of results and efficiency of the total effort would be increased greatly by adopting compatible, if not uniform, methods. Therefore, a recommendation is made for two workshops: the first on taxonomy and nomenclature and the second on sampling and data analysis. No priority has been established, but these workshops are considered highly significant to an orderly assessment of thermal effects on the macrozoobenthos of Lake Michigan.

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SECTION VII

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON THE FISHERY

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SECTION VII MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON THE FISHERY

Introduction

Historical Description of Great Lakes Fish Stocks

The Great Lakes and their tributaries and connecting waters contain an extensive fish fauna which includes representatives of most of the important families of North American freshwater fishes. Hubbs and Lagler (1958) described 20 families and 173 species in the Great Lakes drainage basin and stated that theirs was undoubtedly an incomplete list. Although nearly all of the fish native to the drainage basin had access to Lake Michigan, relatively few species became established in the Lake proper, and most of these were cold water species.

A complete list of the fish fauna of Lake Michigan is not available, but according to Wells and McLain (1973), a number of of species were, or are now common (Table VII-1).

The fish fauna of Lake Michigan, as the early settlers found it, was dominated by salmonids of which the whitefish, lake herring, and lake trout were the most abundant. Since that time, several species of coregonines have become rare or have disappeared from the Lake. The lake sturgeon is now rare, the native lake trout population was exterminated and the Michigan grayling, apparently an anadromous species, is now extinct (See Wells and McLain, 1973 for a detailed description of these and other changes in the fish stocks of the Lake).

Table VII - 1. Fish fauna previously or currently common to Lake Michigan.[1]

COMMON NAME	SCIENTIFIC NAME
Sea lamprey[2]	*Petromyzon marinus*
Lake sturgeon	*Acipenser fulvescens*
Alewife[2]	*Alosa pseudoharengus*
Lake whitefish	*Coregonus clupeaformis*
Blackfin cisco	*Coregonus nigripinnis*
Deepwater cisco	*Coregonus johannae*
Longjaw cisco	*Coregonus alpenae*
Shortjaw cisco	*Coregonus zenithicus*
Bloater	*Coregonus hoyi*
Kiyi	*Coregonus kiyi*
Shortnose cisco	*Coregonus reighardi*
Lake herring	*Coregonus artedii*
Round whitefish	*Prosopium cylindraceum*
Lake trout	*Salvelinus namaycush*
Brook trout	*Salvelinus fontinalis*
Rainbow trout (steelhead)[2]	*Salmo gairdneri*
Brown trout[2]	*Salmo trutta*
Coho salmon[2]	*Oncorhynchus kisutch*
Chinook salmon[2]	*Oncorhynchus tshawytscha*

[1] According to Wells and McLain (1973).

[2] Species that have gained access to the lake and have become abundant during the period of historical record.

Table VII - 1 Continued.

Rainbow smelt[2]	*Osmerus mordax*
Northern pike	*Esox lucius*
Carp	*Cyprinus carpio*
Emerald shiner	*Notropis atherinoides*
Spottail shiner	*Notropis hudsonius*
Longnose sucker	*Catostomus catostomus*
White sucker	*Catostomus commersoni*
Channel catfish	*Ictalurus punctatus*
Bullheads	*Ictalurus* spp.
Trout-perch	*Percopsis omiscomaycus*
Burbot	*Lota lota*
Ninespine stickleback	*Pungitius pungitius*
Smallmouth bass	*Micropterus dolomieui*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*
Freshwater drum	*Aplodinotus grunniens*
Slimy sculpin	*Cottus cognatus*
Spoonhead sculpin	*Cottus ricei*
Fourhorn sculpin	*Myoxocephalus quadricornis*

[2]Species that have gained access to the lake and have become abundant or common during the period of historical record.

While many of the native fishes of the Lake were declining in abundance, several exotic species became established and reached high levels of abundance. In some instances, these exotic species caused or hastened the decline of native stocks by preying on them or competing with them for food or space. The carp was one of the earliest deliberate introductions to the Great Lakes basin. It is mainly a fish of the tributaries and the shallow inshore waters and its effect on the native fish populations of the Lake, although probably detrimental, has not been adequately measured. The rainbow smelt, another deliberate introduction, has become a food, sport and forage fish; however, it is also credited speculatively with causing major declines in the lake herring population. The sea lamprey, a marine species that apparently migrated into the Great Lakes through man-made canals in the 1800's, became abundant in Lake Michigan in the middle 1940's. This species was largely responsible for the decline in abundance of a number of desirable native species and the extinction of the native lake trout and several species of large coregonines. The alewife, a marine invader, was first seen in moderate numbers in the Lake in the middle 1950's after the lamprey had eliminated the larger predators. The alewife reached peak abundance in the fall of 1966, but following a massive die-off that occurred in 1967, the population seems to have stabilized at a substantilly lower level of abundance. The alewife competes for food with many native species and has apparently caused major changes in the zooplankton composition of the Lake (Wells, 1970). The alewife is also the most important food item in the diet of trout and salmon in Lake Michigan.

Control of the sea lamprey and the relatively stringent restrictions placed on the commercial fishery in Lake Michigan since the late 1960's have permitted the recovery of various lake spawning species including the whitefish. Control of the sea lamprey and the presence of a large forage stock of alewives set the stage for the rehabilitation of the lake trout and other anadromous stocks of trout in the Lake. Coho and chinook salmon were successfully introduced in 1966-1967 followed by the apparent successful establishment of the Atlantic salmon in the Lake in 1972.

Utilization by Man

A commercial fishery has existed in Lake Michigan at least since 1843. According to Wells and McLain (1973) the earliest fishery was conducted for whitefish, which were abundant in the inshore waters of the lake. Total commercial fish production for Lake Michigan in 1879 (the first year of record) was nearly 24 million pounds, of which about half was whitefish. Production increased to about 41 million pounds annually in 1893-1908 due primarily to increases in the catch of lake herring. Production fell to about 24 million pounds annually in 1911-1942.

Total production averaged 26 million pounds annually during 1943-1965, but the period was one of marked instability and change in the fishery. During those years the lake trout disappeared from the commercial catch. Whitefish stocks declined to very low levels and the species virtually disappeared from the catch for several years. The catches of smelt and walleye rose briefly to record levels, and the alewife made its first appearance as a species of commercial importance in the lake.

Total production averaged about 51 million pounds annually in 1966-1970 and 46 million pounds annually in 1971-1973. Of the total production, alewives averaged 42 million pounds annually in 1966-1970 and 32 million pounds in 1971 - 1973.

Because of the depleted condition of some fish stocks and the need to reserve other stocks for the rapidly growing sports fishery, the future of the commercial fisheries of Lake Michigan can at best be called uncertain.

Angler interest in Lake Michigan is now at an all time high because of the trout and salmon management programs, and there is every indication that this interest will continue to grow and be a major determinant for management of the fish stocks of the Lake. Angler catches, which in the 1950's and early 1960's probably reached a record low for the Lake, began to climb with the partial rehabilitation of the lake trout and steelhead stocks, the establishment of stocks of lake-dwelling brown trout, and the successful introduction of Pacific salmon. In 1972, the most recent year for which published records are available, the angler catch in the State of Michigan's waters of Lake Michigan was 347,000 steelhead trout, 311,000 lake trout, 610,000 coho salmon, and 234,000 chinook salmon (Michigan Department of Natural Resources, 1973). Few statistics are available on the sport fishery for other species in the Lake, but the once productive inshore (pier) fishery for yellow perch is again attracting large numbers of anglers in some areas and daily catches of up to 100 fish per angler are being reported.

Effects of pollution and the electric power generating industry on fish stocks

In the early days of settlement, untreated sewage and sawmill wastes were problems in river and harbor mouths and adjacent areas and the major effect on the fish populations of the Lake was probably felt by anadromous species. Large pockets of heavy pollution from municipal and industrial sources exist today. The absence of desirable species and the lowered fishery productivity in Southern Green Bay, for example, can be attributed to pollution. Pollution of the entire Lake by DDT, mercury, PCBs and other conservative or long-lasting contaminants from point and nonpoint sources is also a matter of great concern. A number of species in the Lake have contaminant levels that exceed safe levels set by the FDA for human consumption.

Recently the effects of electric power generation on the Great Lakes and their biota have come under scrutiny. Serious inquiry into these effects was initiated in the 1960's when it was recognized by resource agencies in the basin that future waste heat discharges to the Lake might become large enough to pose a threat to water quality and to the fisheries of the lakes. Present concern over the adverse effects of once-through cooling includes not only the effects of waste heat discharges on the Lake and its biota but also losses that occur when fish and other organisms are drawn into plant cooling systems. The kinds of damage that may occur to fish and other organisms as a result of electric power generation at steam electric stations have recently been summarized by Edsall and Yocom (1972) and by Clark and Brownell (1973).

An adequate and reliable demonstration of the effects of electric power generation with once-through cooling on the fish populations of Lake Michigan has not been made. Utility company records show that large numbers of fish are killed at plants now operating with once-through cooling on Lake Michigan, but information on the distribution,abundance,and dynamics of the fish stocks of the Lake needed to assess the significance of these measured mortalities at power plants is not yet available. Consequently, the present basis for concern over the adverse effects of existing power plants on the fishery productivity of the Lake is partly conjectural.

Lack of an empirical assessment of the impact of cooling water use at existing power plants on the fishery productivity of the lake makes it impossible to accurately predict the consequences of future increased use of the lake water for cooling. Nevertheless, the available information suggests that the electric power generating industry will have a serious impact on the fishery productivity of the Lake in the future unless alternatives to open-cycle cooling are employed (Great Lakes Fisheries Lab, et al.1970). For example, withdrawals of cooling water and all discharges of wasteheat by power generating plants on the shores of Lake Michigan occur within the littoral area. In Lake Michigan, these littoral waters are equal in volume to only 0.4 percent of the volume of the whole lake. If projected power demands were met only with plants using once-through cooling, the cooling water withdrawals by the electric power industry on Lake Michigan in the year 2000 would be about 91,000 cubic feet per second. This rate of withdrawal would require passing a volume equivalent to one percent of the littoral water of the entire lake through the cooling systems of power generating plants daily (Great Lakes Fisheries Lab, et al.1970). Because damage is probably proportional to the cooling water use rate, extremely high mortalities of fish in the littoral waters of Lake Michigan could be expected if these waters were used for cooling at a rate of one percent per day.

Although the littoral waters of the lake are only a small fraction of the total lake water, these littoral waters are vital to the existence of almost every species of Great Lakes fish.

Only the deep water sculpin and a few species of deep water chubs are absent from the littoral waters. Fishes such as yellow perch, smallmouth bass, northern pike, and walleyes, are all relatively permanent residents of the littoral waters. Other species such as the lake trout and most of the whitefishes use the littoral waters during the colder portion of the year as feeding and spawning grounds and as nursery areas for their young. Fishes that spawn in tributaries of the lake must pass through the littoral waters on their way to and from the spawning grounds and their offspring must pass through these waters when they migrate to the Great Lakes for the rapid growth phase of their lives. Thus the littoral waters exert considerable influence on the fishery productivity of the Great Lakes and there is a great need to provide protection for fish and their food organisms in this important area of the lake.

Principal Problem Areas

Steam electric generating plants operating with once-through cooling create both intake and discharge "problem areas" for Lake Michigan fish (see Edsall and Yocom 1972 for a review). Although the Fisheries Section of this panel report was restricted to consideration of only the effects of power plant cooling system discharges, it is necessary to present at least a general outline of both intake (Fig. VII - 1) and discharge (Fig. VII - 2) problem areas because the intake and discharge problems at most plants on Lake Michigan are not clearly separated. Many of the fish taken

Figure VII - 1. Principle problem areas associated with power plant intakes.

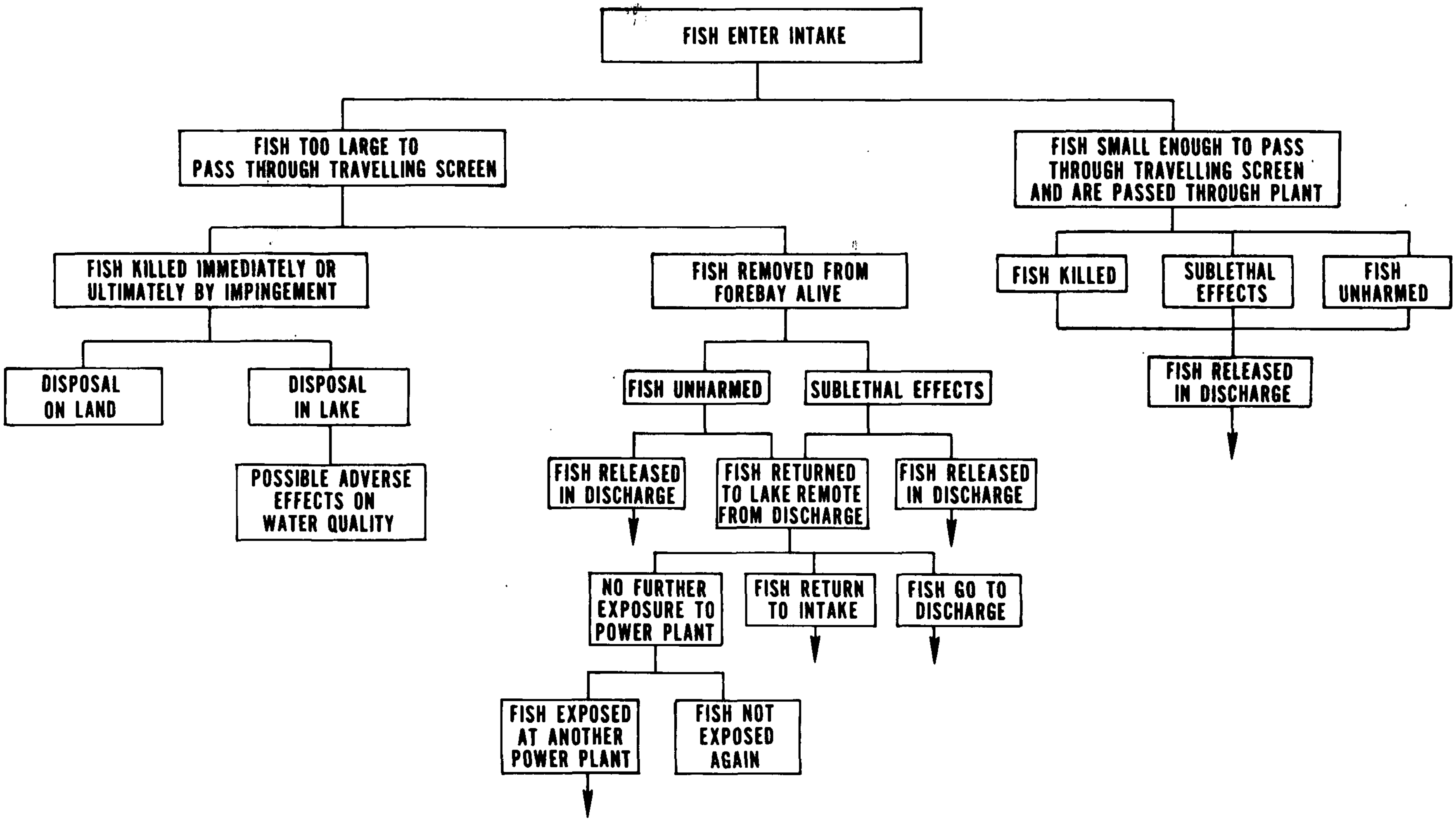
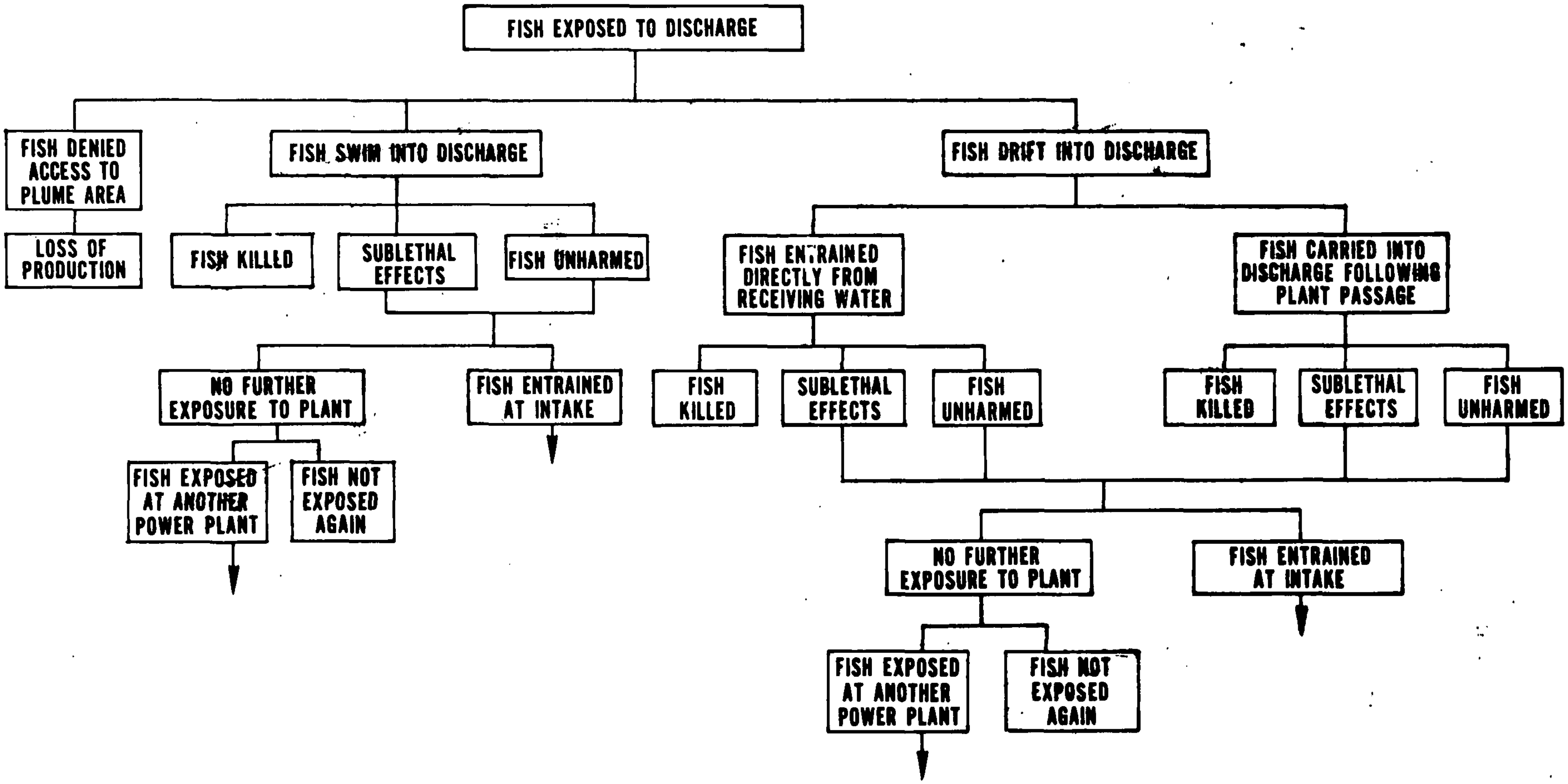


Figure VII - 2. Principle problem areas associated with power plant discharges.



in at the intake may pass into the discharge, and fish present in the discharge may be drawn into the intake when the effluent is accidentally or deliberately recirculated.

Although recirculation is recognized as undesirable because it may result in increased entrainment and impingement of fish, the seriousness of the problem in Lake Michigan appears to be virtually unknown. However, it is clear that all of the fish large enough to be impinged on the traveling screens of existing power plants on Lake Michigan are killed when they are drawn into these plants because none of these plants are now equipped with devices that would permit returning these entrapped or impinged fish to the lake alive and unharmed.

The problem of the combined effects of plant passage and subsequent exposure to adverse conditions in the discharge plume is one that has received general recognition. However, until the level of mortality caused by plant passage alone is determined, it is impossible to state whether the additional exposure obtained in the discharge plume is important to these fish. The available information (see Coutant and Kedl 1975, Beck and Miller 1974, Marcy 1973, 1974, and Clark and Brownell 1973) suggests that fish small enough to pass through the traveling screens will probably experience high to very high mortality during passage through the plant because of exposure to high lethal temperatures, hydraulic or physical mauling (caused by the pumps and collision with internal surfaces of the cooling system) and lethal concentrations of chlorine.

A more thorough discussion of intake problem areas is presented in Section VIII of this report.

Fish that are entrained at the discharge and those that survive passage through the plant cooling system are exposed to various conditions that may threaten their survival. These include:

1) hydraulic mauling, particularly at plants with a high velocity discharge (Clark and Brownell 1973),
2) elevated temperatures (Coutant and Kedl 1975, Clark and Brownell 1973, Edsall and Yocom 1972),
3) chlorination (Basch and Truchan 1973, Stober and Hanson 1974),
4) gas embolism (Coutant and Kedl 1975),
5) predation: those that are incapacitated to some extent, even temporarily, may have reduced ability to avoid predators and have an increased probability of being eaten by predators concentrated in or near the plume (Coutant, et al. 1974, Yocom and Edsall 1974, Coutant 1973, Hocult 1973, Sylvester 1972, Gritz 1971), and
6) displacement: discharge currents may interfere with movements of young fishes and prevent them from reaching required or favored habitat (see Houde and Forney 1970, Houde 1969b).

The discharge of heated water from a power plant will cause marked changes in the distribution of fish in the vicinity of the plant. Most Lake Michigan species appear to be attracted to the heated discharge during a portion of the year and are absent from or avoid the discharge during the rest of the year (Romberg and Spigarelli 1973,Edsall and Yocom 1972). Fish attracted to and residing in a heated plume in Lake Michigan could be killed or damaged in a number of ways. For example:

1) fish encountering a sharp thermal gradient may be unable to respond and may be killed by high temperature (Gall-away and Strawn 1974, Meldrim and Gift 1971, Van Vliet 1956),
2) fish acclimated to high discharge temperatures, especially in winter, die or are debilitated by cold shock if the plant heat output is interrupted (Coutant, et al. 1974, Clark and Brownell 1973, Edsall and Yocom 1972),
3) high gas saturation of the discharge waters, especially in winter, may create conditions in which fish would be killed by gas bubble disease (Otto 1973, DeMont and Miller 1971),
4) chlorination of the cooling water may kill fish, or drive them from the discharge area (Basch and Truchan 1973); those driven from the discharge in winter could suffer cold shock (see 2 above), or experience reduced reproductive success (Arthur and Eaton 1971),
5) fish residing at elevated discharge temperatures will

concentrate pollutants, including mercury and DDT, more rapidly than those living at lower temperatures (Reinert, et al.1974, MacLeod and Pessah 1973),

6) toxicity of some pollutants is higher at higher temperatures (Stober and Hanson 1974, MacLeod and Pessah 1973, Macek, et al.1969, de Sylva, 1969).

7) the incidence and lethality of various fish diseases may increase with temperature (Fryer and Pilcher 1974, Plumb 1973, Ordal and Pacha 1963),

8) reproductive success of yellow perch and possibly other species may be reduced by exposure of mature adults to overwintering temperatures exceeding those found in nature (Brungs 1971, Hubbs and Strawn 1957, unpublished data, National Water Quality Laboratory, Duluth, Minn.),

9) reproduction times may be altered significantly (Adair and Demont 1970, DeVlaming 1972),

10) demersal eggs spawned in areas with even small temperature increases (including those areas impacted by winter sinking plumes) may die (Powles 1974) or will have accelerated embryonic development and hatch early (Colby and Brooke 1973, Brooke unpublished MS, Berlin etal. unpublished MS); the fry may be out of phase with their planktonic food supply and a larger than normal percentage may be lost to starvation,

11) during the winter months, fish residing in heated effluents may lose weight because their metabolism will be high and their food supply may be low (Kelso 1972, Brett

et al.1969, Marcy 1967),

12) migratory fishes may spend a great deal of time at various thermal discharges thereby altering migration patterns or schedules and substantially increasing their exposure to abnormal temperatures (Spigarelli and Thommes 1973).

Program for Measurement of Effects

Introduction and Research Priorities

The research program is divided into five major subsections: Before and After Studies, Intensive Plume Studies, On-site Bioassays, Laboratory Studies, and Lakewide Assessment Studies. The research activities described in these sections are complementary and are intended (collectively) to provide the basis for measuring a portion of the effects of power plant discharges on the fish of Lake Michigan. (A complete description of the effects of power plant operation on Lake Michigan fish and the assessment of the biological significance of these effects requires that data also be obtained on intake damage to fish and on intake and discharge damage to the organisms that serve as food for these fish.)

In each of the five sections we present a list of questions that we believe should be answered for each cooling water use site. It may be possible to answer some of these questions adequately with information that already exists in the literature (for example, published information on the low temperature tolerance of yellow perch suggests that the species would not be susceptible to cold shock death at Lake Michigan power plants) or from information collected at nearby sites. Questions that cannot be adequately answered with existing information define the research needs for that site. These questions are grouped and assigned numerical priority rankings to reflect a logical order for programming research efforts. Some reordering may be necessary when these guidelines are put into practice at a particular site because these priorities must be to some extent site specific.

Definitions of numerical rankings are as follows:

Priorities

1 - Highest priority consistent with achieving the primary LMCWSP goal of determining the effect of cooling water use on the Lake Michigan ecosystem.

2 - High priority item directly supporting priority 1 items.

3 - Intermediate priority item generally supporting priority 2 items.

Categories

1 - Questions which are answerable with currently available data; additional research is not needed.

2 - Questions which may be answerable with data currently available.

3 - Questions which are not answerable with currently available data; additional research is needed.

Qualifying Statement on Program Orientation

This section of the report provides specific methodologies for use as guidelines in the demonstration of the possible adverse effects of once-through cooling on the fish populations of Lake Michigan. Because of the specific nature of these recommendations, it is appropriate to preface them with some qualifying remarks.

Answers to many of the questions posed in the following sections of this subcommittee report can be best obtained through the use of conventional time-tested sampling gear and methods that are of universal acceptance among professionals and resource agencies with long histories of experience with the Lake Michigan fishery. Adoption by the electric power generating industry of these methods and types of sampling gear recommended in the guidelines will provide continuity of record and permit direct comparison of fishery data with data collected over the past several decades by fishery resource agencies.

Despite the need for standardization of gears and methodologies, differences among sites and differences in the design, capacity, and operating characteristics of the power generating plants on the Lake, may make it impossible to carry out identical fishery sampling procedures at all sites. Studies initiated before these guidelines were developed may not conform to these guidelines, but data from these studies may prove to be adequate for the evaluation of certain local effects at the study site. It is also clear that methodologies needed to answer some of the questions posed in the following text (see for example the section dealing with Intensive Plume Studies) have not been developed and considerable latitude in approach toward answering these questions is desirable and necessary. Deviations from prescribed procedures and criteria of performance, however, should not be made without clear justification, nor should they be made in a manner that prevents acquisition of data directly comparable and equivalent to data that would be obtainable following the methodologies set forth herein.

The level of field sampling effort required to reliably describe fish stocks will vary greatly among species and life stages of each species, and it is virtually impossible to specify the level of effort required at a given site without knowledge of the kinds and numbers of fish found on the site and the uses they make of the site. Generally, the level of field sampling effort expended to answer the questions posed in the methods section of this report should at least be high enough to permit detection of true minimum differences of 20 percent at the 5 percent probability level. The amount of field sampling effort specified herein may require adjustment to achieve this degree of sampling precision.

Methods of Investigation

Before and after studies

This section describes methodology to determine the size and composition of the fish stocks at the study site before plant operations begin and following the onset of plant operation, and to determine the uses fish make of the site and the extent to which these uses are altered by plant operation. The recommended period of study is at least three years prior to, and three years subsequent to full plant operation. The sampling grid (Figure VII - 3) is scaled for use at a site occupied by a plant with a cooling water use rate of 3,000 - 4,000 cfs and a temperature rise across the condensor of approximately 11C.

A rescaling of this grid and a change in the effort would be necessary at sites where the amount of cooling water used or the amount of waste heat rejected was markedly different.

Questions to be Answered

1. What kinds and numbers of fish are found in the vicinity of the plant site and how does this change diurnally, seasonally, annually, and as a result of plant operation? (Priority 1, Category 2)

    a. what is the age, size, and sex composition of these populations and how does it change diurnally, seasonally, annually, and as a result of plant operation? (Priority 2, Category 2)

    b. what use is made of the site as a spawning, nursery, feeding or over-wintering ground or as a migration route

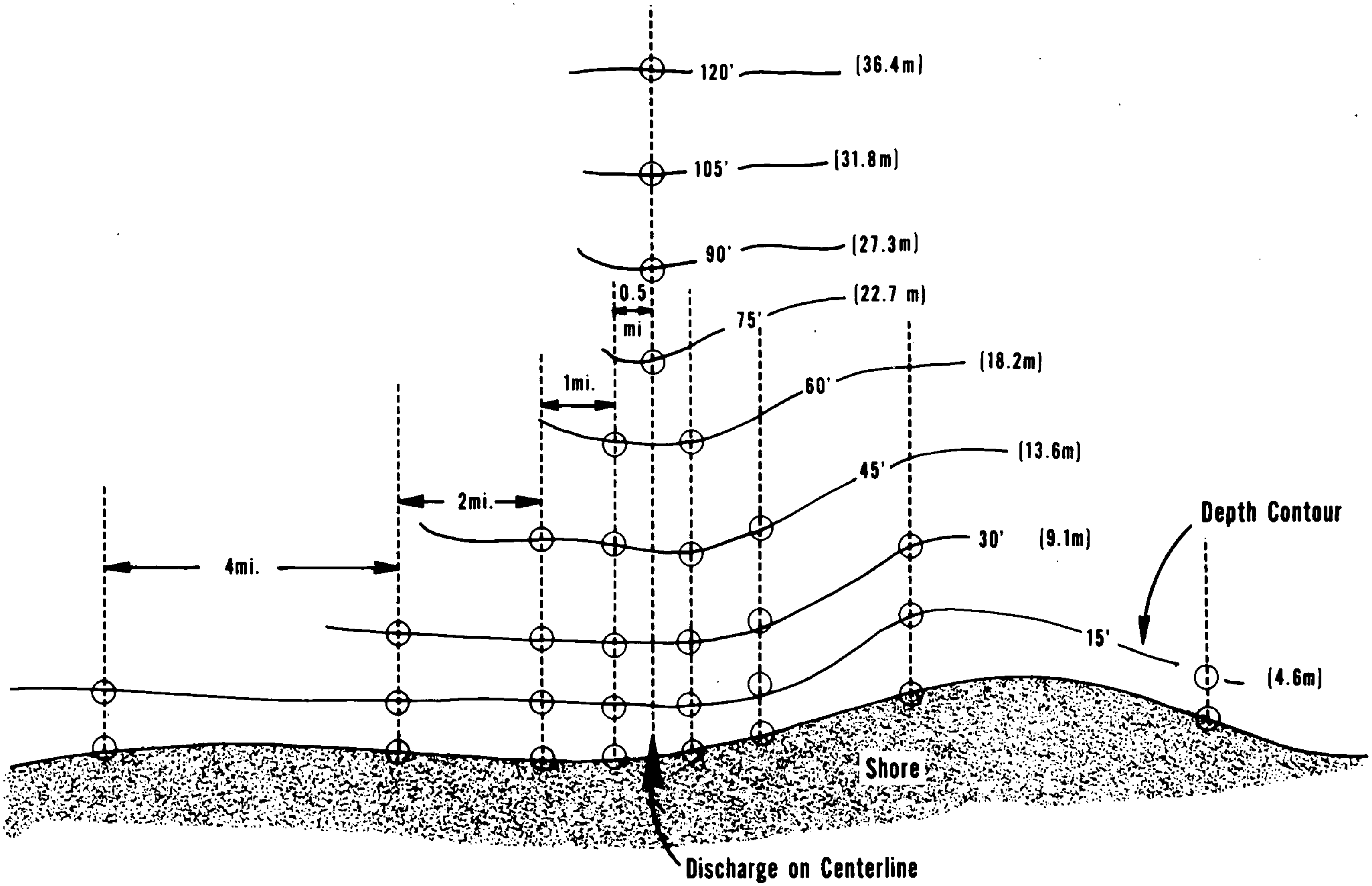


Figure VII - 3. Suggested sampling stations for fisheries investigations of Lake Michigan.

by fish, and does this change as a result of plant operation? (Priority 1, Category 2)

c. what are the age-specific food habits of each species in the vicinity of the site and how do they change seasonally and annually, and do these change as a result of plant operation? (Priority 2, Category 2)

Materials and Methods

1. Trawl sampling of juvenile and adult fish
   a. Sampling Location - All stations shown in Figure VII - 3.
   b. Gear
      1) Sixteen-foot semiballoon bottom trawl for stations 0 - 10 feet; 16-ft headrope, 19-ft footrope (actual spread approximately 12 ft), net made of nylon netting of the following size mesh and thread; 1-1/2" stretched measure No. 9 thread body, 1-1/4" stretched measure No. 15 thread cod end, 1/2" stretched measure No. 63 thread knotless nylon innerliner, head and foot ropes of 3/8" diameter Poly-dac net rope with legs extended 3 ft and wire rope thimbles spliced in at each end with shackles attached to fasten net onto doors. Six 1-1/2" x 2-1/2" Ark floats spaced evenly on center of headrope. 1/8" galvanized chain hung loop style on footrope. Net treated in green copper net preservative. Trawl is available from Marinovich Trawl Co., Inc., 1317 East First Street,

Biloxi, Miss. 39533*.

2) Thirty-nine foot bottom trawl for all other stations in Figure VII - 3: 3/4 size Yankee standard No. 35. Headropes, 39 ft; sweep, 51 ft; wings and squares, 3-1/2 inch stretched, 21 thread nylon; belly, 2-1/2 inch stretched, 21 thread nylon; cod end 1/2 inch stretched nylon seine netting, 12 ft in length. Trawls are available from Gloucester Grocery and Boat Supply Co., Inc., 17-21 Rogers Street, Gloucester, Mass. 01930*.

c. Sampling frequency

1) Collect at all stations monthly.

2) Make duplicate 10-minute trawl tows on the bottom parallel to the bottom contour at each station. Make all tows for each depth on the same day.

3) Record vertical temperature profile with a bathythermograph and record other pertinent physical data at the time of each trawl haul.

d. Sample processing

1) Separate catch into groups by species and when possible into subgroups by age (young-of-the-year, yearlings, and over-yearlings) on the basis of size.

2) Count all fish in each subgroup and obtain a total weight for the subgroups; exception: when the catch of any subgroup is too large to make enumeration practical, obtain a total weight of the subgroup,

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withdraw a subsample and obtain a total weight and count, so as to permit determination of total number of individuals in the subgroup by simple proportion.

3) Process the catch made during each visit to each station as needed to reliably determine the length, weight, sex, state of sexual maturity and age of individuals in each subgroup.

   a) Length - Record total length (distance from tip of snout to tip of caudal fin with lobes compressed) in mm (inches) to nearest whole mm (0.1 inch).

   b) Weight - Record fresh (wet) weight in grams (ounces) to the nearest gram (0.1 ounce).

   c) Sex and state of sexual maturity.

   d) Age determination - The age of the younger subgroups can often be estimated from the length frequency distribution for the species. Scale samples provide a reliable method for determining the age of most fish.

      Remove 10-20 scales from the left side of a representative number of fish in each subgroup below the origin of the dorsal fin and midway between the insertion of the fin and the lateral line. Although this should be the best location for obtaining scale samples for age and growth studies, it is recommended that this be verified for the species and stocks being sampled in each geographic area, before large numbers of the scale samples are collected.

Place the scales from each fish in an individual envelope and record on the envelope the species sampled, the location, date, method of capture, and the individual length, weight, sex, and state of sexual maturity.

A plastic impression of the scale can be made in the laboratory to facilitate age determination (Smith, 1954). A roller for producing plastic impressions is available from Wildlife Supply Co., 301 Cass Street, Saginaw, Mich. 48602*.

Back calculation of body length in earlier years of life can be accomplished using the scales (Hile 1941, Tesch 1968).

4) Routine observations

   a) Record any occurrence of disease or infestation by parasites.

   b) Examine all trout and salmon (and other fishes for which tag and release studies are being conducted) for fin clips, tags, or other marks, and record mark, size and conditions of each marked fish.

5) Preserve samples for laboratory analysis as needed, after gathering the data prescribed in previous

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sections.

a) Feeding habits

Kill fish selected for analysis and preserve stomach contents immediately in 10 percent formalin. Small fish can be preserved whole in formalin. These fish should have the body cavity punctured or slit or injected with formalin to facilitate preservation (retard digestion) of their stomach contents. For specimens too large to preserve and store conveniently, record length and weight and assign a code number. Remove the stomach and preserve it in 10 percent formalin after labeling with the code number.

Examine stomach samples, and record the frequency of occurrence and the total volume of each kind of organisms eaten, following the methods of Windell (1968), or Wells and Beeton (1963).

b) Determination of contaminant level

Kill fish selected for analysis and preserve by freezing.

Perform analyses for PCBs, pesticides, heavy metals, etc., as needed, according to methods described in Section IV of this report.

c) Fecundity estimates

Small fish can be preserved whole in 10 percent formalin and the ovaries can be removed and examined in the laboratory. Large fish should be weighed, measured, and given a code number. The ovaries can then be removed, weighed fresh, and preserved in 10 percent formalin or in Gilson's fluid (Bagenal and Braum, 1968).

Determine fecundity according to methods given in Bagenal and Braum, 1968.

The use of fecundity data (in conjunction with information on the total number of eggs spawned and the size and sex composition of a population may be used to estimate fish stock abundance (Saville 1964).

e. Sample analysis

1) Population size estimate

a) The catch statistics from trawl samples (together with those from gill net, seine, plankton net, and pumped samples--see later sections) can be applied toward an estimate of total population based on estimates of catch per unit effort. Some methods of estimating population from catch statistics are given by Ricker (1958), Chapman (1961), Saville (1964), Robson and Regier (1968), Beverton and Holt (1957) and Gulland (1969).

b) Other analyses concerning biological interrelations will be outlined in later sections.

2) Use data collected from trawling (and from gill netting, plankton netting, seining, pumping, and tagging--see later sections) to determine the importance of the study

area as a spawning and nursery ground, and to determine the seasonal size distributions of the resident fish populations and some of the interrelations of these populations.

2. Gill net sampling of juvenile and adult fish

   a. Sampling location

      1) Bottom gill net sets at all stations 15 ft and deeper as shown in Figure VII - 3.

      2) Oblique sets along center line of Figure VII - 3 at 30', 60', and 120'.

   b. Gear

      1) Standard bottom gill net gangs each including 50 linear feet of 1-1/2-, and 100 linear feet each of 1-1/2-, 2-, 2-1/2-, 3-, 3-1/2-, 4-, 4-1/2-, 5-, 5-1/2-, and 6-inch mesh. Each mesh size is a separate net and all of the nets are joined end-to-end, with nets of different mesh sizes interspersed randomly.

      2) Two oblique gill nets. One gang with 1-1/2 inch mesh and one gang with 4-1/2 inch mesh. Lengths will depend upon the water depth where fished.

      3) Specifications

         a) Net specifications are those proposed for standard bottom gill nets by the Great Lakes Fishery Commission and currently used by the Michigan Department of Natural Resources. The net is 6 ft deep (float line to lead line). Table VII - 2 contains specification for each mesh size.

Table VII - 2. Gill net specifications for various mesh sizes.

Stretched mesh size (inches)	Net length (feet)	Twine Size	No. of meshes deep
1-1/2	50	110/3	55
2	100	110/3	41
2-1/2	100	210/2	33
3	100	210/2	27
3-1/2	100	210/2	23
4	100	210/3	20
4-1/2	100	210/3	18
5	100	210/3	16
5-1/2	100	210/3	15
6	100	104 thread nylon	13

b) All thread to be used in making this gill netting shall be nylon of American manufacture. Thread must withstand scalding process without injury. Stretched measure is in inches when wet, as measured with an 8-ounce sliding weight gauge. Measurement is to be made after webbing has been soaked in water for one-half hour or longer. Webbing is to be pre-shrunk and heat set, and knots must hold without slipping. Measurement shall be made of at least 10 different meshes chosen at random, but well away from the selvage for each piece of netting. Mesh sizes shall not vary over 1/32 of an inch. All netting must be double selvage top and bottom.

The netting is hung on No. 6 Starlite braided nylon maitre (or equivalent) with No. 9 t-spun nylon seaming twine (or equivalent). The nets are hung on the one-half basis, i.e., 200 feet of netting are hung on each 100 feet of unstretched maitre. Use regular aluminum gill net floats, and space 7-1/2 feet apart. Attach a 1/3 pound lead directly under each float.

All specifications refer to the nets after they are constructed. When the nets are being hung, the maitre should be under a tension of about 100 pounds; allowance therefore needs to be made for the stretch of the maitre so that when the tension is released 200 feet of netting will be on 100 feet of maitre, and the floats will be spaced properly.

c. Sampling frequency

1) Collect at all stations monthly.

2) Make three replicate sets at each depth (overnight sets) on successive days.

3) Measure water temperature and other pertinent physical factors at the time of each net set.

d. Sample processing

1) Separate catch by species and mesh size and whenever possible by age (young-of-the-year, yearlings, and older); for oblique sets separate catch by depth also.

2) Determine age composition, length, weight, state of sexual maturity and fecundity, and stomach contents of each subgroup or an adequate subsample of each age group.

If necessary preserve subsamples in 10 percent formalin for processing at a later date.

3) See previous section on sample preservation.

e. Sample analysis - See previous section on sample analysis.

3. <u>Seine sampling for juvenile and adult fish</u>

a. Sampling locations - All shoreline stations shown in Figure VII - 3.

b. Gear

1) Gear should include a nylon bag seine, 1/2 inch

square mesh, 100 feet long and 8 feet deep with an 8' x 8' x 8' bag of 1/4 inch mesh in the center. Seine should be constructed of strong (50 - 80 lb. test) mesh. The bottom line should be weighted to hold the net on the bottom while the net is being pulled; floats should be numerous enough to prevent sections of the top line from submerging. A lead line of 30 strands of "Regal Rope" around a polypropylene core will conform to most bottom types. One supplier of such nets is: The Nylon Net Company, P.O. Box 592, Memphis, Tenn. 38101*.

2) Larger seines (12' x 1000') should be used where the capture of large salmonids is probable.

c. Sampling frequency

1) Collect at all stations monthly.
2) Make triplicate seine hauls across contours at each station on the same day.
3) Estimate wave heights and measure water temperature, turbidity, and other pertinent factors at the time of each seine haul.
4) Sample processing - See previous sections.
5) Sample analysis - See previous sections.

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*This does not constitute endorsement by the Lake Michigan Cooling Water Studies Panel or the authors.

4. Plankton net sampling for fish fry

a. Sampling locations

All stations on the 15 foot depth contour should be sampled as shown in Figure VII - 3, plus one station at the intersection of the centerline and each of the following depth contours: 15, 30, 45, 60, 75, 90, 105, and 120 feet.

Sample the 0 (surface), 1-, 2-, 4-, 6-, 8-, and 10-meter depth levels within the water column at each of the above stations, as water depth permits.

b. Gear

Gear should include a one-half meter nylon plankton net, 351 micron Nitex with 1/2-m ring diameter, nylon covered stainless steel bridle, and PVC bucket 5" in diameter and 8" long with 351 micron stainless steel bolting cloth window. Length of the net is 2.5 meters. One source of nets of these specifications is: Wildlife Supply Company, 2200 South Hamilton Street, Saginaw, Michigan 48602. The approximate cost is $130.00*.

c. Sampling frequency

1) Sample all stations weekly from May through September.

2) Make duplicate 5-minute tows at each depth at each station on the same day.

3) Measure water temperature and other pertinent physical factors at the time of each plankton net tow.

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d. Sample processing

1) Rinse organisms adhering to inside surface of net body into bucket and preserve them in 10 percent formalin.

2) Sort by species and developmental stage (prolarvae, larvae, post larvae, or juvenile).

3) For each developmental stage: enumerate, measure an adequate sample of individuals (total length in mm), and obtain a total dry weight.

e. Sample analysis - See previous section.

5. <u>Pump sampling of fish eggs</u>

a. Sampling locations

All stations shallower than 75 feet shown in Figure VII - 3.

b. Gear

Centrifugal lift pump passing bottom water through #30 screen with a flow meter to record volume of water samples.

Specifications - None available at this time.

c. Sampling frequency

1) Make duplicate 5-minute pumpings on the bottom along the depth contour at each station.

All stations must be sampled on the same day.

2) Sample weekly, May 1 - August 1 and again on December 15 and March 1.

3) Measure water temperature and other pertinent physical factors at the time of each pumping.

d. Sample processing

1) Sort eggs into major size (species) groups separating live (translucent) eggs from those that are dead (opaque, fungused, etc.) and record the number in each subgroup.

2) Measure the diameters of an adequate sample in each subgroup of live eggs.

3) Record the developmental stage of live eggs in each subgroup, if possible.

e. Sample analysis - see previous sections.

6. <u>Tagging or Marking of Fish</u>

Fish captured at the site can be tagged (or marked) to provide information on the local movements and lakewide migration patterns. Although some species, including the Pacific salmons, are known to range widely throughout the lake, the extent to which many important native species undertake local and lakewide movements is poorly known. Knowledge of whether the fish found at a cooling water use site are permanent residents of the site or simply migrants passing through the area is important in evaluating the impact of the plant on the fish populations of the lake.

a. Sampling location

Capture, tag and release fish at any of the stations shown in Figure VII - 3, but concentrate on those stations shallower than 75 feet.

b. Gear

1) Tags and marks.

a) Fin clipping may be suitable for short term population size data on fish other than trout and salmon (these salmonids are already being fin clipped for various studies by state agencies; further clipping would cause confusion).

b) Anchor spaghetti tags (FLOY tags*) or other commercially available tag where recognition of individual fish is necessary (i.e., growth and movement studies), or where fin clipping is not recommended (Rounsefell and Kash, 1946).

c) Dyes or pigments

Specifications:

Imbed biologically inert fluorescent pigment in fish scales or integument with compressed air. This method permits simultaneous marking of large numbers of fish with a minimum of fish handling; the method may be suitable for fish that are sensitive to handling or are too small for tags or fin clips. Pigments persist for over one year and fluoresce under black (ultraviolet) light. Pigments and spraying apparatus are available from:

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Wildlife Supply Co.*, and Day-Glo Color Corporation, 4732 St. Clair Avenue, Cleveland, Ohio 44103*. See Arnold (1966) and Jessop (1973).

d) Hot or cold branding - See Moav et al. (1960) and Raleight et al. (1973).

e) Radio or ultrasonic transmitters - See studies of residence time in thermal plumes discussed on Page 280 (Intensive Plume Studies).

2) Capture and recapture equipment - Fish may be taken by any means that does not reduce their viability.

a) Seine - 30 ft seine (6' deep) with knotless mesh (1/2" or less) to reduce abrasion to capture fish. One source of such nets is the Nylon Net Co., P.O. Box 592, Memphis, Tenn. 38101*.

b) Trap or fyke net - Nylon net with 8' diameter mouth with 2 funnel-shaped throats on 2nd and 4th hoop. Wings 50' long. Whole net tarred. Mesh size 1". Such nets are available from Nylon Net Co., P.O. Box 592, Memphis, Tenn. 38101*. The approximate cost is $100.

c) Electrofishing - We can make no specific recommendations at this time.

d) Hook and line - As appropriate.

c. Sampling frequency

1) Tag and release fish as frequently as is needed to permit adequate description of the movements of fish using the site. Record data and location of release

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and if possible length and weight of each fish.

2) Recapture as part of general survey.

d. Sampling processing

1) Record any marked fish taken, the date and location of capture, and their lengths, and weights if possible.

2) Minimize handling; anaesthetize fish if necessary to prevent injury to fish during handling.

3) Release fish at capture site unless site-specific requirements indicate displacement studies of marked fish are also desirable.

e. Sample analysis

Data on time and location of recapture should give indications of patterns and rates of movement or migration and thus help determine whether populations found at each site are local or transient. Further information on analytical procedures is found in Spigarelli and Thommes (1973).

Intensive Plume Studies

These studies are designed to describe the fish community in the discharge plume and the area immediately surrounding the plume and will determine the behavioral and pathological responses of fish to the physical, chemical, and biological environments that exist in the plume.

It is difficult to present a detailed sampling plan that permits a reliable characterization of the fish populations of heated plumes, because adequate physical plume measurements (including data on sinking plumes) are not available for most of the plants now operating (or under construction) on Lake Michigan; furthermore, fish populations in and around these plumes have received little study until relatively recently. In general, the sampling gear and methodologies described elsewhere in this report can be successfully adapted to local conditions for use in sampling the plume populations; new approaches such as electronic plume mapping and fish locating and radio tracking may also be needed.

Questions to be answered

1. What kinds and numbers of fish are residing in the discharge plume; and what are the diurnal, seasonal, and annual patterns and trends? (Priority 1, Category 3)
    a. What is the age, size, and sex composition of each species composing the resident population and what are the diurnal and seasonal trends? (Priority 2, Category 2)
    b. What are the residence times within specific isotherms in the plume, of these fish (i.e., to what temperatures are these fish acclimated) and what are the diurnal, seasonal, and annual trends? (Priority 1, Category 3)
    c. What percentage of the fish residing in the plume during the colder months of the year are killed or

made susceptible to predation when plume temperatures rapidly decrease to receiving water temperatures, because of plant shutdown? (Priority 2, Category 3)

d. What percentage of fish killed by cold shock float on the surface where they are visible? (Priority 1, Category 3)

e. What percentage of the fish residing in a discharge plume are killed, incapacitated, or driven out of the plume during chlorination? (Priority 2, Category 3)

f. What percentage of the fish resident in the plume during the colder months of the year develop gas bubble disease symptoms and are killed, made susceptible to predators, or driven out of the plume? (Priority 2, Category 3)

g. What percentage of the fish driven out of the plume during the colder months of the year suffer cold shock and death or are made more susceptible to predators residing outside the plume? (Priority 2, Category 3)

h. What percentage of the fish residing in the plume during the warmer months of the year, are killed or are shocked and made susceptible to predation when plume temperatures drop suddenly because of an upwelling that reduces intake water temperatures? (Priority 2, Category 3)

i. Do fish residing in a discharge plume accumulate a significantly higher level of contaminants such as mercury, PCBs, pesticides, etc., than fish in adjacent unheated lake water? (Priority 2, Category 3)

j. Does the discharge of waste heat into Lake Michigan lower the reproductive success of the lake's desirable species of fish, and/or increase the reproductive success of less desirable species of fish? (Priority 1, Category 3)

k. Are any of those species with low temperature or "winter chill" requirements (as determined by laboratory studies) found in heated plumes, and is their timing and duration of residence in the plume adequate to cause a reduction of reproductive success? (Priority 2, Category 3)

l. What kinds and numbers of fish spawn in areas impacted by the heated discharge? (Priority 2, Category 3)

m. What is the reproductive success of these fish and does it compare favorably with the success of members of the same stock that spawned outside the heated discharge, or that spawned in the area before the plant was constructed and waste heat was released? (Priority 2, Category 3)

n. What kinds and numbers of fish are prevented from spawning in their "ancestral" spawning areas by the heated discharge? (Priority 2, Category 3)

o. Will those fish that are prevented from spawning on an "ancestral" spawning ground (by the discharge of waste heat) be able to locate other suitable spawning grounds, or will their reproductive contribution be lost because they spawn in areas where the survival of eggs and fry will be low? (Priority 2, Category 3)

p. Will the addition of heat to spawning grounds accelerate embryonic development and cause premature hatching? (Priority 2, Category 1)

q. Will fry that hatch prematurely and out of phase with their normal food supply be able to find sufficient food to permit good growth and survival? (Priority 2, Category 3)

2. What effect does cooling water use have on the availability of suitable food and feeding conditions for Lake Michigan fishes? (Priority 2, Category 3)

   a. Do fish inhabiting heated plumes in winter lose significant amounts of weight due to the unavailability of food? (Priority 2, Category 3)

3. Do heated effluents or intake flows serve as barriers to fish movements? (Priority 3, Category 3)

4. Does the discharge plume affect the numbers and types of fish trapped at the intake? (Priority 2, Category 2)

5. How does winter deicing by recirculation of heated effluent influence patterns of residence or entrapment of fishes at the intake? (Priority 2, Category 2)

Materials and Methods

1. Conduct simultaneous plume mapping and echolocation of fish in the plume and in the unheated water surrounding the plume to determine the abundance of fish within specific isotherms. The methodology for a study of this type is currently under development at the Point Beach nuclear plant site by Argonne National Laboratory (Spigarelli, et al.,1973a; Romberg and Spigarelli, 1972)
   a. Sampling location

      The heated plume and surrounding unheated lake waters; sampling stations will not be geographically fixed because plumes change shape, size, and location in response to wind and lake currents and level of plant operation.
   b. Sampling gear

      Data are collected continuously by electronic means with shipboard equipment.
   c. Sampling frequency
      1) Conduct one or more complete plume mapping and fish echolocation surveys each month for at least one year until the seasonal patterns of distribution and abundance of the major fish species relative to stable plume isotherms are reliably established.
      2) Conduct additional surveys as needed to determine the effect of upwellings, plant shutdowns

and chlorination on the distribution and movements of the fish populations of heated plumes and adjacent waters.

d. Sample processing

See Spigarelli, et al. (1973a) and Romberg and Spigarelli (1972).

2. Conduct intensive fish sampling with nets (in conjunction with plume mapping and fish echolocation studies) to determine the size, density, composition, and condition of the fish populations in heated discharges.

a. Sampling location

Collect samples in the heated effluent and in the surrounding waters where temperatures are not elevated; whenever possible collect samples within discrete isotherms.

b. Sampling gear

Bottom trawls, gill nets (anchored and drifted), seines, lift and dip nets may be employed as the situation demands.

c. Sampling frequency - see previous sections

d. Sampling processing

1) Sort catch into subgroups by net mesh size, species, and life stage or age group (young-of the-year, yearling, and over-yearling) and obtain and record a total weight for each subgroup. Count and record all individuals in each subgroup when number is small, otherwise count and weigh

and record data for a representative sample of the subgroup to permit later expansion of the data by simple proportion.

2) Collect the following according to procedures outlined in Materials and Methods Section of Before and After Studies (Page 260).

   a) Scale samples (to permit estimates of age composition and growth in length and weight; includes length-weight-sex data).

   b) Stomach contents (to establish food habits and general level of feeding).

   c) Whole fish (for analyses of concentrations of pollutants such as DDT, PCBs, heavy metals, etc.); uptake and concentration of some pollutants is higher at elevated temperatures and fish in heated plumes may be accumulating these materials more rapidly than those in unheated lake water.

3) Examine fish and record:

   a) Any brands, tags, fin clips or other identifying marks

   b) Incidence of infectious diseases or parasites

   c) Symptoms of gas bubble disease.

3. Conduct studies to determine residence time of individual fish in the plume, and temperatures to which these fish are acclimated under stable plume conditions.

Residence time data for individual fish will permit estimation of the turnover rate of the populations in the plume. Data on residence time and acclimation temperature will also permit more precise judgments concerning temperature dependent effects of cooling water use. For example, when the acclimation temperature of the plume population is known, data from laboratory temperature tolerance studies can be used to predict whether an interruption of the discharge of a heated effluent would cause low temperature mortality among the plume residents. It will also be possible to estimate the degree of reproductive impairment occurring among populations of yellow perch that overwinter in heated plumes (due to their winter chill requirements not being fully met), when both the population turnover time and acclimation temperature are known.

No single method is entirely suitable for determining residence time and acclimation temperatures of fish inhabiting the heated discharge plume and several complementary methods may have to be applied.

Deep body temperature measurements (Spigarelli et al., 1973b) made on fish immediately after capture and removal from the water give some idea of the temperatures experienced immediately prior to capture. Deep body temperatures can be measured by inserting the temperature sensing probe of an electronic thermometer into the rectum or muscle tissue of the fish; if the former method of insertion is used, the fish can also be tagged or marked and released. Body temperature measurements have been made at the Point Beach nuclear plant by the Argonne National Laboratory (Spigarelli et al., 1973b).

Marking fish by branding, removal of fins, spraying with fluorescent pigment or the application of an external tag may yield information on length of plume residence and migration tendencies (See discussion of tags and marks on page 273).

Thermoluminescent dosimeter tags (Romberg et al., 1972) appear to have promise for use as short-term integrating temperature recorders; they can also trace long-term movements of the tagged fish.

Temperature sensitive transmitters implanted in fish and monitored by radio-tracking systems offer perhaps the greatest potential for obtaining precise, detailed thermal histories of individual fish. Data can be collected continuously to determine residence times of individual fish within specific isotherms. A system using shore based receivers and capable of tracking several fish simultaneously is under development by University of Wisconsin researchers for use at the Point Beach nuclear plant.

4. Conduct studies to determine behavioral responses of fish populations to upwellings of water from the hypolimnion, plume shifts, and chlorination.

   All of these events can result in sudden exposure of the plume fish population to temperatures considerably lower than those to which they are acclimated. During upwelling, the temperature of the water entering the plant cooling system intake may drop as much as 10C (18F) in a few hours, causing the discharge temperature and the inshore water temperature to fall by a similar amount. Plume shifts in response to wind and lake current changes occur relatively frequently and may cause portions of the plume population to drift away from the discharge in isolated "lenses" of heated water that can be observed when plume shifts occur.

   Although very low concentrations of chlorine are lethal to some fish (trout and salmon and possibly others), studies have shown that fish may be able to detect and avoid even sublethal concentrations. As a consequence, chlorination of cooling waters, especially during the colder months of the year, may force fish residing in the plume to leave the heated plume waters, thereby risking cold shock and low temperature death; those that remain in the plume may receive lethal exposures to chlorine.

No single method is entirely suitable for documenting behavioral responses of plume fish populations to sudden changes in water temperature or to chlorination (which may result in the population moving out of the heated plume to areas with lower temperature). A combination of the methods detailed in the section on plume mapping and fish location and those which propose to determine plume residence time and acclimation temperatures will be adequate to the task (see also Kelso, 1974).

On-site Bioassays

These studies are required to produce data of a site specific nature. For example, chlorine toxicity may vary widely with water quality, which in turn may vary widely among sites. Therefore, chlorine toxicity studies should be conducted at each cooling water site where chlorination is practiced.

Questions to be Answered

1. What are the acute and chronic effects of intermittent chlorination on fish in the thermal discharge area and how do these effects vary with species, life stage, water temperature and other seasonal changes in lake water quality? (Priority 2, Category 2)

2. What are the acute and chronic effects on fish in the thermal discharge area of cold shock caused by plant shutdown? (Priority 2, Category 2)
3. Is there a higher incidence and virulence of infectious of contagious diseases among fish in the plume than among fish in unheated areas of the lake? (Priority 2, Category 3)
4. Do fish in the plume exhibit symptoms of gas bubble disease and if so, what are the consequences to the fish that are displaying those symptoms? (Priority 2, Category 3)

Materials and Methods

1. Effects of intermittent chlorination on caged fish held in the thermal discharge. Recommended procedure: see Basch and Truchan (1971).
2. Acute and chronic effects of continuous and intermittent chlorination and temperature on fishes found in power plant thermal plumes. Recommended procedure: Arthur and Eaton (1971).
3. Effects of plant shutdown on caged fish held in the thermal discharge. Recommended procedure: see Basch and Truchan (1971) for details on cage construction and installation; see Brett (1952) and Fry, Hart, and Walker (1946) for details on conducting thermal bioassays and interpreting results under conditions of constant and changing temperature.

4. Effects of plume residence on incidence of gas bubble disease. Recommended procedure: No specific procedure has been developed that appears totally satisfactory for direct application to all Lake Michigan situations; but see Bouck et al. (1970), and Ebel (1969) who provide background information on GBD; DeMont and Miller (1971) who report the first incidence of GBD among fish in a thermal plume and Otto (1973) who provides information on the tolerance of Lake Michigan fishes to GBD.
5. The rate and severity of infection of contagious diseases among caged fish in a thermal plume. Recommended procedure: None developed at this time but see Plumb (1973).

Laboratory Studies

Laboratory studies produce information on the physiological and ecological requirements and tolerances of organisms, that can be used for independent interpretation and verification of field observations and field bioassay studies. It is our intent that these laboratory studies be broad in scope and applicability of results so that the necessity for repetition as part of the demonstration of effect at each plant is precluded.

Questions to be Answered

1. What are the preferred and avoidance temperatures of Lake Michigan fishes? (Priority 2, Category 2)
2. How are fish fry and eggs affected by the shear forces

generated by turbulent cooling water? (Priority 3, Category 3)

3. What are the temperature tolerances of the egg, larvae, juvenile, and adult life stages of the fishes of the lake? (Priority 1, Category 2)
4. What are the effects of sublethal exposure to elevated temperatures and rapid temperature drops on fish reproduction and predator avoidance? (Priority 2, Category 2)
5. What are the effects of temperature on the feeding requirements and on the growth and conversion efficiency of fishes? (Priority 3, Category 2)
6. What are the swimming capabilities of larval and juvenile Lake Michigan fishes relative to power plant intake current velocities? (Priority 2, Category 2)
7. What are the effects of temperature on the uptake of pesticides and other contaminants by fish residing in the plume? (Priority 3, Category 2)

Materials and Methods

1. Preferred and avoidance temperatures of Lake Michigan fishes. Recommended procedure: See McCauley and Tait (1970), and Meldrim and Gift (1971).
2. Studies of the deformation and disruption of fish fry and fish eggs in turbulent, shear-flow conditions. Recommended procedure: No procedure for experimentation has yet been developed. The problem was discussed by Goodyear

and Coutant (U.S. Atomic Energy Commission, 1973); see also Cox and Maxon (1971), Csanady (1973), Coutant and Kedl (1975), and Pommeranz (1974).

3. Temperature and tolerance of larval, juvenile, and adult fish. Recommended procedure: Use method of Brett (1952) for sudden continuous exposure to an elevated constant temperature.
4. Effect of sublethal thermal shock on the ability of larval and juvenile fishes to avoid predation. Recommended procedure: See Yocom and Edsall (1974), Coutant et al. (1974).
5. Swimming speeds of juvenile and larval inshore fishes of Lake Michigan. Recommended procedures: Methods are currently under development by T.G. Yocom at the Great Lakes Fishery Laboratory, Ann Arbor, Michigan; see also Houde (1969a).
6. Effects of temperature on food intake, conversion efficiency, and growth of juvenile and adult Lake Michigan fishes. Recommended procedure: See McCormick et al. (1971), and Brett et al. (1969).
7. Effects of temperature on maturation, spawning, fertilization, and embryo survival of fishes. Recommended procedure: See Hokanson et al. (1973), and Colby and Brooke (1970). The National Water Quality Laboratory, Duluth, Minnesota has also developed a procedure for determining temperature requirements for the maturation of the gonads and reproductive success of the yellow

perch (MS in preparation) that should be suitable for investigating these temperature requirements of other Lake Michigan fishes.

8. Effects of elevated temperatures on the rate of uptake and concentration of toxic materials directly from lake water by fish. Recommended procedures: See Reinert et al. (1974), Reinert (1970), Willford et al. (1973), and MacLeod and Pessah (1973).

Lakewide Studies

Lakewide fish stock assessment is needed to determine the distribution and abundance of fish in Lake Michigan and to obtain the vital statistics including the age composition and age-specific birth, death, and growth rates of the populations. These data, when treated according to currently accepted methods for the analysis of fish population dynamics will permit an evaluation of the lake-wide effect of cooling water use on the fish populations of Lake Michigan.

Lakewide studies of the scale needed to evaluate the effects of cooling water use on Lake Michigan fish will require careful planning and execution if useable results are to be obtained. Studies to assess the fish populations of the lake are already underway by the various state and federal resource protection and management agencies with proprietary interest in the lake. Any additional studies designed to describe these populations for the purpose of determining cooling water use effects should be closely coordinated with these ongoing efforts.

We have not attempted to present a review of the ongoing fish population assessment activities on the lake, but reports of these studies may be seen in the minutes of the annual Lake Michigan Lake Committee Reports of the Great Lakes Fishery Commission. Recently completed estimates of biomass for several Lake Michigan fish populations are available in Fisheries Report No. 1813 of the Michigan Department of Natural Resources (1974) and in Edsall et al. (1974).

The sampling program presented in the "Materials and Methods" Section that follows, if conducted independently of ongoing assessment studies, is the minimum effort that would permit adequate description of the areal and depth distribution and relative abundance of the populations of important fish in the lake (Item 1 in the "Questions to be Answered" Section). Coordination of the Lakewide Studies program with those of the various resource agencies may permit a reduction in the effort required of the Utilities as outlined in the Materials and Methods Section that follows.

<u>Questions to be Answered</u>

1. What are the areal and depth distributions and relative abundance of the various fish populations of the lake throughout the year? (Priority 1, Category 2)
2. What is the absolute size (age specific numerical abundance and biomass) of each of the populations of fish in Lake Michigan? (Priority 1, Category 3)
3. What are the age specific rates of growth, reproduction, mortality (including fishing mortality) and the food habits for each population of Lake Michigan fish

(Priority 2, Category 3)

4. What magnitude of age specific loss or damage caused by cooling water use can each population sustain without a significant decline in productivity and in the ability of each of these populations to recover to former levels of importance and abundance if the cause of loss or damage from cooling water use is removed? (Priority 1, Category 3)

Materials and Methods

1. Trawl sampling of juvenile and adult fish
   a. Sampling location - Cross-contour sampling transects, at least every 50 miles of lakeshore. Trawl hauls at 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 25, 30, 35, 40, 45, 50, 60, 70, and 80 fathoms across each transect (parallel to the bottom contours).
   b. Gear - See Materials and Methods in Before and After Studies (Page 260).
   c. Sampling frequency
      1) Visit all stations in spring and in fall for at least one year.
      2) See additional notes on frequency in Materials and Methods Section of Before and After Studies (Page 261).
   d. Sample processing - See processing information in Materials and Methods Section of Before and After Studies (Page 261).
   e. Sample analysis - See Materials and Methods Section of Before and After Studies (Page 265).

2. <u>Gill net sampling of juvenile and adult fish</u>

a. Sampling location

Cross-contour sampling transects, every 50 miles of shoreline.

1) Bottom gill net sets at 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, and 80 fathoms across each transect (nets set parallel to bottom contours).

2) Oblique gill nets set at 5, 15, and 30 fathoms across each transect (parallel to bottom contours).

b. Gear - See gill net specifications in Materials and Methods Section of Before and After Studies (Page 266).

c. Sampling frequency

1) Visit all stations in spring and in fall.

2) See discussion of frequency in Materials and Methods Section of Before and After Studies (Page 269).

d. Sample processing - See processing in Materials and Methods Section of Before and After Studies (Page 269).

e. Sample analysis - See analysis of samples (Page 265).

3. <u>Seine sampling for juvenile and adult fish</u>

a. Sampling location

Cross-contour sampling transects, every 50 miles of lakeshore.

Seine hauls in beach zone water (0-10 ft).

b. Gear - See Materials and Methods of Before and After Studies (Page 269).

c. Sampling frequency

1) Visit all stations in spring and fall for at least one year.

2) See sections on sampling frequency in Materials and Methods of Before and After Studies (Page 270).

d. Sample processing - See discussion of processing in Materials and Methods of Before and After Studies (Page 261).

e. Sample analysis - See analysis of samples in Materials and Methods of Before and After Studies (Page 265).

4. Plankton net hauls for fish fry assessment (see Wells, 1973).

a. Sampling locations

Cross-contour sampling transects, at least every 50 miles of lakeshore.

Sampling stations at 15, 30, 45, 60, 75, 90, 105, and 120 feet.

Sample the 0 (surface), 1-, 2-, 4-, 6-, 8-, and 10-meter depth levels within the water column at each of the above stations, when water depth permits.

b. Gear - See Materials and Methods of Before and After Studies (Page 271).

c. Sample frequency - See Materials and Methods of Before and After Studies (Page 271). Sampling to continue for at least one year.

d. Sample processing - See Materials and Methods of Before and After Studies (Page 272).

e. Sample analysis - See Materials and Methods of Before and After Studies (Page 265).

5. Pump sampling of fish eggs

a. Sampling locations

Cross-contour sampling transects, at least every 50 miles of lakeshore.

Make triplicate 5-minute pumpings on the bottom along the contour at each station at 0.5, 1, 1.5, 2.5, 3, 3.5, 4, 4.5, 5, 7.5, and 10 fathoms.

b. Gear - See Materials and Methods of Before and After Studies (Page 272).

c. Sample frequency - See Materials and Methods of Before and After Studies (Page 272). Sampling to continue for at least one year.

d. Sample processing - Materials and Methods of Before and After Studies (Page 273).

e. Sample analysis - Materials and Methods of Before and After Studies (Page 265).

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SECTION VIII

MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON ENTRAPPED AND ENTRAINED ORGANISMS

Section VIII **MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON ENTRAPPED AND ENTRAINED ORGANISMS**

Table of Contents

Section VIII. MEASUREMENT OF THE EFFECTS OF COOLING WATER USE ON ENTRAPPED AND ENTRAINED ORGANISMS

Introduction

The possible ecological effects of entrapment and entrainment of Lake Michigan organisms in water intake systems are of significant concern. Entrapment is defined here as the trapping or confinement of organisms within an intake system, or impingement of organisms on screening devices such that the organisms are unable to return to their natural habitat. Organisms with potential for becoming entrapped are of a size sufficient to preclude passage through a 3/8 inch screen mesh and whose swimming ability is insufficient to permit them to swim against inward moving intake currents. Fish are of primary concern although larger invertebrates may also become entrapped or impinged.

Entrainment is defined as a process whereby small organisms in the lake water are passively carried with the cooling water into an intake structure, through a cooling system and thence back to the lake. Entrained organisms are small organisms drawn into an intake system whose size does not preclude their passage through a 3/8 inch screen mesh and on through a cooling water system. Planktonic forms entrained in the effluent plume by mixing processes are also included within the category of entrained organisms. These two types of entrainment are referred to as plant and plume entrainment, respectively. Entrainable organisms include members of the phytoplankton and zooplankton communities, small fish, fish eggs and larvae and small benthic forms periodically in the water column.

The published literature does not contain an abundance of information relating to the problems of entrapment and entrainment. However, a considerable amount of information has been collected at operating power plants and is made available in published reports. A report prepared by the Lake Michigan Cooling Water Intake Technical Committee, 1973, specifically relates to water intakes on Lake Michigan. This contains an excellent review and discussion of intake structures, and entrapment problems on Lake Michigan. Others of more general context include Sonnichensen, et al., 1973; Sharma, 1973; and U.S. EPA, 1973; these are excellent review documents on cooling water intakes and entrapment problems. A recent publication edited by Jensen (1974) contains 35 papers dealing with both entrapment and entrainment research at power plants and other water intake facilities. Papers in this report cover the entire spectrum of concern from phytoplankton entrainment to fish entrapment and include current bibliographic citations for further reference.

Entrapped Organisms

Introduction

The entrapment of organisms in a water intake system depends on the area of the lake from which the water is withdrawn, the physical arrangement and hydraulics of the particular system and the specific location of the intake, whether it is onshore, offshore at the surface or submerged. The proximity of an intake to areas highly populated with lake organisms, spawning grounds, etc., are also important in determining the numbers of organisms which may be entrapped.

Before the impact of intake systems on populations of Lake Michigan organisms can be evaluated, information is needed on the numbers of species, and life history stages currently being entrapped. The program outlined below is designed to document the numbers of organisms which are or may be entrapped or impinged at intakes. It is suggested that these data be evaluated in terms of such factors as intake location and type to determine if certain areas of the lake or specific intake designs contribute disproportionately to the entrapment of organisms. This information is essential to the evaluation of the impact of entrapment on Lake Michigan populations. If design and location factors are significant, it will also be necessary for the proper evaluation of existing intake systems and for the design of future intake structures.

Monitoring Program for Existing Water Intakes

Objectives

The primary objective of this program is to determine the daily and seasonal variations in numbers, size and weight of all species entrapped in intake systems. This monitoring scheme is adapted from that suggested by the Lake Michigan Cooling Water Intake Technical Committee, 1973.

Sampling Frequency

Sampling should be conducted through one calendar year. Data on organisms which become impinged on the intake screens should be collected daily.

Sampling Methods

Collection of large invertebrates, juvenile and adult fish impinged on screening devices can be accomplished using collection baskets in the backwash sluiceway. Mesh size of the collection baskets should be equal to or smaller than the intake screen mesh.

Sampling Data Required

1. Plant operating data required during monitoring period:
   a. Flow rate
   b. Temperature - intake and discharge
   c. Time started, duration and amount of warm water recirculated for intake deicing.
   d. Total residual chlorine contained in recirculated water during condenser cleaning.
   e. Current velocity at intake(s) over the range of water volumes used in plant operation.
   f. Number of times screens are operated between sampling intervals.
2. Data required from biological collections:
   a. Species, life stage, number and size of each organism collected from the screens.
   b. Volume of water sampled.
   c. Number, length, weight, and age group (young-of-the-year, yearlings and older) of all fish collected from screening devices.

d. Representative samples of each species for determina-ion of sex and breeding condition.

e. Numbers of naturally occurring dead fish in the area ahead of the intake screening system should be estimated.

Monitoring Program for New and Proposed Water Intakes

Objectives

The primary objective for preoperational biological sampling is to determine the abundance of potentially entrappable organisms in the area of proposed intakes and to determine if fish are using the area as spawning, nursery or feeding grounds, and/or as migration routes.

Methods of Investigation

1. Field studies to obtain this information are discussed in the fisheries, benthos, and microbiology sections of this report.

2. Model studies may be necessary to determine the optimal design of intake structures which would reduce potential loss through entrapment or impingement.

3. Initial operation: When a new intake system becomes operational it should be closely monitored for one year as prescribed above for existing intakes.

4. Design modification: If a new intake system entraps an unacceptable number of organisms, design modifications should be considered, tested as per 2 above, and implemented.

Entrained Organisms

Introduction

Organisms in the intake water not stopped by the plant screens, diverted, or otherwise removed from the circulating water intake flow, pass through circulating water pumps, steam condensers and, related appurtenances and back into the receiving water. Passage through the cooling system may place stresses on the organisms including: mechanical abrasion due to turbulence and irregular surfaces in the system, pressure effects caused by pumping and head losses, temperature effects caused by heat transfer in the condenser and, on occasion, toxic effects caused by addition of biocides to control fouling.

Because of the small size of entrained organisms, and their near neutral buoyancy, it is assumed that each organism behaves hydrodynamically as a water parcel during passage through pumps and condensers. Organism travel paths are probably dissimilar, so effects may also differ. For instance, the position of organisms relative to pump impellers and the vertical distance an organisms must be raised to reach the level of a given condenser tube in a system can result in slightly different pressure histories. Hence, it is necessary to deal with averages rather than individual organisms. This is consistent with physical measurements made in circulating water systems, such as pressure, velocity and temperature gradients which are also described in terms of averages. Pressure through a system typically varies from one atmosphere to positive pressures of about 20 psig after passage through the pumps. Negative pressures may also be encountered. The temperature conditions experienced by a hypothetical organism passing through a cooling system are more uniform than pressure. The temperature history may be determined by assuming a linear increase in temperature through the length of a condenser tube equal to the average temperature rise through the condenser. The effluent temperature rise can be quite variable, depending on the amount of water circulated, and variations in plant load. Typical temperature rises through a condenser range from about 6C to 15C with flow velocities in the condenser tubes ranging from 1.5 to 3.0 m/sec.

The following sections describe investigations necessary to determine effects of entrainment on phytoplankton, zooplankton (including entrainable benthos), and fish (including fish eggs and larvae). Specific sampling techniques are suggested for use at power plants on Lake Michigan. In addition, suggestions for laboratory studies are included which could be instituted if necessary to isolate causes of entrainment effects.

The results of these studies should be carefully evaluated with information on lakewide populations of entrainable organisms to determine the impact of entrainment on the lake ecosystem.

Phytoplankton

Introduction

The phytoplankton of Lake Michigan (described in the Microbiology section of this report) are susceptible to entrainment and possible damage in cooling water systems. Two major concerns regarding the effects of entrainment on the phytoplankton are:

1. Does entrainment affect the rates of mortality, growth, reproduction, and primary production?

2. Do the effects of entrainment influence lakewide populations of phytoplankton and other species dependent on them?

If the answers to these questions indicate that there is a significant effect on the ecology of the lake resulting from entrainment, additional questions may be asked to isolate the causes:

1. Is the effect caused by thermal, mechanical or chemical perturbations?
2. Where does the effect occur, at the intake, in the plant, at the discharge, or in the discharge plume?
3. What corrective measures could be employed to reduce adverse effects.

Objectives

1. Determine the effects of entrainment on phytoplankton.
2. Determine if these effects influence local and lakewide phytoplankton populations.
3. If warranted, based on answers from 1 and 2 (above) determine the causes of observed entrainment effects within the cooling system.

Methods of Investigation

Studies to determine the effects of entrainment on phytoplankton should involve one or more basic types of observations:

1. microscopic examination of phytoplankton,
2. measurement of chlorophyll concentrations,
3. measurement of rates of primary production, and
4. observations of cell growth and division.

Without elaborating on specific procedure, the following research outline is presented to answer basic questions concerning phytoplankton entrainment. Procedures involve both field and laboratory studies.

Effects of Plant Entrainment on Phytoplankton Mortality

Immediate Effects

It is extremely difficult, if not impossible to determine living or dead cells from visual observation of a sample of phytoplankton. It is necessary therefore to rely on an indirect physiological measurement. Following are some measurements that might be made:

1. Rate of Carbon Uptake

   Measurement of carbon uptake rates using an isotope of carbon ^{14}C is a sensitive indicator of the general viability of the algae. A comparison of uptake rates at the intake and discharge of a power plant may be used as a measure of the effects of plant entrainment on the phytoplankton.

2. Chlorophyll measurements

   Chlorophyll "a" is a plant pigment common to all phytoplankton. It is easily and accurately measured, and it degrades rapidly when a phytoplanker dies. A comparison of the concentration of chlorophyll "a", and its degraded forms at the intake and discharge of a power plant provides another indirect measure of plant entrainment effects.

3. Other physiological measurements

Other physiological-biochemical techniques, such as ATP determination, have been employed to assess entrainment effects on phytoplankton. These techniques are not specific for phytoplankton and are not acceptable for this purpose without careful control.

Long-Term Effects

The long-term effects of entrainment on phytoplankton may be more important to the lake than immediate effects. What happens to a phytoplankter several hours or days after it has been discharged? Is it dead when it leaves the plant only to decompose in the lake? Is it living when discharged but unable to reproduce? Or, is its rate of growth and division accelerated as a result of entrainment? Are some species affected more drastically than others?

The following are techniques which could be used in an attempt to answer these questions:

1. Observation of cultures

Intake and discharge water maintained at ambient temperature over a period of several days provides one means for answering these questions. Subsamples from such cultures may be periodically examined for changes in species composition and abundance, chlorophyll content, and carbon uptake rates.

2. <u>The effect of plant entrainment on phytoplankton growth, division and primary productivity</u>

   Studies outlined under "Immediate Effects," coupled with No. 1 above, are also suitable for determining the influence of entrainment on growth, division, and primary productivity of the phytoplankton.

3. <u>The effect of plume entrainment on phytoplankton</u>

   Although organisms entrained in the plume do not pass through the plant, they may be exposed to turbulence, elevated temperatures, and residual biocides. Comparisons of phytoplankton samples collected in the plume with samples obtained from the intake of the plant and from a reference area may provide insight into plume entrainment effects. Studies similar to those outlined above for plant entrainment effects are suitable here for comparative purposes. In addition, samples of intake and discharge waters may be mixed in various proportions to simulate the dilution of effluent water in the plume to observe plume entrainment effects under more controlled conditions.

4. <u>Determination of the cause of observed plant entrainment effects</u>

   If preliminary studies of plant and plume entrainment demonstrate a significant adverse effect, the following studies should be initiated to isolate the cause:

a. Carbon uptake studies

Through a series of sample manipulations and comparisons it is possible to assess the total effect of plant entrainment on carbon uptake rates and to discern the individual effects of temperature evaluation, biocide addition, mechanical action and the duration of exposure to elevated temperatures. Table VIII-1 summarizes these manipulations and the effects measured.

b. Phytoplankton growth and cell division studies

Observations of chlorophyll concentrations, and species composition and abundance on a series of cultures manipulated as shown in Table VIII-1 would yield information concerning plant effects on these parameters.

c. Experiments of opportunity

When a power plant is out of service for maintenance, the plant often has the capability of circulating cooling water without the addition of heat. During these periods information may be obtained on the mechanical effects of the cooling system and the addition of biocides exclusive of thermal effects.

d. Preoperational studies

A complete assessment of entrainment effects on phytoplankton cannot be made prior to startup, but tests which simulate entrainment conditions

Table VIII - 1. Sample manipulation and comparison to assess the effects of the power plant on rate of primary production through the use of ^{14}C uptake.[1]

Effect Measured	Sample Collected At	Incubation Temperature	Compared With	Sample Collected At	Incubation Temperature
Total					
Plant entrainment (temp.,pressure, pumps, turbulence)	Intake	Intake	----	Discharge	Discharge
Mechanical	Discharge	Discharge	----	Intake	Discharge
			or		
(pumping, pressure, turbulence, cavitation)	Intake	Intake	----	Discharge	Intake
Temperature	Intake	Intake	----	Intake	Discharge
			or		
(thermal elevation)	Intake	Intake	----	Intake	Other temperature increases above and below discharge temperature
Biocide addition	Intake	Intake	----	Discharge and Biocide	Intake
Duration of exposure to elevated temperature	Intake	Intake	----	Intake	Various elevated temperature for various lengths of time

[1] Adapted from Brooks et al., 1974.

can be conducted before final plant design. Similar tests may be conducted to those discussed above for operating power plants but which simulate expected plant condition.

A thorough literature review and a series of well-designed experiments could provide preoperational information applicable to the entire lake which could then be used to design cooling systems to minimize ecological impact.

Methods of Sampling

Each of four basic types of observations (carbon uptake, chlorophyll, microscopic examination and culturing) should be made on subsamples of a larger, well-mixed sample to assure that all measurements are performed on the same water mass. It would be beneficial if a subsample could also be taken for chemical analysis of plant nutrients and toxic substances. Subsampling a single large sample maximizes the amount of information for interpretation and minimizes sample collection.

All samples of water for phytoplankton investigations should be collected in non-metallic, non-toxic vessels such as a plastic bucket or Van Dorn bottle. The use of pumps and nets which may damage organisms or which are size selective are not acceptable for the collection of phytoplankton. Samples should be held in glass or non-toxic plastic containers. Transferring samples through rubber or Tygon-type tubing, which are toxic to phytoplankton, must be avoided.

Sampling Interval

During the initial phases of study, samples should be collected and observations made monthly for a period of at least one year. One sampling site such as the intake should be monitored weekly to note sudden changes in the phytoplankton populations. Drastic population shifts in the weekly samples should trigger full-scale investigations described above.

Sampling Frequency

During monthly sampling, phytoplankton should be collected at least three times during 24-hours: early morning, midday, and late evening. This schedule could be reduced to one collection per day when diurnal patterns for the area have been determined.

Sampling Site Selection

The exact point of collection is difficult to designate in general guidelines since nearly every power plant has a different cooling system design. The following points in the cooling system are appropriate for sample collections:

1. at the intake, ahead of any pumps or screens,
2. at the point of discharge, and
3. in the discharge plume.

If more detailed investigations are necessary to determine the causes of entrainment effects, additional samples may be obtained within the cooling system i.e., before and after pumps and condensers.

Special Problems

For valid comparison of two points in the cooling system, it is imperative to collect samples from the same well-mixed water mass as it flows through the plant. Preliminary studies should be conducted with tracers to determine travel times through the cooling system from intake to discharge. It is also extremely important to make sure that samples collected at the intake, for example, are representative of the water actually entering the plant. Stratification and nonhomogeneous conditions have often been observed in what appear to be turbulent well-mixed waters. The same caution would hold for the discharge of the plant.

Zooplankton and Entrainable Benthos

The zooplankton of Lake Michigan, described in another section of this report, are susceptible to entrainment and possible damage in cooling water systems. Primary concerns regarding the effects of entrainment on the zooplankton are: 1) Does entrainment affect the rates of mortality, growth, reproduction? 2) Do the effects of entrainment influence lakewide populations of zooplankton and other species dependent on them? If the answers to these questions indicate that there is a significant effect on the zooplankton population of the lake resulting from entrainment, additional questions may be asked to isolate the causes:

1. Is the effect caused by thermal, mechanical or chemical perturbation?

2. Where does the effect occur, at the intake, in the plant, at the discharge or in the effluent plume?
3. What corrective measures could be employed to reduce any adverse effects?

<u>Objectives</u>

1. To determine the kinds and numbers of zooplankton entrained.
2. To assess the effect of entrainment on survival and reproduction of zooplankton.
3. To describe the seasonal and diurnal patterns of entrainment.
4. To relate research findings to lakewide studies.
5. If warranted, to distinguish between mechanical and chemical damage and thermal effects in relation to plant design.

<u>Methods of Sampling</u>

1. Pumped samples are more desirable than net samples provided the pump does not damage the organisms. A pump which will transfer small fish without harm is satisfactory for zooplankton and benthos. Non-toxic material should be used throughout the sampling system.

   Nets used to concentrate zooplankton and benthos from the pumped sample should have a maximum mesh size of 160 microns and should be metered, or the pumping rate should be timed to provide an accurate determination of the volume filtered.
2. Samples should be taken in duplicate. If no vertical stratification of organisms occurs, duplicate mid-depth or integrated samples may be taken.

3. Sampling sites should be established in the forebay, immediately ahead of the traveling screens, and as close as possible to the point of discharge. Sites for plume entrainment studies are dictated by plume characteristics.
4. Samples should be carefully concentrated in non-toxic containers and inspected microscopically for mortality and damage as soon as possible after collection. (See 1 below).

The following studies could be undertaken at one or two sites to answer the questions pertaining to the entire lake, or major regions.

1. Special studies should be conducted to establish criteria for damage and to examine the relationships of motility, vital dye uptake, or other indices to long-term effects.
2. Time-temperature studies should be conducted to establish thermal tolerances of important species and to permit an estimate of plume entrainment effects.
3. Zooplankton and benthos entrained in the plant and/or the plume may experience a non-lethal thermal shock that will adversely affect normal reproduction. Special studies should be conducted in which zooplankton and benthos are exposed to a thermal regime through time for observations of growth and reproduction.
4. If biocides are added to the cooling water, special studies should evaluate effects on zooplankton and benthos.

Sampling Frequency and Interval

Samples should be taken in the forebay and at the discharge during a 24-hour period at least monthly. Duplicate samples should be taken every 3 to 4 hours during the 24-hour survey.

Fish

Introduction

Entrainment of fish, fish eggs, and larvae has been observed in once-through cooling systems of plants located on the Lake Michigan shoreline, but the species and numbers of these organisms and their fate have been poorly documented. The potential for damage to the lake fish populations by entrainment depends on the numbers of organisms that pass through the condenser system and on the conditions experienced during passage. Fish, fish eggs, and larvae also can be entrained directly in the effluent plume from the receiving water when the effluent is discharged into the lake, especially at plants where diffuser systems are used to enhance mixing for rapid temperature reduction.

Objectives

Plant Entrainment

1. Determine the species and numbers of fish, fish eggs, and larvae drawn into and discharged from cooling systems using Lake Michigan water.
2. Determine the immediate and delayed effects of cooling system passage on these organisms.

Plume Entrainment

1. Determine the species and numbers of fish, fish eggs, and larvae entrained directly into the discharge plume from the receiving water.
2. Determine the immediate and delayed effects of plume entrainment on these organisms.

Questions to be Answered

Plant Entrainment

1. What species and numbers of non-screenable fish, fish eggs, and larvae are drawn into and discharged from cooling water systems?
2. Are there statistically significant differences in the species and numbers of non-screenable fish, fish eggs, and larvae drawn into cooling water systems on a diurnal, seasonal and annual basis?
3. Assuming 100% mortality of the fish, fish eggs and larvae that are entrained, is it reasonable to expect that this loss in itself, or when added to the other losses resulting from cooling water use will significantly affect fish populations? If so, the following questions should be answered to more clearly identify the specific causes of the entrained losses.
4. Is there a statistically significant difference between the numbers of viable, non-screenable fish, fish eggs, and larvae drawn into a power plant and the numbers discharged from the cooling system?
5. Is there a statistically significant correlation between densities of non-screenable fish, fish eggs, and larvae in the area of the lake near the cooling system intake and the species and numbers in the cooling water drawn into the plant?
6. Will eggs that survive plant passage be able to complete development; will fish and fish larvae that survive plant passage be mobile and able to locate and capture food effectively?

7. Will fish and fish larvae surviving plant passage be more susceptible to capture by predators concentrated in or near the discharge plume?
8. Will the simple physical transport of undamaged fish, fish eggs, and larvae from the intake area into the discharge plume reduce survival?
9. If the answers to the above questions confirm the potential for significant detrimental effect on lakewide fish populations caused by entrainment, to what extent are the following factors responsible: pressure changes; elevated temperatures, changes in gas saturation; chlorination; collision with screens, pump impellers and other internal surfaces of the cooling system; and shear forces created by turbulence?

Plume Entrainment

1. What kinds and numbers of fish, fish eggs, and larvae are entrained directly into the discharge plume from the receiving water?
2. What are the diurnal, seasonal, and annual discharge entrainment patterns?
3. What percentages, if any, of the entrained fish, fish eggs, and larvae are killed because of the conditions encountered?
4. If the answers to questions 1 - 3 above demonstrate a significant detrimental effect on the fish populations caused by plume entrainment, to what extent are each of the following factors responsible: gas saturation; chlorination; shear forces created by turbulence; probable decrease in ability to avoid predators concentrated in or near the plume; displacement of entrained organisms from one habitat to a second, perhaps

less favorable habitat?

Methods of Investigation and Sampling

Plant Entrainment

Sampling with a Pump Sampling System

A pump sampling system is recommended as the primary method for determining species and number of non-screenable fish, fish eggs, and larvae of each species passing through plant cooling systems. A pump sampling system is preferred because a standardized system can be built that can be used at most if not all plants, thereby providing a basis for comparability of data collected among plants. Pumped systems also are easier to automate than systems in which sampling is done with nets suspended directly in the mainstream of the cooling water flow. (An automated pump sampling system is under development at the Great Lakes Fishery Laboratory.)

Continuous pumped sampling is recommended as the primary method for determining species and numbers of fish, fish eggs, and larvae of each species entrained and passing through power plant cooling systems, because (a) the numbers of these organisms, even in areas known to be good spawning and nursery areas, are typically low, and (b) their distribution in time and space is usually either changing rapidly or patchy as a result of natural conditions. Therefore, adequate representation of these organisms can only be obtained with continuous sampling.

The actual volume of water to be pumped to provide an adequate sample is dependent on the densities of fish, fish eggs, and larvae in the water surrounding the cooling system intake structure. If the maximum recorded density of 6.4 alewife larvae per cubic meter at the

Cook Plant intake on July 20, 1973 (see Wells, 1973) is taken as an example, a continuous pumping rate of 0.75 cubic meters per minute or about 1,090 cubic meters per day would have to be maintained to obtain a sample of approximately 7,000 larvae. By the same logic, reducing the larval density in the influent water by two orders of magnitude (to 0.064 per cubic meter) would reduce the number captured to about 70 per day--probably still an adequate number from which to estimate the daily larval entrainment rate. However, reduction of larval density by 3 orders of magnitude (to 0.0064 per cubic meter) would require a higher pumping rate to insure adequate representation of this species in the sample.

Alewife larvae are probably more abundant in the lake than those of any other species of fish, e.g. perch never exceeded 0.071 per cubic meter and most samples had less than 0.047 perch larvae per cubic meter (Wells, 1973). Smelt were even less abundant (0.038 per cubic meter) than perch, and few if any larvae of other important species were captured at all. The available data, therefore, indicate that continuous sampling at a pumping rate of at least 0.75 m^3/min. would be needed to detect the entrainment of these species.

Sampling Location

Pump intake ports of the sampling system should be located:

1. Immediately behind the traveling screens, if possible; otherwise, immediately ahead of the traveling screens.
2. At a suitable point in the discharge system.
3. One sampling port should be located near the surface, one near the bottom, and one at mid-depth. If uniform mixing can

be demonstrated, one sampling depth may suffice.

Sampling Frequency and Duration

Sample continuously for one year to determine the kinds and numbers of non-screenable fish, fish eggs, and larvae that pass through the plant; sample for at least one additional year during periods of peak entrainment to provide a measure of year-to-year variability.

The 24-hour sampling day should be divided into four parts corresponding to the four major diel periods (dawn, daylight, dusk, darkness) and a single composite sample should be obtained daily for each of these periods.

Sample Processing

1. Preserve each sample in 10 percent formalin. (Note: It is not necessarily intended that every sample collected under this continuous sampling routine be examined and analyzed; rather the sampling objectives, the sample variance, and the required level of precision will dictate which of the preserved samples are to be subjected to the following additional processing).
2. Sort preserved fish by species and by developmental state (prolarvae, larvae, post-larvae, or juvenile) within species, enumerate each subgroup separately, and measure an adequate sample (total length in mm).
3. Sort eggs by size group or species; measure diameters of an adequate sample in each group.

Sampling with Anchored Plankton Nets

These experiments are designed to provide data for comparison of sampling efficiency of pumped and non-pumped sampling methods and to provide data on the number of non-screenable, live and dead fish, fish eggs, and larvae that are drawn into and discharged from the plant. Note: The need for estimates of in-plant mortality of these non-screenable fish, fish eggs, and larvae depends on the answers obtained to questions 1 - 3 above for Plant Entrainment.

Sample Location

Suspend one plankton net immediately downstream from each of the intake ports of the pumped sampling system, in the traveling screen well or at another plant location upstream from the condensers, where comparative studies can be made.

Sampling Gear

A conventional 1/2 meter oceanographic plankton net with a maximum mesh aperture of 351 microns and with a flow meter installed in the net opening, and a large "non-flow through" collecting chamber in the apex is the gear of choice.

Sampling Frequency and Duration

Collect net and pump samples simultaneously for as long as necessary to permit comparison of the effectiveness of the two methods and to provide the needed data on in-plant mortality of non-screenable fish, fish eggs, and larvae. Note: It will be necessary to determine the filtering efficiency of the suspended nets by comparing the flow rate recorded by the net flow-meter for the complete net (net frame, flow-meter, net bag, and collecting vessel) fished in the normal sampling location, with the flow rate recorded by the net flow-meter after the net bag and collecting vessel have been removed. Flow rates obtained under the latter conditions also will provide information needed to expand the catches obtained by the pump sampling system.

Sampling Process

1. Sort eggs by size group or species, measure diameters of an adequate sample in each group, and record the condition of each egg (live or dead).
2. Preserve the entire catch in 10 percent formalin after live examination.
3. Sort fish by species and by developmental state (prolarvae, larvae, post-larvae, or juvenile) within species, and enumerate each subgroup separately; record the condition of each fish (live or dead).
4. Measure an adequate sample (total length in mm) of each subgroup.
5. Preserve the entire catch in 10 percent formalin after live examination.
6. Methods should be developed to permit rapid distinction (under field conditions) between live and dead fish, fish eggs and larvae, and between live, damaged individuals and those that have suffered subtle but irreversible damage that will directly or indirectly cause their death, or otherwise prevent them from completing their normal life cycle. Vital staining techniques currently under development may prove helpful in making these determinations.

Plume Entrainment

Determine the species and numbers of fish and fish eggs and larvae entrained directly into the discharge plume, and the effects of the entrainment on these organisms by sampling with towed plankton nets in and around the discharge plume.

Sampling Locations

Collect samples simultaneously at the discharge, in the plume, and in unheated waters adjacent to the plume. If a physical plume model can be developed to show the amount of receiving water that is mixed with the heated effluent at various points along the longitudinal axis of the plume, only information on the density of the entrainable fish, fish eggs, and larvae in the receiving waters adjacent to the plume is needed to estimate the kinds and numbers of these organisms that may be entrained. Sampling at intervals on the longitudinal axis of the plume within discrete temperature isotherms permits evaluation of the condition of fish and fish eggs found there, so their condition can be related to the effects of plant and plume entrainment.

Sample Gear

The gear of choice is a conventional one meter, 351 micron mesh, oceanographic plankton net with a flow meter installed in the net opening and a large non-flow through collecting chamber installed in the apex of the net. When towing these nets at the appropriate speed to capture small fish (maximum of about 4 mph, true net-speed through the water) a steel towing cable (about 1/8 inch) and a heavy metal "net depressor" (about 45 pounds) will be required.

Sampling Frequency and Duration

No estimates of sampling frequency can be made until reliable descriptions are obtained of the species and numbers of fish,

fish eggs and larvae entrained from the receiving water.

Sampling Process

See above section for processing live fish, fish eggs, and larvae on page 335.

Priority Research

The research priorities listed below are designed to provide answers to questions concerning the local and lakewide effects of entrapment and entrainment at cooling water intakes and discharges on the biota of the lake.

1. What are the effects of entrainment on the phytoplankton and zooplankton populations of Lake Michigan?
2. What are the effects of the entrainment of fish and fish eggs and the entrapment of fish on the Lake Michigan fishery?

An adequate answer to each of these questions clearly demands a rather complete understanding of the spatial and temporal aspects of the population dynamics of Lake Michigan phytoplankton, zooplankton, and fish. Distinguishing the effects of entrainment and entrapment on the biota of the lake from natural background variation will be difficult and expensive but will be necessary if we are to predict the effects of cooling water use.

The following is a list of priority research topics of a more specific nature. Priority values have been ranked according to the following scheme:

1. - highest priority, consistent with achieving primary goals of the Panel,

2. - high priority studies supporting priority 1 items,

3. - intermediate priority, but ultimately providing support to priority 1,

4. - low priority supporting other programs but not of critical importance in itself,

5. - deferred priority of a general supporting nature.

Categorical values may be interpreted in the following way:

Answers to these questions should be developed:

1. - as soon as possible using available data,

2. - using data currently being collected,

3. - by means of individual research projects which are not now underway.

A. <u>Entrapment</u>

1. To evaluate the data on the numbers of fish currently entrapped at Lake Michigan cooling water intakes and

determine if this loss is detrimental to the local and lakewide fish populations.

Priority 1, Category 1 and 2

2. To evaluate fish entrapment data to determine which of the existing intake designs entrap the fewest fish.

   Priority 2, Category 1 and 2

3. To investigate alternate intake designs of fish diversion devices to minimize fish entrapment.

   Priority 2, Category 3

B. <u>Entrainment</u>

1. To evaluate existing data concerning the effects of plant and plume entrainment on the phytoplankton, zooplankton and fish populations of Lake Michigan.

   The following sequence should be followed:

   a. Determine the species and numbers of each species entrained.

   b. Determine percentage mortalities resulting from entrainment, based on available data. Where data are lacking for specific groups of organisms, assume 100 percent mortality.

c. Gather existing data on concentrations of entrainable organisms in representative zone around the lake, and estimate the size of the local and lakewide populations.

d. Obtain data on flow rates of cooling water through selected plants within these zones and the volumes of water entrained by the effluent plume within the 1.0C isotherm.

e. Calculate percentage loss of the local and lakewide population of each organism group within the representative zone.

f. Determine whether these losses will significantly affect the local and lakewide populations of these organisms and what effects will be manifest in the overall Lake Michigan ecosystem.

Priority 1, Category 1 and 2

2. If significant data gaps are found or if adverse effects are predicted from the analyses outlined above, proceed with the monitoring program suggested.

Priority 3, Category 3

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SECTION IX

RADIOECOLOGICAL CONSIDERATIONS RELATED TO COOLING WATER USE

Section IX. RADIOECOLOGICAL CONSIDERATIONS RELATED TO COOLING WATER USE

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Section IX. RADIOECOLOGICAL CONSIDERATIONS RELATED TO COOLING WATER USE

General Discussion of Problem

Within the scope of the charge to the Lake Michigan Cooling Water Studies Panel, radioecological considerations are limited to the area of the cooling water discharge where temperature and other effluents remain measurably higher than ambient levels. The effect of radiation from both internal and external sources on a wide variety of aquatic biota have been examined in considerable detail in the laboratory, and to a lesser extent in the field. The objective of much of this work was to establish the lethal radiation dose (LD_{50}) for various aquatic organisms. The effects of radiation on reproductive capacity, spawning behavior, and lifespan have also been investigated in laboratory and field experiments.

It is clear that radiation does effect some biological parameters in adverse manner although the one of outstanding concern is reproduction. These effects increase as a function of increased temperature. Radiation should be regarded as a biological stress similar to temperature variations from the norm, chemical toxicants, and disease states except that long-term and cumulative effects must be considered. Under the "as low as practicable" concept for routine releases from nuclear operations, it is doubtful if biota resident immediately in the discharge will receive an additional radiation dose equal to natural background (about 125 mrad/year). Hence, radiation per se will be a minor contributing factor rather than a primary causative factor in the biological effect of discharges from once-through cooling of nuclear power stations. However, in order that observed biological effects (if there are such) in the outfall region not be falsely attributed to radiation, or conversely to another causative agent if radiation levels are high, the following measures are recommended:

1. Radiation exposure levels to aquatic biota should be calculated on the basis of radiological monitoring data at specific nuclear plant sites.
2. Radionuclide analyses should be performed at least seasonally on representative biota collected in the discharge region and the internal dose from such analysis should be calculated for these same biota. This recommendation is probably fulfilled by most current radiological monitoring programs.
3. Deploy clams or other suitable shellfish as biological accumulators and indicators of maximal radionuclide uptake and exposure; TLD dosimeters should be employed along with these biological probes. Taken together, these devices (Clams and TLD's) should provide a reasonable estimate of the upper limit of radiation exposure experience by resident biota at any given site.

Conclusion

In summary, the subcommittee feels that biological effects due to radiation under routine operation of nuclear power plants will be minimal, and in all probability unmeasurable. For the sake of completeness, however, it is felt that a quantitative fix on radiation levels should be obtained at various plant sites to test the validity of this prediction.

Priority Effort

In light of limitations of the interest of the Panel to radio-ecological aspects of the cooling water alone, and to the findings of the author, that biological effects due to radiation during routine operation of nuclear plants will be minimal, no research priorities have been assigned.

The author has recommended the following effort in order to insure that these limitations may be satisfied. Obviously no priority value or categorization is necessary.

A priority effort should be made to establish whether data on radioactivity from present monitoring programs is adequate to reliably predict the dose to the biota entrained or otherwise interacting with thermal discharge. Field measurements of radiation exposure are a necessary part of this effort.

APPENDIX

Comments of Members and Participants of the Panel related to Report Number 1

Appendix

Comments of Members and Participants

of the Panel related to Report Number 1

During the course of preparation of Report Number 1, a number of comment periods were designated by the Panel. On June 6, 1975, the final draft was forwarded to members and active participants of the Panel (those individuals who had commented on the previous draft report) for a final comment period. At the July 8, 1975 meeting, comments were distributed to authors of various sections of the report. Following discussion, authors agreed to incorporate comments where possible and prepare a written response to those comments which they did not choose to incorporate.

The following comments and written replies are the product of this endeavor:

Comments related to Section III

Measurement of the Effects of Cooling

Water Use on Physical Parameters

Comment of Jacob Verduin, Southern Illinois University, Carbondale, Illinois:

There is a great deal of data available concerning the chemical changes associated with once-through cooling. The data show that the chemical changes are small. No attempt has been made to summarize, review, or reference such data in the report.

Numerous studies have been made concerning the present, and projected level of thermal loading in Lake Michigan. These contain estimates of the temperature increment that can be associated with present and projected (year 2000) thermal injections. Such studies have not been reviewed, or referenced in the report.

Pertinent information on lake currents near the shore has been ignored. Bellaire made a study of currents in Lake Michigan (Publ. No. 10, Great Lakes Research Division, University of Michigan, Ann Arbor, 1963) that can be used to assign approximate values to alongshore currents. He portrays a net northward flow parallel to the west shore of about 0.3 miles per hour. Such a current pattern will move water from the Chicago area to the Milwaukee area in about 20 days. Consequently, any data obtained in the Milwaukee area probably reflect a strong influence of contributions from the Chicago area.

During 1973 six current meters were maintained near Zion, Illinois, by Hydrocon, Inc. These records confirm the net northward flow described by Bellaire, and show that periods of near-zero current flow usually last for only a few hours. Current reversals occur at 2-3 day intervals, there is an average northward flow of 4.6 miles per day, an average southward flow of 2.2 miles per day, yielding a net northward flow of about 2.4 miles per day.

Such currents have a profound influence on the dispersal of thermal (and other) injections, and they have a distinct bearing on proposed monitoring programs. For example: A "Reference" station located 8 miles north of a point of injection will be occupied by water that has moved up from the injection point within the previous few days. All direct evidence of a thermal injection will have been obliterated, but the biota sampled will not be "Reference" biota but will contain individuals that have recently passed through a thermal plume area.

There are many other pertinent data that should be referenced and evaluted if the report were to comply with the initial charge (page 2) to review background information.....relating to thermal discharges....

A written reply to these comments was not received.

Comments related to Section IV

Measurement of the Effects of

Cooling Water Use on Chemical Parameters

Comment of J.J. Ney, Wisconsin Electrict Power Company, Milwaukee, Wisconsin:

Operational Monitoring (pp. 114-115) presents an unjustifiably intense intake-discharge monitoring program. Studies at Lake Michigan power plants have demonstrated that concentration of nutrient and general water quality parameters are not perceptibly affected by condenser passage. However, concentrations do change on a seasonal basis. The parameters included in weekly measurement (p. 115) need be measured only seasonally.

A written reply to this comment was not received.

Comments related to Section V

Measurement of the effects of

Cooling Water Use on Primary Producer

and Consumer Communities

Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The field study guides described in this section are based to a large extend on two assumptions. It is assumed that residence time of plankton is sufficiently long that plume populations can be defined and thermal effects (through plume vs. reference area comparisons) isolated. A second, related assumption is that thermal input induces first-order perturbation such that change in lake populations can be traced to heat as the causative agent. Evidence to data from numerous studies tends to negate these assumptions. Plume entrainment time is generally limited to a few hours. Nutrient input from agricultural runoff and point sources is the primary agent of historical change in Lake Michigan planktonic communities.

While the 16 mile-transect sampling program in the various biological provinces as detailed for both phytoplankton and zooplankton assemblages should enable documentation of changes over time, it does not in itself permit determination of the sources of change. The site-specific program utilizing as many as 64 sampling stations at all depths is incapable of defining heat-induced changes to the transient populations.

A more constructive approach, partially outlined in this section, involves the development of predictive models of the reaction of the plankton communities to thermal addition. Input would include quantification of plumes, entrainment time and characterization (seasonal composition and abundance) of nearshore planktons assemblages. Short-term and repeated exposure bioassays and in-situ productivity experiments should be employed to determine thermal tolerance and response. Ultimately, models could be tested by field observation and simulation techniques. Like other studies described in this section, some of the necessary methodology remains to be developed. However, the total effort should be considerably less intensive and more fruitful since general models could be adapted to site-specific situations.

It is of interest that this approach is being used to define water quality standards for nekton, which are capable of establishing resident discharge-area populations. The fact that planktonic populations are incapable of such residency further recommends development of the modeling approach to assess thermal effects.

Written reply of E.F. Stoermer, University of Michigan, Ann Arbor, Michigan:

The possibility of greater reliance on modeling was discussed at considerable length by this subcommittee. Two major points became obvious from these discussions: (1) There is a great deal of uncertainty if state of the art simulation models can deal with the time transients possible in the near-shore zone of Lake Michigan; and (2) Data requirements for viable model would certainly be no less stringent than those proposed. It is probably desirable to work toward developing realistic ecological models of the scale Dr. Ney envisions, but it should be recognized that this would require considerable effort and resources beyond those presently employed by contractors engaged in site studies on Lake Michigan.

Comment of R.P. Herbst, The University of Wisconsin, Waukesha, Wisconsin:

General Comments:

These items have not been adequately addressed in the Microbiology Section.

1. The study area and areas of concentration should be indicated along with a rationale for those limits.
    a. Extensive and statistically sound use should be made of reference locations and times.
2. Collection of data on each environmental parameter should be justified.

Specific Comments:

Page 137 - Sub-paragraphs numbered 2 and 3 of, Measurements which should be made.... Rationale is not provided nor study design! Again justification is needed as to why ten stations are required when a minimum of two will be sufficient. Why are depth samples measured when the plume floats? Depth sampling will provide information on light penetration but why is this necessary? What is the justification for estimating nitrogen fixation? I cannot identify any rationale as to why this information would serve to be useful or how it would be applied to thermal discharges with the possible exception of baseline academic information. I think some rationale should be presented as to its use and validity for some environmental parameter affected by thermal discharges. Is it to be a metabolic indicator of the blue-green algal populations, or the amount of nitrate added to Lake Michigan from this source compared to sewage, industrial, agricultural, and natural inflows such as rivers and rainfall, etc.?

Page 138 - First and second paragraphs on the page beginning, "In addition.... There is very little justification for doing any of this work as well as more speculative statements without support. For instance why should there be an array of stations to "16 statute miles from shore" if the thermal discharge never reaches this far and "significant changes" in the algal populations occur over very short distances?!" It is further stated that these stations could serve as a possible monitor of whole lake effects. I see no way that this could be possible especially when it was stated earlier that the open lake's populations are completely different! Therefore, how could whole lake effects be determined from this sampling pattern? This is better attempted from the experimental procedures mentioned in the following paragraphs although there are severe limitations. In addition, the Statistical Analysis Section also presents the procedures for detecting variability as well as differences between locations and neither implies nor suggests a sampling scheme as indicated here. If the authors provide a statistical design for this "16 mile transect" perhaps its purpose, etc. can be ascertained. If again this is a "gut feeling" or a "nice bit of information" it should be so stated. If it can be justified that this will indeed provide some "monitor of possible whole lake effects" it should be so indicated.

In summation of my comments, I think it would be especially important for this section to have an economic assessment. It would be very noteworthy if extended to detail the information considered essential for thermal discharges and that which is of academic interest. This would enable a more precise evaluation of suggested studies and techniques for not only the writers but potential users. A great deal of the material in the Microbiology Section, while necessarily being the opinions of the authors and not the consensus of the Panel, would not answer with anymore validity, statistical designs of a more basic nature to assess effects of thermal discharges. Further, when costs for redundant data are examined, the financial consequences to taxpayers via grants, etc. as well as potential users are extremely high and might better be channeled into special studies of a nature which would delineate cause, effect and possible redesign.

Finally, I would like to compliment both Dr. Stoermer and Dr. Neese for a fine effort. Having actively participated in the many Panel discussions regarding the report and their section it becomes only too apparent that it is easy to criticize but that not enough recognition is given to the good parts. All aspects of this section cannot be completely satisfactory to everyone nor will they necessarily answer with any finality many of the questions asked. I think both men have attempted to provide the necessary background, etc. for this section. With only a few exceptions they have done an excellent job.

A written reply to these comments was not received.

Comment of Roy F. Heberger, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

In the current draft, most of my technical comments were adopted. I remain firmly opposed to use of the trophic level references. They are confusing and often misleading. The footnote on page 146 is, in my opinion, inadequate with regard to this problem. The only purpose the footnote served was that of avoiding necessary changes in the text.

A written reply to this comment was not received.

Comment of Jacob Verduin, Southern Illinois University, Carbondale, Illinois:

The recommendations concerning investigation of phytoplankton are unrealistic. The intensity of sampling number of depth intervals, number of stations, and biochemical analyses recommended (chlorophyll, organic nitrogen, organic carbon, nutrient uptake rates, nitrogen fixation rates, etc.) are not justified by any explanation of the goal such analyses are designed to achieve. It seems, rather, that most of the phytoplankton researches that have appeared in the literature during the past twenty years are here recommended for a monitoring program at an unprecedented level of sampling intensity in the hope that such a program may reveal some evidence of thermal impacts on the communities.

The program does not hold real promise of such a result. The postulated effects of thermal injection are:

a. injury by superoptimal temperature

b. stimulation of metabolism by increased temperature within the range of tolerance

c. shift in major component species from desirable to nuisance forms

However, none of these effects are specific for thermal injuections.

Injury to aquatic organisms has been a demonstrated effect of chlorination, and it is well known that chlorination of sewage effluents is required by Health Department regulations. Moreover, the currents along the west shore of Lake Michigan are of such magnitude and direction that waters from the Chicago area are distributed along the shore all the way to Milwaukee. If one were to establish a detectable injury to phytoplankton between Waukegan and Milwaukee, how would one distinguish between damage from chlorinated sewage effluents and damage from postulated thermal injury?

Stimulation of phytoplankton metabolism is a well-known effect of nutrient enrichment. Sewage outfalls, storm runoff from lawns and fields, provide such injections. If one were to establish a detectable increase in phytoplankton metabolism between Waukegan and Milwaukee, how would one distinguish between the stimulus derived from nutrient enrichment and that derived from the postulated thermal stimulus?

The trickling filters of sewage treatment plants are heavily populated with blue-green algae, which constantly break away from the filter and enter the lake as a potential innoculum of nuisance algae. If one were to detect an increase in nuisance algae between Waukegan and Milwaukee how would one distinguish between the importance of this source and the postulated influence of thermal impacts?

There is no evidence in the report that the serious problem of separating such effects is recognized. There certainly are no recommendations which will serve to isolate these effects so that a clear conclusion can be reached as to which source is responsible for a particular kind of community perturbation. The presence of sewage outfalls and the plant nutrient injections from the watershed must have an order of magnitude larger impact on lake ecology than the thermal injections of power plants on the lake.

Finally, there is an abundant literature concerning the response of aquatic (and other) organisms to temperature change. This literature makes it possible to evaluate the metabolic changes that are likely to occur in a thermal plume. Analyses of this kind have been made and are available, both in the scientific literature, and in testimony presented at operating permit hearings. They reveal that phytoplankton and zooplankton passing through a plume in Lake Michigan are likely to experience a 15 percent increase in their metabolic rate for a period of about two hours, after which they will return to ambient temperatures and normal metabolic rates. There is no evidence that such an experience has any prolonged or deleterious effects. Moreover, photosynthetic and respiratory rates have been measured within thermal plume areas under normal plant operation. These studies confirm the correctness of the predictions based on temperature coefficients gleaned from the literature. The failure to reference any of this literature, and to summarize and evaluate the predictions concerning metabolic rates in thermal plumes which have been derived from it, represents noncompliance with the first paragraph of the charge to the panel, as quoted on page 2 of this report.

Written reply of E.F. Stoermer, University of Michigan, Ann Arbor, Michigan:

It would appear to me that the substance of Dr. Verduin's extended comment is that anthropogenic effects on the Lake Michigan ecosystem are multiple, complex, and synergistic. It would appear to me that this is precisely why a reasonably comprehensive data collection program is needed to partition thermal effects. It is, unfortunately, a fact of life that Lake Michigan is a highly perturbed system. At this time it is entirely futile and unproductive to speculate what might be if other environmental insults did not exist. What is needed are studies which will evaluate the impact of thermal loadings on the real world Lake Michigan system as it exists. I agree with Dr. Verduin that it may eventually be necessary to extend studies to include synergisms, which presently appear improbable, such as the imput from trickling filters, but I do not think it possible to anticipate all possible effects in the present document.

Comments related to Section VII

Measurement of the Effects of

Cooling Water Use on the Fishery

1. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

As per your July 1, 1975, request to Mr. Howe, we have rewritten my June 25, 1975, letter concerned with the Fisheries Section of the Panel

Report in order to meet your needs for the final report. Commonwealth Edison requests that this section of the Report be deleted unless Mr. Edsall and Mr. Yokum reply to our January 16, 1975, comments as per the Minutes of the October 1, 1974, meeting.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We responded verbally to the comments in your letter of January 16, 1975, (as directed by the Panel on October 1, 1974) at a meeting held in the Region V EPA office (Mr. Howe represented your company at that meeting). We were advised by Mr. Bremer on July 1, 1975, that you subsequently requested a written reply to your letter of January 16, 1975, and we provided that reply on July 2, 1975.

2. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Unless they have already done so, they should also reply to comments of Dr. Verduin, Dr. Ney and Mr. Patriarche. The authors rebuttal to these comments should subsequently be appended to the report along with the comments.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We responded verbally to Mr. Patriarche who seemed satisfied with our reply and prepared a written response to Dr. Ney; we have not been advised that Dr. Verduin requested a written response and so did not prepare one.

3. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Because we believe based on past experience that no substantial changes will be made in the Fisheries Section, we also request that the Qualifying Statement (page iii) be identified. This modification should emphasize that the various Sections reflect primarily the opinion of the authors and are not a result of Panel consensus and do not constitute Panel approval.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe the comment regarding our unwillingness to make substantial changes in the Fisheries Section is untrue. We invite the reader to examine the 10/1/73, 2/22/74, 5/23/74, 10/29/74 drafts of Fisheries Section and to compare these earlier versions with the most recent one, which is being readied for publication. For example, as the result of discussions with Mr. Howe (and others), we:

1. updated and increased (nearly doubled the length of) the Literature Cited Section of the Fisheries portion of the Report;
2. altered the text of the Report relating to the tagging program to make it clear that mark and recapture studies are not recommended for use in the estimation of population size;
3. changed the performance criterion that asked the field sampling

program be adequate to detect differences of 5% (at $\alpha = 0.05$) to one adequate to detect true differences of only 20% (at $\alpha = 0.05$);

4. added the Qualifying Statement on pages 256-257;

5. revised, reordered, and "nested" our research priorities;

6. expanded and revised the Introduction;

7. added Figures VII-1 and 2 to provide a basis for bridging the gap between the intake and discharge effects sections of this report;

8. we did not attempt to present a complete review of the literature regarding cooling water use effects but rather selected for presentation only what we believe were important overview papers or papers that would lead the reader to the most current, relevant literature or to important ongoing studies.

See also our response to comment 4.

4. <u>Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois</u>:

We have prepared a modified Qualifying Statement which is attached for Panel consideration. (Statement not attached - cf. written reply to this comment).

<u>Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan</u>:

The Report now carries a Qualifying Statement that was approved by a majority of the Panel on July 8, 1975.

5. <u>Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois</u>:

Our last general consideration relates to impingement and station entrainment of various fish life history stages. A different committee addressed these considerations, and all reference in the Panel Report to fish impingement and entrainment should be deleted as referenced to the Intake Committee Report. We further note that neither consideration was a charge of the Panel in the November 9, 1972, U.S. EPA Statement which established the Intake Committee and Panel.

<u>Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan</u>:

We believe that the Panel was charged by the Region V Administrator to deal with the subject of cooling water use, which includes consideration of the entrapment/entrainment issue.

As authors of the Fisheries Section we exercised our prerogative of modifying the content of that section. The opportunity to comment on that section in your letter of July 3, 1975, was afforded you.

6. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

We strongly recommend that this Panel meet all of the original directives before assuming additional responsibilities. For example, the charge to the Panel was "to review background information dealing with past, present and future studies relating to thermal discharges in Lake Michigan". This has not been done, and in fact this charge should have been addressed before any recommendation related to additional studies was made. The recommendation for additional studies was the last and not first charge of the Panel which is the logical order by which the charges should be addressed.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe the record shows that the Panel reviewed the ongoing research programs at the Cook, Zion and Point Beach plants.

7. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

The Fisheries Section consists entirely of additional studies without review of past, present and planned future studies to support their proposal or list of priorities.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We cannot comment on the companies "planned future studies" because we have not been privileged to see these plans (but see also our response to comment 6).

8. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

The Fisheries Section should also delete references to impingement since the previous report we reviewed did not discuss impingement.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We have discussed impingement only to the extent we believed necessary to provide an adequate perspective for viewing discharge effects.

9. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

We strongly disagree with the statement on page 245 which indicates that current information on the abundance and dynamics of fish stocks is inadequate to assess impingement losses as they relate to respective populations. There is an abundance of literature or unpublished information related to stocking rates, commercial catch and standing crop of several species. Losses at screens are currently being computed and these losses can easily be compared to these population statistics to determine if there is a concern.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We point out on page 293 of the Report that limited information does exist on the abundance and dynamics of the fish populations of Lake Michigan (and indeed reference our unpublished report dealing in part with alewife abundance in Lake Michigan). However, we believe, as stated in the Report, that the available information is not yet adequate to assess the significance of the impingement losses at Lake Michigan power plants, and (as also stated in the Report) that the present basis for concern over the adverse effects of existing power plants on the fishery productivity of the lake is partly conjectural.

We assume that if an adequate demonstration of the significance (or non-significance) of these impingement losses could be made on the basis of the available data that such a demonstration would probably have been made.

10. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

On page 293, the authors reference a report which contains a standing crop estimate of alewives. This is undoubtedly the species which constitutes most of the biomass removed at traveling screens. Yet from reading page 245, one is led to believe there is no information available.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We certainly did not intend to imply that no information is available and would be agreeable to inserting a parenthetical statement on page 245 directing the reader to page 285 of the report.

11. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

We have no additional general comments about the Fisheries Section and would like now to specifically address the before and after studies described on pages 258-276. The following is basically a reiteration of our comments in my January 16, 1975, letter which the authors have not addressed.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See our response to comment 1.

12. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

The tremendous effort which the study plan recommends will not meet the stated objectives of determining size of fish stocks at the specific sites. The authors indicate mark and recapture methods will be used in making these estimates. All models, using such a technique, assume no immigration or emigration in the area for which the population estimate is to be made. The authors should review the assumptions in those references they used to support their techniques on page 265.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We are aware of the assumptions inherent in the use of mark and recapture data to estimate population size. The Before and After Section of the Report does not recommend that mark and recapture studies be used for this purpose (see page 273 of the Report), but rather that they be used to provide an assessment of which populations or stocks are resident or not resident in the site area.

13. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

There is more than adequate information to document that considerable movement takes place within a given study area and plume area. The authors should review some of the work conducted by Spigarelli (1972) at Point Beach.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We refer the reader in particular to the following papers which describe onshore-offshore movements of fishes and movements of fishes within and between effluent plumes in Lake Michigan: Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U.S. Fish and Wildlife Service, Fish. Bull. 67(1): 1-15, and to papers by Spigarelli, Spigarelli et al., Romberg et al., and Thommes et al. that appear in the Argonne National Laboratory Annual Report for 1973 (full citations of these latter papers are given in the Fisheries Section of the Report).

14. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Results of studies by Cochran (1974) at Waukegan Station demonstrated that the plume does not interrupt seasonal onshore-offshore movements, and in general, plume abundance is not much different than abundance in reference areas.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We suggest the reader study carefully Cochran (1974) and also those papers cited in the response to comment 14.

15. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Not only would the program not determine population size, which is the stated objective, but it could result in a greater kill of sport salmonids than impingement.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Given a 6-year Before and After sampling program (as outlined in the Report), an annual bottom gill net catch of 686 salmonids (data for 1973-1974; Table 1 of your letter), a four-fold increase in sampling effort (comment 19), and 100% mortality of fish caught in these nets (comment 20), we assume you would calculate a maximum kill in bottom gill nets of (6 x 686 x 4 =) 16,486 salmonids at the sampling site; using the data from Table 1 for the 6 months in 1974 we assume you would calculate a maximum kill of (6 x 474 x 2 x 4 =) 22,752 salmonids as a result of the sampling plan. Using a three-fold increase in sampling effort (comment 20) we assume you would calculate a kill of (6 x 686 x 3 =) 12,348 salmonids at the sampling site on the basis of your 1973-1974 data (your Table 1) and a kill of (6 x 474 x 2 x 3 =) 8,532 salmonids on the basis of your 1974 data (your Table 1).

Given an impingement kill of 145 salmonids per year (1973-1974 data from Table 1 of your letter) for the estimated 40-year life of the Zion Plant (316a demonstration for the Zion Plant) we calculate a maximum kill of (145 x 40 =) 5,800 salmonids by impingement; using the 1974 data we calculate an impingement kill of (138 x 2 x 40 =) 11,040 salmonids due to impingement.

The validity of the above estimates for the field sampling program must be viewed in respect to the responses we made below to comments 19-25 and 28-29. Likewise the estimates of the impingement loss cannot be verified by us without information on the seasonal pattern of entrainment during one calendar year of full plant operation.

We agree that the loss of salmonids and other valuable fishes killed by impingement and by the field sampling program is regrettable, but we cannot offer any alternative to measuring the effects of cooling water use that does not require the sampling of stocks and the killing of fish.

As stated in paragraph 3 of page 256 and paragraph 2 of page 257 of the Report, we clearly recognize that sampling plans and levels of sampling effort other than those proposed in these guidelines may be adequate for answering the questions posed in these guidelines. A clear demonstration of which of these questions can or cannot be answered with existing data or with data from ongoing studies would be of great interest to the Panel and to us.

16. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

This is the only effect of power plant operation, outside of speculations about chlorine, for this group which has been documented.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We refer the reader to pages 35-46 and 71-74 in Edsall and Yocum (1972) and to the papers of the Argonne National Laboratory cited in response to comment 13.

We believe that no adequate studies have been done at Great Lakes power plants of the effects of plant shutdown during that period of the year when salmonids in the plume would be susceptible to cold shock kill, despite the fact that shutdowns occur at this time of the year and that salmonids are present in the plumes at this time of the year; adequate data are also lacking for the effects of gas bubble disease despite the fact that conditions exist in effluent plumes during the colder portion of the year that could cause mortality (see Otto, 1973; full citation is given in the Fisheries Section of the Report.)

17. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Most State Conservation Departments would probably be reluctant to allow such a program.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe that the State Conservation Departments will make the appropriate decision in this regard.

18. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

We made a comparison of salmonid impingement at Zion with numbers collected in the monitoring program. Our sampling effort is about 3-4 times less than that recommended in the Report, and the results of this comparison can be found in the following table:

Comparison of salmonids collected at travelling screens with numbers collected in lake monitoring by gill nets, trawls and seines

Study Interval	Species	Sampling Method			Impingement
		Gill Net	Trawl	Seine	
July 1973 to June 1974	Lake Trout	237	12	0	1
	Rainbow Trout	11	3	3	5
	Brown Trout	41	18	12	4
	Coho Salmon	339	2	0	133
	Chinook Salmon	58	4	330	2
Total		686	39	345	145
July 1974 to Dec. 1974	Lake Trout	152	1	0	13
	Rainbow Trout	24	0	1	60
	Brown Trout	55	1	0	21
	Coho Salmon	116	0	0	44
	Chinook Salmon	127	1	16	0
Total		474	3	17	138

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We cannot respond to this comment without being advised of the manner in which this estimate was obtained (see also our response to comment 24).

19. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Assuming 100% kill of only gill net collected fish, the number of salmonids killed in Zion's present monitoring program was four times higher than the number impinged in the first year of operation, at what admittedly was reduced operating levels.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We have no basis for not accepting this statement.

20. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

The monitoring program for the last six months of 1974 killed about 2 1/2 times more salmonids than were impinged.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe the correct value, based on the data in Table 1 and the assumption of 100% mortality is 3.4 rather than 2.5.

21. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

Assuming a proportional increase in the number of salmonids killed in monitoring if the proposed study plan were initiated, approximately 1350 salmonids would have been lost or about 10 times the number impinged. This projection was based on increasing the number of bottom gill nets from 16/month in our present monitoring program to 46/month in the Panel Report.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See response to comment 16.

We believe the stated assumption of 100% mortality of salmonids captured in gill nets (and the apparent implied assumption of zero mortality of fish collected in trawls and seines?) is open to debate. Mortality would depend on a number of factors including: the manner in which the nets and their catch were handled; the season of the year (water temperature is important); the size of the individual captured relative to the size of the net mesh in which the individual was captured; the species captured (large coho salmon die quickly in gill nets and chinook salmon less rapidly whereas lake trout can survive gill net capture and release if proper precautions are taken).

Assuming a 100% kill of the 474 salmonids captured in gill nets (comment 20) and a three-fold increase in sampling effort (comment 19) you would expect a kill of 1,422 fish; likewise a four-fold increase in sampling effort would result in a kill of 1,894 salmonids--more than a ten-fold increase. However, we believe these estimates of kill are open to debate because the assumption of 100% mortality is not verified (see response to comment 20) and because it has not been shown that estimates of a three- to four-fold increase in sampling effort reflect sampling effort that would occur at times and places where salmonids would be present (see comment 22).

22. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

These estimates did not include any salmonids which would be killed by the oblique nets which would substantially increase the number killed.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Generally oblique gill nets catch far fewer fish per linear foot of net than do bottom gill nets, unless fish are distributed throughout the water column or are much less abundant on the bottom than at higher levels in the water column.

See also our response to comment 21.

23. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

It can also be expected that the number killed would increase for power plants located in states where extensive salmonid stocking programs are underway.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that larger numbers of salmonids probably would be captured and killed in areas of higher salmonid abundance.

24. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

We did not have time to stratify these projections by depth contour...

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

This is essential if your statements regarding the magnitude of the loss of salmonids resulting from implementation of the sampling plan outlined in the Fisheries Section of the Report are to be accepted at face value.

25. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

...but we did not use the general tactic employed by Mr. Edsall and Mr. Yocum in their review of power plant studies. In this case we would have selected the single gill net with the highest number of salmonids and multiplied by 552 or the total number of sets for each year.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

This comment appears to be related to a review we prepared for the Panel of the PL 92-500, section 316a demonstration for the Zion Plant. We believe it would not be proper to deal with it here but wish to point out that it suggests that the view expressed in comment 6 is not entirely justified.

26. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

The before and after studies are estimated to cost approximately $1 million dollars/year or $6 million dollars for a new station with 3000-4000 cfs intake flow.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We cannot respond to this comment without access to the cost factors on which the estimate is based.

27. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

In light of the above review, the studies should be substantially reduced. We recommend that sampling be done only within the 10 meter depth contour as recommended by Mr. Patriarche. In addition, sampling for quantitative purposes should also be designed to evaluate primarily the dominant species as recommended by Dr. Verdiun.
(NOTE: Six lines of comment have been deleted here and are presented below as comment 28.)
An attempt to detect these differences at each location over time and between locations within time in Figure VII-3 for most species would be ecologically irresponsible and should require an Environmental Impact Statement.

Thus, we urge that for quantitative purposes only two locations, one reference and one experimental, be sampled with sufficient intensity to detect a 20% change. This experimental design would permit an evaluation of preoperational-operational abundances as well as attraction - avoidance to the thermal plume. Furthermore, the sampling effort should be restricted only to dominant species. These studies, including the bottom trawls, use relative abundance as an index to population change and do not estimate population size.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe that the Questions to be Answered that are presented in the Fisheries (and Entrapment/Entrainment) Section(s) of the Report require answers if the effects of cooling water use on the fish and the fisheries of Lake Michigan are to be adequately assessed. These Questions can be answered with existing data if adequate data exist, or with new data yet to be collected.

We enclose a copy of our response to Dr. Ney's letter of July 1, 1975, which deals with the issues raised in your comment above. (Enclosure is not a part of this appendix.)

28. Comment of J.H. Hughes, Commonwealth Edison, Chicago, Illinois:

On page 257, the authors recommend a sampling effort which can detect a 20% change in population size with $\alpha = 0.05$. This should only be done for major species at a few locations since the number of replicates at each location would also have to be substantially increased above the two replicates the authors recommend if they wish to detect a 20% change.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe Mr. Howe informed us that a 20% change in population size with $\alpha = 0.05$ could be obtained with the data currently being collected for your company which we believe involves duplicate (two replicates) sampling (Cochran 1974).

* *

1. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

It is unfortunately not possible to endorse this section or even to provide brief constructive comments which render it more scientifically acceptable. A number of fisheries biologists who have reviewed it have expressed strong reservations about both the feasibility of the proposed program and its ability to answer relevant questions concerning cooling water effects. Alternative methodology has been suggested but largely ignored.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Approximately 100 copies of the Lake Michigan Cooling Water Studies Panel Report were distributed for comment and we have attempted to respond (as directed by the Panel on 10/1/74) verbally or in writing to each person who offered comments of substance on the fisheries section of the Report and to make changes in the text of the Report that we believed would improve the usefulness of that section of the Report as a guideline for assessing the local and lakewide effects of cooling water use on the fish and the fisheries of Lake Michigan.

Issues of substance in these written comments that did not result in modification of the text of the final draft of the Report should be included in the Appendix of the Report.

2. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The description of intake effects on Lake Michigan fishes (pp. 246-248 and p. 250) is completely out of place in this section. The situation has been thoroughly discussed in the Lake Michigan Cooling Water Intake Structure Technical Committee Report (1973) and in Section VIII of this document. Inclusion of a separate interpretation of the problem here serves only to further confuse the issue.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe that the charge to the LMCWSP by the Region V Administrator included consideration of intake effects. We have discussed intake effects in Section VII of the Report only to the extent necessary to provide an adequate perspective for viewing discharge effects.

3. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The presentation of conjecture (e.g. "it is clear that all of the fish large enough to be impinged on the travelling screens of existing power plants on Lake Michigan are killed"...p. 250) as fact is especially deleterious to objective analysis of entrapment effects.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

The reader is directed to paragraph 2 of page 250 of the Report from which the above quote was excerpted. The remainder of the quote is, "...when they are drawn into these plants because none of these plants are now equipped with devices that would permit returning these entrapped or impinged fish to the lake alive." We believe this is a true statement and as such can only aid in the objective analysis of the effects of cooling water use.

4. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Most of the survival-threatening conditions noted on pp. 251-254 have not been observed to occur as a result of Lake Michigan cooling water discharge.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Various published studies (see pages 251-254 of the Report for references) suggest that high velocity jet-type discharges may cause damage to fish. Therefore, we believe that this potential problem area should be systematically investigated at Great Lakes plants.

We believe that the potentially adverse effects of chlorine in waste heat discharges have been adequately demonstrated (item 3 on page 251 of the Report). We also believe that predation on fish fry incapacitated by heat shock and mechanical damage has been observed in the discharge of the Nanticoke generating plant on Lake Erie (item 5 on page 251 of the Report).

5. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Laboratory experiments and studies of other ecosystems serve only to define areas of potential concern.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree in part. We would add that the behavioral responses of unconfined fish at the cooling water use site must be studied to provide a completely satisfactory interpretation of laboratory or on-site bioassay studies.

6. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

This report was designed as a guide for study design. As with any guide, flexibility in implementation of procedures is a requisite. While standardization of methodology is a commendable goal, it should not be realized at the expense of rational design.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree in principle (see pages 256 and 257 of the Report); however, see also our response to comment 18 as it relates to Lakewide Studies and the attendant need for intersite standardization of sampling plans.

7. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Deviation from prescribed procedures (p. 257) do not require "clear justification" (to whom?) since these procedures are often arbitrary in themselves (See comments 8, 9, 10, and 11)

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We had hoped that the Report would be viewed as an attempt to provide a comprehensive guide to aid in objectively determining the effects of cooling water use on the fish and fisheries of Lake Michigan. We believe that the accumulation of a scientifically acceptable body of fact regarding the effects of this use of the waters of the lake is the best approach to resolving this issue objectively. To this end we propose that the word "scientific" be inserted between the words "clear" and "justification."

8. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Encompassing and saturation of the plume area with sampling stations is exorbitantly expensive and unnecessary to determine cooling water effects.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that the proposed sampling plan for Before and After studies will be expensive, but have no way of determining its cost relative to the cost of ongoing studies at Lake Michigan plants because information on the latter costs are generally unavailable to us.

9. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Stations should be limited to 6-foot-interval depth contours within the plume area and at similar depths in a representative reference area.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We doubt that this proposed alternative plan would be an adequate substitute for the plan offered in the Report. (See also our respone to comment 10).

10. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Adoption of the pattern in Figure VII-3 would impose a degree of rigidity on the study design which can't be justified relative to the variable configurations of plumes and lake morphometry for each unique facility.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

The sampling grid (Figure VII-3) was chosen after examining a large number of other study plans. It incorporates what we believe are the most desirable features of these other study plans as these features could be adapted to the situation on Lake Michigan (for example, see: Garton, R.R. and R.D. Hawkins. 1970. Guidelines: Biological surveys at proposed heat discharge sites. U.S. Environmental Protection Agency. Water Pollution Control Research Series. 16130--04/70. 99 pages).

Two of the major considerations we took into account in designing the grid were lake morphometry/bathymetry(one determinant of the station locations are the depth contours) and the variable nature of the effluent plumes (the grid was designed to cover that portion of the lake in which the waste heat from the plant could be expected to be detectable, plus a surrounding reference or control area in which no temperature elevation could be expected to occur).

The area of highest station density within the grid reflects what we believe to be the area in which the plume will be most frequently located. Shoreline extensions of stations (up to 7.5 m in both directions from the center line were included to take into account the poorer mixing conditions that occur when an offshore wind holds the effluent against the shoreline, thus creating a more elongate plume. The lakeward extension of stations (those along the center line on the 90-120 foot depth contours) was included primarily to permit documentation of the offshore-onshore distribution and movements of fish in the site area, as these would affect seasonal changes in vulnerability of the various fish species and their life stages to the effects of the plant. For example, if it could be demonstrated that the offshore waters of the lake (rather than only the waters of the littoral zone) were an important nursery area for most species of fish, our concern over locating plant intakes and discharges in the littoral zone would be greatly reduced.

The "bilateral" symmetry of the grid (stations at depths of 60 feet and shallower) was included as a design feature because it permits nested analysis of the data.

11. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

As a workable alternative, the following design should be considered:

Sampling stations should be located at 6 foot-interval depth contours within the plume. Owing to the variable configuration of plumes, potential sampling stations should be located on a grid, with actual stations dependent on the plume configuration on each sampling day. One station should be located in the immediate proximity of the discharge. Fixed stations should be located on the same depth contours in a representative, thermally-unaffected reference area. To illustrate: if the areal extent of a plume is limited to the 30 foot depth contour, stations would be located along the 6', 12', 18', 24', and 30' depth contours in the plume and in the reference area. In this instance, a total of 10 stations would be sampled.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Because the stations are fixed,they can provide the time-series data needed for a Before and After type analysis. We believe that the alternate sampling plan outlined in the above comment would be more suitable for use in answering questions posed on pages 276-280 (Intensive Plume Studies) of the Report (see also our response to comment 10).

12. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The Materials and Methods described beginning page 260 are unnecessarily intensive to obtain answers to basic questions. The costs (biological and economic) of this type of sampling program cannot be justified, especially since direct evidence for significant adverse effects of thermal addition on Lake Michigan fishes is negligible.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

To our knowledge it has not been adequately demonstrated that the effects of power plant discharges on the fishes of Lake Michigan are negligible.

13. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Comparison with the results of previous sampling indicate that the gill net sampling program along would kill in excess of 20,000 salmonids/site/year.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

The validity of this statement cannot be determined by us because the basis for the estimate is not given.

14. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

This is clearly intolerable to the various management groups; no one wants to destroy the fishery in order to save it.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See our response to comment 18. Without answers to the Questions posed on pages 293 and 294 of the Report, we are left with little on which to base our assessment of the significance of the effect of cooling water use.

If use of the sampling plan results in an intolerable kill of salmonids and other desirable fish, we believe the management groups with proprietary interests in the fish and fisheries of the lake would order a reduction in that kill.

15. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The following modifications are suggested for consideration in development of a realistic sampling plan:

Page 260 - 1a. Trawling should be conducted on transects along contours, not at stations.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

This is covered in item c.2. on page 261 of the Report.

16. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 260 - 1b(1). Use of the 16 ft. bottom trawl results in redundant sampling in the 0-10 ft. zone. b(1) can be deleted in favor of using the 39 ft. trawl at depths greater than 6 feet and the seine from 0-6 feet.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

The vessel required to tow a 39-foot trawl effectively would probably not be able to operate safely in less than 10-12 feet of water; the 16-foot trawl could be towed effectively and safely with smaller, shallow draft vessels at water depths of less than 10 feet.

17. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 260. Bottom trawling is often not possible due to obstacles (rocks, trees, etc.). Provision should be made for substitution of midwater trawl, so that sampling will cover those depths contacted by the plume on the sampling day.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

If bottom trawling in shallow water is not possible, we would recommend the use of a seine or trapnet. We believe midwater trawling technology has not been developed to the point that we would recommend that it be used routinely as a substitute for bottom trawling in shallow water.

18. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 262- 1.3d. Age determination, if it is to characterize populations, is an involved, laborious process which must be performed for each species. Length-frequency analyses and condition factor determinations will provide sufficient information concerning population structure and well-being to reveal harmful effects. Aging, if conducted at all, should be confined to species known to be resident. Applying this effort to transients in a localized study is fruitless.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Section VII of the Report deals with the assessment of both local and lake-wide effects. The objectives of the lakewide studies are stated on page 292 of the Report and include a description of the age structure of the fish populations of importance. The (local) studies we have outlined for implementation at cooling water use sites are designed to provide data that will contribute to the success of the lakewide study effort.

We would be agreeable to insertion of the following paragraph in the text of the Report on page 262 between paragraph 2 and 3 of section 3d:

Scale samples should be taken monthly from at least 300 fish (age group I and older) of each of the following species: smelt, alewife, yellow perch, and each species of coregonine captured. If subsequent analyses of the age composition of the annual catch shows agreement with estimates obtained by resource agencies conducting similar research on the fish stocks of the lake, this sampling effort can be reduced so that scales are collected annually only during one of the fall sampling series.

19. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 264-265-(5)(a) through (5)(c) - Feeding habits, contamination, and fecundity analyses should be limited to only those species known or suspected of prolonged plume residence. Killing deepwater ciscoes, for example, to perform these analyses is both superfluous and deleterious. (5) should include a provision limiting sample preservation to those species suspected of plume residence.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that items 5a-c should be performed on fish known or suspected of prolonged plume residence. However, we do not wish to exclude the possible need to study plume effects on those other fish species which may avoid the plume or reside in the plume briefly. For example: if the periodic presence of the plume in a given area alters the benthos community in that area, the feeding opportunity of fish (that avoid the plume but move into that area after the plume has departed) may be altered; also the successful incubation of fish eggs spawned in a given area when the plume is not impacting that area, may be reduced when the plume returns.

20. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 265 e(1). Population estimates should only be made for resident populations. As with aging, population estimation is a laborious and somewhat sophisticated process and should not be performed on transient species, estimates for which would be useless.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See paragraph 1 of the response to Comment 18.

21. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 266 2(a). Gill net sets should be located as follows: one oblique and one bottom net at near field and at far field stations in the plume and at comparable depths in the reference area. Sampling frequency should be limited to four successive 12-hour sets.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Reduction in the sampling effort below levels specified on pages 266 and 269 of the Report is desirable (see paragraph 2 on page 257 of the Report), if it can be demonstrated (for the entire area impacted by the plume during all seasons of the year) that the "Questions to be Answered" on page 258 of the Report can be adequately answered with a reduced sampling effort.

We do not believe the alternate sampling program proposed in the above comment would be an adequate substitute for the sampling plan presented for use in the Before and After Section of the Report; we believe the alternate sampling plan presented in the comment above may be better suited for studies of the type outlined in the Intensive Plume Studies portion of the Report (pages 276-287).

22. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 271 4a. Fry sampling should be conducted on transects along contours from 6' to edge of plume and over same depths in reference area. Sample at surface, middle depth and, where possible, bottom. 4c (2) should advise night sampling to reduce larval avoidance.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See response to comment 21.

23. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 272 5a. Pump sampling stations should be confined to 6' interval depth contours in plume and reference area. 5b - Water should be passed through 351 micron mesh to be compatible with entrainment sampling. 5c(2) Sampling should commence April 15, unless smelt are not considered.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

See response to comment 21.

A number 30 mesh screen would retain the smallest fish egg that would be encountered in Lake Michigan, therefore, there is no need to use a 351 micron mesh for pump sampling for fish eggs.

We agree that pump sampling should begin early enough in the spring to assess deposition of eggs by smelt.

24. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 275 6(b) (2). Tagging should be performed coincidental to other sampling, with viable fish tagged and returned. The separate effort outlined here is unnecessary unless viable fish are not captured by trawl, seine and gill net. Tagging should also be confined to these species suspected of plume residence e.g., if brown trout members are seasonally higher in the plume than in the reference area, tagging studies should be performed to determine potential interference of the plume with migratory behavior.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that "coincidental tagging" may provide enough fish to meet Before and After study needs; but see also pages 276-287 of the Report.

25. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Intensive Plume Studies (page 276) and Laboratory Studies (page 289) afford the best means of defining real problems of fish relative to cooling water discharge. In the logical sequence of investigation, the seasonal plume residence patterns of the various species should first be determined. Results of thermal laboratory bioassay and behavioral studies can then be applied to focus concern on those species for which adverse effects can be anticipated. The field sampling program should then be refined to determine the magnitude of such effects.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

In general we agree that the most obvious direct effects of cooling water discharges on Lake Michigan fish will be most easily defined by means of Intensive Plume Studies and Laboratory Studies. We are in general agreement with the rest of the comment.

26. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

The results of both Intensive Plume and Laboratory Studies should have general application and need not be replicated at each site.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We believe that some of the studies conducted at each cooling water use site may not have to be repeated at other sites.

27. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Intensive Plume Study No. 4 (p. 286) is only relevant if ΔTs experienced in plume shifts or upwelling have a potential for deleterious effects. This information has been, or can be, obtained in bioassay. The same holds for chlorination. This study guide should note that efforts should be confined to those species which show adverse effects at the ΔT or chlorination levels observed at the site.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that information from the literature, or from the results of on-site bioassay studies or studies conducted in the laboratory, together with information on plant operating characteristics and local limnological conditions can be used to provide a demonstration of the likelihood of damage to fish as a result of the discharge of waste heat and toxic chemicals at a given site; therefore, we also agree that these "non-field" studies can serve adequately as the basis for excluding species of fish from study of specific effects at particular cooling water use sites.

28. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

There is little evidence that water quality in Lake Michigan varies so widely as to necessitate site-specific chlorine toxicity tests (p. 287). Section III of this report, while describing chemical parameters makes no mention (other than influence of adjacent tributary streams) of intra-lake water quality differences. Information obtained using water within the range of normal Lake Michigan chemical composition should be of general application.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We have seen no evidence to indicate that water quality in Lake Michigan at the various cooling water use sites is so uniform as to preclude the need for onsite or site-specific chlorine toxicity tests. Furthermore the design and operating characteristics of plants on Lake Michigan vary widely and these may be important in determining the probability of damage to fish occurring as the result of chlorination.

29. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

(Pages 287-289). Although on-site bioassays can be of value in determining actual effects of chlorination, cold shock etc. as they occur in the field, it should be recognized that *in-situ* bioassays which require caging of fish apply artificial stress which can have an additive effect. Results of such studies must be considered relative to their limitations. If the natural environment cannot be successfully simulated, on-site bioassays and behavioral experiments may be worthless. Cage studies can be used to verify results of laboratory experiments - an iterative procedure. However, results at odds with lab findings are of value in inverse proportion to the artificiality of the situation.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We realize the laboratory studies and on-site bioassays cannot be expected to reproduce exactly the field conditions that result from cooling water use at a particular site. We recognize that the behavioral responses of unconfined fish at a cooling water use site must also be studied to provide a completely satisfactory interpretation of non-field studies and therefore of the effects of cooling water use.

The procedures that we recommend on pages 288 and 289 of the Report represent the best methodological approaches available at the time we drafted our contribution to the Report. As better methods become available they should be used.

30. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Materials and Methods 1, 3, and 5 (pp. 288-289) are completely artificial situations and results can have, at best, limited relevance. They should be discounted.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We disagree (see responses to comments 27 and 29).

31. Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

In addition, all cage studies must include control groups and both groups should be tested for sub-lethal physiological stress. It should also be noted that results of all of these experiments have general application.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

We agree that the use of control or reference groups is essential and that measures of both acute and sub-acute effects may be necessary and that some of the results of these studies may have application at more than one cooling water use site.

Comments related to Section VIII

Measurement of the Effects of Cooling Water Use

on Entrapped and Entrained Organisms

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Pump Location - Pumps should be located behind the traveling screens if at all possible to avoid the problem of pumping adult fish in the collecting nets. We have experienced several pump cloggings when numerous adult fish inhabit the intake bays.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I agree completely.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Planktonic eggs - It has been impossible to establish numbers of planktonic eggs being entrained due to the problem referred to in Pump Location (above) and compounded by the occurrence of ripe females in the intake that expel their eggs during the stress of impingement. These eggs would be sampled on either side of the screens thus possibly resulting in a significant error in estimates of planktonic eggs.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I believe that the freshwater drum (Aplodinotus grunniens) is the only fish species in the Great Lakes that has a truly planktonic egg.

The problem of distinguishing between eggs entrained from the lake and those expelled by entrained fish may be a difficult one, however, sampling simultaneously at the intake crib and in the traveling screen well should provide a basis for determining the relative importance of the two sources.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Net Mesh Size - The recommended 351 micron size is not a normal stock size at Wildco, thus necessitating a special size. Why is 351 micron mesh so critical. Why not their 363 micron size? Its been our experience that the small 333 micron size we are using collects so much zooplankton and suspended material that samples take much longer to pick at times. We are also using 571 micron mesh at the Monroe Plant, due to the heavy organic load, and still collect eggs and all developmental stages of fish.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

Our experience has show us that 351-micron mesh is about the largest mesh size that will capture the smallest fish eggs and larvae found in the Great Lakes. We have conducted no mesh selectivity studies using 363-micron mesh but suspect that it would result in a slightly lowered catch of the earliest life stages of some Great Lakes species. There can also be little doubt that 571-micron mesh would permit the loss of a considerably higher percentage of the earliest life stages of several species of Great Lakes fish than would either 351- or 363-micron mesh.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Pump Type - What type of pump can be used to insure an adequate sample size and still not cause damage and mortality to the larval fish? This should be included in this report, and also inclusion of the basic plan for the Great Lakes Fishery Laboratory's automated pump system, if that is the recommended type.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

The Report suggests (pages 333-334) that "damage and mortality" assessment be made with samples collected in plankton nets suspended in the cooling system flow rather than with the samples obtained by pumping.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Pump Numbers - What procedure should be utilized to establish exact pump locations when the plant has more than one unit? This should be in this section, especially when investigators are asked to "document horizontal and vertical stratification" in the intake and now I assume in the discharge.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I can only suggest that the investigator take the empirical approach in answering this question. If the investigation cannot demonstrate that he has satisfied the assumptions implicit in sampling, then his results surely will be open to debate.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

Determination of Live and Dead Larva. Has any work been done on survival rates of larval fish pumped and collected in nets and the effect on them? How long can a larval fish survive retention in a net, a matter of minutes or several hours. This will directly affect frequency of sample removal and determination of mortality.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I agree that information of this kind is needed to adequately evaluate the effects of entrainment in some situations.

Comment of R.S. Benda, Aquinas College, Grand Rapids, Michigan:

I agree this is probably one of the most important parts of the overall evaluation of the impact of once-through cooling, but it seems that aspects are going to be difficult if not impossible to determine (i.e. page 330, number 9). Thank you for allowing me to comment on the section. I'm sure its been a difficult task to accomplish.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I agree that it may be difficult to answer question 9 on page 330, but if the answer to question 3 on page 329 is "yes", then it becomes necessary to address question 9 if means other than closed cycle cooling are sought to reduce entrainment damage.

Comment of J.R. Gammon, De Pauw University, Greencastle, Indiana:

I have expressed the view previously concerning the entrainment section of the Report, but let me briefly reiterate my views. I believe that the research program outlined in this section is a very complete and ambitious one. I would very much like to see it implemented at one or more (up to four strategically located) stations to test its capability and search out its difficulties. However, I feel that such a program at each and every power station would not be reasonable in terms of use of time, effort, and money.

A written reply to this comment was not received.

Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 329, Number 3. The phrase "when added to the other losses resulting from cooling water use" should be deleted. Evaluation of cooling water intake structure impact should be made separately (per Public Law 92-500, Section 316 (b)) from other cooling water use effects. Remedial (best available) technology for cooling water intakes to alleviate entrainment/entrapment impact can be applied without substantial modifications to other facets of power plant operation. Since evaluation of the impact and the application of potential corrective measures for cooling water intakes are not dependent on other aspects of cooling water use, the issue is self-contained. If cooling water use effects are considered in toto, it will be extremely difficult to determine appropriate corrective action. If the present wording is retained, it could be construed that Questions 4 - 9 on pp. 329-330 should be addressed in situations where entrainment/entrapment is negligible, but other cooling water use effects on fish populations are significant. In this instance, considerable effort and expense would be directed toward answering irrelevant questions.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I have asked to have the words, "...in itself, or...", inserted immediately ahead of the phrase you suggest be deleted. I believe that this addition will help convey to the reader the idea that evaluation of the significance of the effects of entrainment on "non-screenable" fish, fish larvae, and eggs should first be made independently of the other possible adverse plant impacts on these classes of organisms. However, it should also be apparent to the reader that the incremental loss of fish, fish larvae, and eggs cannot be judged insignificant until it is added to the incremental losses caused by all of the other aspects of plant operation and until this "total" loss is evaluated in respect to its impact on the local and lakewide fish population for the (one) plant operating alone and for the plant operating in concert with other similar plants on the same water body.

Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Page 333, Sampling Frequency and Duration. Sampling should be performed continuously every fourth day of plant operation April 15 - October 31, during one year. Sampling in additional years should be contingent on the results of the first year's study and may not be required. The Lake Michigan Cooling Water Intake Technical Committee's Report on the Best Available Technology (1973) recommends one day per week sampling as a minimum. The several regulatory agencies which are currently administering Lake Michigan entrainment survey programs have suggested sampling of approximately this frequency.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I have seen no data which shows that "...sampling every fourth day..." (etc.) would be adequate to describe the kinds and numbers of fish eggs and larvae (ichthyoplankton) that are entrained (continuously), and until such data demonstrating the adequacy of that sampling frequency are made available for public review, I believe it is appropriate for me to support the sampling program outlined in the Report.

Comment of J.J. Ney, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

Sample Processing (p. 333) and Sampling Process (p. 335) should be identical; instructions need not be repeated.

Written reply of T.A. Edsall, U.S. Fish and Wildlife Service, Ann Arbor, Michigan:

I disagree. The Sampling Process outlined on page 335 is for studies designed to permit assessment of in-plant mortality of non-screenable fish, fish eggs and larvae and requires examination of the samples at the time they are collected. The Sampling Process outlined on page 333 is intended only to determine the kinds and numbers of non-screenable fish, fish eggs, and larvae that pass through the plant; this can be done from preserved samples as indicated on page 333.

General Comments

related to Report Number 1

Comment of F.R. Boucher, Wisconsin Electric Power Company, Milwaukee, Wisconsin:

I have reviewed and discussed with my staff the Lake Michigan Cooling Water Studies Panel (LMCWSP) Report recently entitled "A Statement of Concerns and Suggested Ecological Research" and offer the following general comments as a member of the LMCWSP.

1) While the document may well represent a "best efforts" attempt by a panel of diverse technical background and interest, the report unfortunately retains much of the inconsistency of approach, format and possible purpose which plagued its earlier drafts. Most sections are reasonably well-organized, defining pertinent questions concerning

cooling water effects and proposing logical measures to provide answers. This is especially true of the Macrozoobenthos Section. Other sections, notably those dealing with Primary Producer and Consumer Communities and with Fisheries, appear significantly less rationally developed and may negatively affect the utility of the entire report. In these sections, study measures of immense magnitude are described, often with no clear explanation of why they might be either necessary or even capable of providing useful answers relative to cooling water effects. Little or no concern is given to the feasibility of their implementation. It is obvious that the clarity and logic of these sections must be markedly improved if our report is to reflect the quality and intention of the Panel and be the meaningful document which we all intend it to be.

2) As I understand the motion adopted by the Panel at our October 1, 1974, meeting, comments on the program were to be solicited for incorporation into the October 29th draft of the Report. Comments not incorporated were to be rebutted by the section authors. It is apparent that comments on several sections were neither incorporated nor rebutted. For example, Dr. J.J. Ney and other fisheries biologists have charged (ref. J. Ney letter to T. Edsall, December 26, 1974) that the Fishery sampling program would bill an intolerable (to management groups) number of sport fish. This allegation, if true, could jeopardize acceptance of the entire report; yet no response to it has been made. To satisfy the explicit intention of the Panel expressed by its action of October 1st, the Report cannot be finalized until the solicited comments are considered in this manner.

3) As you yourself have noted in your June 6th memorandum, sections of the Report reflect the view of a particular author. The Report clearly is not a product of the Panel on the whole. It was for this very reason that comments of other acknowledged experts were requested so that a more balanced overview might be presented. It is fundamental to the production of the Report as an objective and useful document that expert commentary not be ignored and that the procedure adopted by the Panel be followed prior to its completion, printing and distribution.

Written reply of E.F. Stoermer, University of Michigan, Ann Arbor, Michigan:

Studies of the type outlined under the section on Primary Producer and Consumer Communities are routinely accomplished by any number of scientific institutions. I see no reason why the feasibility or implementation of such a project should present "immense" problems to any qualified investigator.

Reply of K.E. Bremer, U.S. Environmental Protection Agency, Chicago, Illinois:

A reply to comment 2 is furnished on page 356, reply to comment number 2.

Comment of J.Z. Reynolds, Consumers Power Company, Jackson, Michigan:

This is in response to your request for consideration and comment on the final draft of the Lake Michigan Cooling Water Studies Panel Report Number 1. Inasmuch as I have commented in detail on previous draft sections of the report, I will limit my remarks here to general observations of how I feel about the final version of the report.

The improvements that have been made from earlier drafts are largely editorial and do not reflect much responsiveness of a technical or objective nature to the comments received. The various sections remain largely the product of the invividual authors, and are not a concensus of the Panel or those who commented. The Microbiology and Fisheries Sections suffer most in this respect, since they received the most critical comment but, lacking a formalized review procedure, this must be the case to some degree for all sections. Therefore, the Qualifying Statement should more clearly emphasize that the different sections represent the personal views of the authors and various references to "Panel" views scattered throughout the report are generally those of the section authors.

The final title for the report adequately characterizes the content, but much of the "suggested ecological research" has not been justified in terms of scientific validity or cost effectiveness. Suggested data collection activities are not related to study objectives or the Panel's role of determining what is ecologically significant or important. Further, while the priorities for research in each category reflect some ordering of concerns, there has been no attempt to relate the priorities of one category to the relative needs in another. This is a severe limitation on the usefulness of the report.

I regret that I am not being very constructive in my comments, as you requested, but I feel compelled to note also that the findings related to the charge to the Panel, of reviewing and assessing the adequacy of studies relating to thermal discharges, are not reflected in the report. In many cases the Panel, in reviewing specific study plans, determined them to be adequate, but comparison with the "suggested ecological research" would indicate they are totally inadequate. Such contradictions without explanation, in my opinion, severely threaten the credibility of the Panel as a technical advisory group.

A written reply to this comment was not received.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-905/3-75-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE A Statement of Concerns and Suggested Ecological Research: Report Number 1 of the Lake Michigan Cooling Water Studies Panel		5. REPORT DATE November, 1975 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lake Michigan Cooling Water Studies Panel C.D. Meyers and K.E. Bremer, editors		8. PERFORMING ORGANIZATION REPORT NO. Report Number 1
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lake Michigan Cooling Water Studies Panel U.S. Environmental Protection Agency 230 South Dearborn Street Chicago, Illinois 60604		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Surveillance and Analysis Division, Region V 230 South Dearborn Street Chicago, Illinois 60604		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report presents a statement of concerns and suggested research by the Lake Michigan Cooling Water Studies Panel. The intent of the statement is to assist the development of investigations of the effects of cooling water use on Lake Michigan.

The introductory considerations of Lake Michigan are presented in the first section. The second section presents recommendations toward objective quantification of the effects of cooling water use through proper statistical planning, study design, and data collection. The remaining seven sections relate information the authors consider basic to an understanding of the effects of cooling use on physical and chemical aspects, primary producer and consumer communities, macrozoobenthos, fishery, entrapped and entrained organisms, and radioecology of Lake Michigan.

All sections of the report attempt to produce improvement in research design and a trend toward standardization of results. In addition, questions are posed and ranked resulting in numerical priorities with the intent to guide research in those areas of knowledge which are barriers to an adequate understanding of the effects of cooling water use.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Cooling Water Aquatic Biology Biostatistics Entrainment Benthos Plankton Fisheries Hydrology Water Chemistry Limnology Ecology	Lake Michigan Thermal Effects Radioecology	6 F 13 B

18. DISTRIBUTION STATEMENT Limited number of copies from U.S. EPA, Chicago. At cost of publication from NTIS, 5285 Port Royal Rd., Springfield,Va. 22161.	19. SECURITY CLASS *(This Report)* 20. SECURITY CLASS *(This page)*	21. NO. OF PAGES 22. PRICE

EPA Form 2220-1 (9-73)