MASTER

~~C00/2003--T1~~

C00--2003--T1

NUTRIENT ENRICHMENT AND
EUTROPHICATION OF LAKE MICHIGAN

Progress Report

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Claire L. Schelske

Great Lakes Research Division
The University of Michigan
Ann Arbor, Michigan

November 1, 1975 to September 30, 1978

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LB

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. EY-76-S-02-2003.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
NEARSHORE PROCESSES	2
MIXING AND WATER TRANSPORT	4
PHYTOPLANKTON NUTRIENT ENRICHMENT EXPERIMENT	6
ECOSYSTEM ANALYSES	7
LITERATURE CITED	11
PAPERS PRESENTED	12
COMPLETED REPORTS	14
LIST OF APPENDICES	18

INTRODUCTION

This progress report begins with a summary of research activities during the past three years and ends with eleven appendices as supplemental reference materials. In the following summary ~~of the appended reports,~~ ^{will} brief narratives ~~have been~~ prepared integrating the reports under the following headings: nearshore processes, mixing and water transport, phytoplankton nutrient enrichment experiments and ecosystem analyses. The purpose of the summary is to point out the significance of research efforts with reference to broader environmental questions than those which have been studied. The appended materials are in various stages of completion, ranging from reports which have been published, manuscripts which have been submitted for publication and manuscripts which are being readied for publication.

The report on phytoplankton and physical conditions in selected rivers and the nearshore (Appendix 11) is to be published as a report of the Great Lakes Research Division. This report is largely ready for publication, but will require some additional synthesis and incorporation of additional references dealing with river studies. It will also require additional editing prior to publication.

Results of research undertaken with funds from this contract have been presented at a number of scientific meetings. Papers have been presented on most of the aspects covered in the progress report, mainly at the annual Conferences on Great Lakes Research and at the annual meetings of the American Society of Limnology and Oceanography. A list of papers presented is included with this progress report.

A list of papers published with support from this contract is also included in this progress report.

NEARSHORE PROCESSES

Several papers have been prepared which deal with the nearshore zone. These papers contribute to the literature concerned with inshore-offshore differences in large lakes (see Appendix 2) with data obtained from Lake Michigan and Lake Huron and discuss some of the processes which are important in establishing inshore-offshore differences.

One of the factors involved in maintaining inshore-offshore differences in phytoplankton in large lakes is the spring thermal bar. Although there has been some controversy about whether the thermal bar is a barrier to mixing, we believe it is obvious from an examination of the southern Lake Huron chemical and physical data that the thermal bar effectively isolates the nearshore region from the offshore waters (see Appendix 1). The thermal bar may be an area of intense mixing between the two water masses, but our data show high nitrate concentrations in the nearshore waters as long as the thermal bar persists and a decrease in nitrate to open lake levels soon after the thermal bar has disappeared. During mixing at the thermal bar the nearshore portion is growing in size by entraining offshore waters and in the process does not destroy the distinct chemical and biological character of the nearshore waters which result from nearshore inputs during the spring. One interesting question which has not been resolved is what is the source of the large inputs of nitrate on the eastern shore of southern Lake Huron? Inputs of comparable magnitude appear not to occur on the western shore nor have they been reported from the other Great Lakes.

In Lake Michigan tributary inputs and precipitation on the lake are the main sources of water for the lake; whereas in Lake Huron about 75% of

the outflow is due to inflows from Lake Superior and Lake Michigan so only about 25% of the outflow is due to inflow from streams. Precipitation on the lake surface roughly balances evaporation so these terms cancel in a crude hydrologic budget. Tributary inputs therefore would appear to have a greater impact on the nearshore waters of Lake Michigan than in Lake Huron.

One of the more significant findings related to nearshore dynamics in Lake Michigan is the process by which river water and its associated materials are mixed in the nearshore waters. Good evidence has been obtained that during summer thermal stratification at least part of the mixing process occurs at thermocline depth (see Appendices 3 and 4). This evidence is based on chemical conditions (chloride) and phytoplankton species which can be traced from the river to offshore waters at thermocline depth. The pattern has been observed during periods of offshore and onshore winds and should be considered not only as a pathway for materials entering the lake from rivers but also for materials associated with other large flows such as industrial discharges.

A conceptual model of the importance of different factors involved in the establishment of greater standing crops in the nearshore zone has been developed. It appears that a combination of physical factors and high nutrient loading to the nearshore are the major factors involved. The nearshore zone is shallower than the offshore and as a consequence has a smaller volume and a smaller surface area to volume relationship at the air-water interface and sediment-water interface, which increases the availability of light and nutrient recycling to the phytoplankton community. In addition water transport is typically longshore which would tend to

limit mixing and diffusion of nearshore waters with the offshore waters.

Finally, the most significant concept advanced in this paper is that nutrient loading to the nearshore is much greater than to the offshore waters because the nearshore zone of the lake represents only 20% of the surface area and 5% of the volume. Based on total inputs to the lake, loading to the nearshore on an areal basis is at least three times greater than the offshore and on a volumetric basis is nearly 20 times greater than the offshore. More significantly these nearshore loads enter the lake mainly in the southern basin in contrast to atmospheric loads, though large (roughly 20% of the total to the lake), which are distributed fairly uniformly over the lake's surface. Tributary loads therefore contribute mainly to nearshore problems in localized zones and should not be averaged for the whole lake if regional water quality is of interest (Appendix 2).

MIXING AND WATER TRANSPORT

In conjunction with research projects conducted with primary support from the Environmental Protection Agency, the effects of mixing and transport of water have been studied in the Straits of Mackinac and at the mouth of Saginaw Bay. The study of the Straits of Mackinac was important because we were able to coordinate one cruise supported by EPA with one cruise supported with funds from this contract and make parallel measurements in the Straits of Mackinac, northern Lake Huron and northern Lake Michigan over a period of one week.

Two very important results were obtained from these coordinated cruises (see Appendix 6). First, it was shown that in September the epilimnetic waters of northern Lake Michigan were nearly depleted in silica

and supported a phytoplankton assemblage dominated by green and blue-green algae (which confirmed a hypothesis by Schelske and Stoermer 1971 which resulted from earlier studies on this contract). Second, that this silica depleted water with blue-green algal populations was being transported into Lake Huron through the Straits of Mackinac where it could have a significant impact on the waters of Lake Huron.

In addition studies of the Straits of Mackinac revealed that the subsurface flow of water from Lake Huron when entrained in the epilimnetic waters of Lake Michigan west of the Straits of Mackinac stimulated the growth of phytoplankton--this effect is probably due to enrichment of the Lake Michigan surface waters with silica and phosphorus contained in the westward subsurface flow from Lake Huron. The deep waters from Lake Huron are obviously richer in silica and presumably would also be richer in phosphate although the differences were not determined chemically (Schelske et al. 1976).

Saginaw Bay also serves as a source of nutrient-rich waters for Lake Huron, but unlike the flow from Lake Michigan these waters are greatly enriched over open waters of the lake. Studies of the mixing zone between Saginaw Bay and Lake Huron have confirmed the differences between the two environments and have shown that the mixing process can affect the metabolism of the plankton community (see Appendix 5). Differences in phytoplankton metabolism varied in relation to the location of the mixing zone in Saginaw Bay which is dependent largely on wind-induced patterns of water circulation. This study also demonstrated that Saginaw Bay water was confined to the bay by the thermal bar during spring warming so it would be expected that during the thermal bar period transport of Saginaw

Bay water would be confined largely to the nearshore zone except during periods of very intense storms. Under average conditions during the thermal bar period one would then expect that enriched water from Saginaw Bay would largely be transported along the Michigan shoreline and not mixed into the offshore waters.

PHYTOPLANKTON NUTRIENT ENRICHMENT EXPERIMENT

An experiment was conducted to determine the potential importance of nutrients and phytoplankton transported with river water on the dynamics of the deep phytoplankton layer in Lake Michigan (see Appendix 7). Results of another study demonstrated that materials in river water are transported at thermocline depth (see Appendices 3 and 4). Results showed that growth of some species of phytoplankton from the river occurred under the experimental conditions and that the growth of lake phytoplankton populations from the deep layer could be increased by additions of phosphorus and filtered river water. Because the river water contained phosphorus (data are available but were not included in Appendix 7), at least part of the response in the river water treatments was due to phosphorus; however, because the river water apparently produced a greater response than phosphorus alone, some factor in addition to phosphorus present in river water must have stimulated the growth of phytoplankton.

Peterson in a study supported only partly from this contract has shown that the deep-living phytoplankton in Lake Michigan are light limited (see Appendix 8). The results of the nutrient enrichment experiments (Appendix 7) tend to confirm Peterson's conclusion that nutrient supplies for these deep-living populations are derived from the upward flux of

nutrients from deeper waters. Results of the nutrient enrichment experiments showed that the deep-living populations were stimulated by nutrients at increased light, but that growth was not stimulated at or only stimulated to a limited extent with increased light, meaning that the populations under laboratory conditions quickly become nutrient limited.

ECOSYSTEM ANALYSES

One of the by-products of a number of years of research experience on the Great Lakes is a growing awareness of the need to consider the large size and complexity of these systems in understanding system processes. These systems are indeed inland seas. Using the thermal cycle as an example, it is generally recognized that the shallow parts of the lake warm more rapidly in the spring than the deeper parts producing the vertical thermal stratification known as the thermal bar. Nearshore waters then may be thermally stratified while the offshore waters are $< 4^{\circ}\text{C}$. In addition Lake Michigan extends over several degrees of latitude so that the southern part of the lake may be thermally stratified while the northern part is $< 4^{\circ}\text{C}$. Considering these simple temporal and spatial thermal relationships and the different seasonal chemical and biological cycles in the surface and deep waters of the lake serves to illustrate the complexity of the system.

Given these complexities and the problems associated with sampling large bodies of water one can conclude that detecting trends in biological or chemical variables (other than conservative substances) is not a simple matter of obtaining a small number of samples at several stations (see Appendix 9). It has been concluded that such trends can only be obtained

by sampling over long periods of time or conversely that differences cannot be detected from year to year because relatively small changes would be expected in different variables due to inputs and outputs which are small compared to the total in the lake.

A second interesting conclusion related to detecting trends in environmental conditions in the upper Great Lakes is that large and significant changes in the phytoplankton fauna have occurred in these systems even though the concentration of the forcing variable (phosphorus) has changed little (see Appendix 9). At present, the average total phosphorus concentration for the lake has been estimated to be from 7 to 8 $\mu\text{g P/liter}$ --a seasonal cycle probably exists but adequate data have not been collected to confirm this supposition. This level of phosphorus is only twice as great as that presently existing in Lake Superior, leading one to conclude that the levels of phosphorus have only doubled or possibly tripled (if Lake Superior has also increased) during the period of anthropogenic enrichment.

Earlier work on this contract resulted in a paper which proposed the use of nutrient depletion, either silica or nitrate in the upper Great Lakes, as one means of detecting environmental change (Schelske 1975). The amount of depletion (utilization of either nutrient by phytoplankton) is a function of the growth and production of phytoplankton in the lake. Depletion of nutrients over the season is a much more sensitive detector of change than measuring the concentrations of the nutrient controlling the change because this value integrates nutrient utilization over time. This earlier study showed that silica and nitrate nitrogen levels were larger in Lake Superior, the most oligotrophic of the Great Lakes, than

in either of the other upper Great Lakes and that the seasonal variation in either nutrient was smaller in Lake Superior than in any of the Great Lakes.

Evidence of ecosystem response to phosphorus loading has again been confirmed by a recent study of silica relationships in the upper Great Lakes (see Appendix 10). In 1971, when Schelske and Stoermer advanced the silica depletion hypothesis, available data on total phosphorus concentrations were quite variable which we now know represented poor analytical procedures for much of the historical data. Most of the older data suggest higher levels of phosphorus than most investigators now believe ever existed in the lake. Similarly the data on silica from lake-wide studies were questioned because the older data indicated much larger levels than those which had been determined for the lake in 1969. However, the recent analysis of historical silica data for Lake Huron, Lake Superior and Lake Michigan leads to the conclusion that the earlier data for silica from the 1950's and 1960's were in fact reliable and that silica changes in Lake Michigan and Lake Huron have been very large. The exact change may be open to debate, but it is clear that the winter maximum concentration in Lake Michigan has decreased by a factor of three or four in the last 50 years and by more than a factor of two in the last 25 years.

Confidence in the old silica data was obtained through an analysis of data from the Straits of Mackinac and northern Lake Huron in the mixing zone for inflows from Lake Michigan and Lake Superior. These flows comprise the major inputs so no other inputs need be considered. Because the lakes have different specific conductance, 95 $\mu\text{S}/\text{cm}$ for Lake Superior and 267 $\mu\text{S}/\text{cm}$ for Lake Michigan, mixing curves can be used to determine the

proportion of water from the two sources. This relationship was used in a regression analysis of silica on specific conductance for data collected over a 20-yr period to show that data collected in 1954 in Lake Huron were valid; from this it logically followed that the data collected in Lake Michigan were also valid because values from 1955 for the Straits of Mackinac region agreed with the values expected from the regression analysis. This analysis is based on the sound assumption that silica values in Lake Superior were unchanged during the 20-yr period, making it possible to "calibrate" the Lake Huron and Lake Michigan data with the "known" values for Lake Superior.

The decline of silica in Lake Michigan and Lake Huron are ecosystem responses of diatoms to phosphorus loading. As such this environmental change may be unique in the Great Lakes, because although many environmental changes have been documented the causal relationships are not known for biological changes which have generally been attributed to one or more of several factors.

LITERATURE CITED

Schelske, C. L. 1975. Silica and nitrate depletion as related to rate of eutrophication in Lakes Michigan, Huron and Superior, p. 277-299.

In A. D. Hasler (ed.), Coupling of land and water systems, Springer-Verlag New York Inc.

_____ and E. F. Stoermer. 1971. Eutrophication, silica nad predicted changes in algal quality in Lake Michigan. Science 173: 423-424.

_____, _____, J. E. Gannon and M. S. Simmons. 1976. Biological, chemical and physical relationships in the Straits of Mackinac. Ecol. Res. Series, U.S. Environmental Protection Agency, Duluth, MN, Rep. No. EPA-600/3-76-095. 266 p.

Reprints + Preprints Removed

PAPERS PRESENTED

- Davis, C. O. and N. F. Breitner. 1975. A simulation model of silicate-limited diatom growth. 38th Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Halifax, Nova Scotia, June 22-26, 1975.
- _____, R. A. Moll and C. L. Schelske. 1975. Phytoplankton populations in the frontal zone between Saginaw Bay and Lake Huron. 18th Conf. Great Lakes Res., Albany, N. Y., May 20-23, 1975.
- Moll, R. A., C. L. Schelske, M. S. Simmons and L. E. Feldt. 1975. Water mass relationships in the Straits of Mackinac. 18th Conf. Great Lakes Res., Albany, N. Y., May 20-23, 1975.
- Stoermer, E. F., C. L. Schelske, R. G. Kreis, Jr. and T. B. Ladewski. 1975. Lake summer phytoplankton distribution in the Straits of Mackinac region. 18th Conf. Great Lakes Res., Albany, N. Y.
- Davis, C. O. and C. L. Schelske. 1976. Nutrient and phytoplankton distributions in the Michigan and Ontario nearshore waters of Lake Huron during thermal bar conditions. 19th Conf. Great Lakes Res., Guelph, Ontario, May 4-6, 1976.
- _____ and _____. 1976. The Grand River as a source of nutrients to Lake Michigan. 39th Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Savannah, Georgia, June 21-24, 1976.
- Feldt, L. E. 1976. Plankton diatoms found in river inputs to Lake Michigan in 1972. Third Internat. Diatom Conf., Academy of Natural Sciences, Philadelphia, PA, September 23-25, 1976.
- Harrison, P. J. and C. O. Davis. 1976. Use of the perturbation technique to measure phytoplankton nutrient uptake rates at sea. 39th Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Savannah, Georgia, June 21-24, 1976.
- Stoermer, E. F., B. Ladewski and C. L. Schelske. 1976. Population responses of Lake Michigan phytoplankton to nitrogen and phosphorus enrichment. 39th Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Savannah, Georgia, June 21-24, 1976.
- Davis, C. O. 1977. Water chemistry and phytoplankton distributions in the nearshore zone of southeastern Lake Michigan. 20th Conf. Great Lakes Res., Ann Arbor, MI, May 10-12, 1977.
- Schelske, C. L. 1977. Nutrient-phytoplankton relationships in the upper Laurentian Great Lakes. Symposium paper, 40th Ann. Meeting, Amer. Soc. Limnol. Oceanogr., East Lansing, MI, June 22, 1977.
- Davis, C. O., E. Seibel and R. Rossmann. 1978. Definition of the near-shore zone in the Laurentian Great Lakes. Sundridge Coastal Process Workshop, Sundridge, Ontario, February 21-23, 1978.

Harrison, P. J. and C. O. Davis. 1978. The use of outdoor phytoplankton continuous cultures to analyze factors influencing species selection. 41st Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Victoria, British Columbia, June 19-22, 1978.

Schelske, C. L. 1978. Unique nutrient-plankton relationships in the coastal zone. Sundridge Coastal Process Workshop, Sundridge, Ontario, February 21-23, 1978.

_____, R. A. Moll and T. P. Peterson. The deep chlorophyll layer in northern Lake Michigan in 1976. Poster presentation, 41st Ann. Meeting, Amer. Soc. Limnol. Oceanogr., Victoria, British Columbia, June 19-22, 1978.

COMPLETED REPORTS

C00-2003-1

Progress Report, November 1, 1968 to July 31, 1969. C. L. Schelske, E. Callender, and E. F. Stoermer. MS. July 1969.

C00-2003-2

Nutrient enrichment experiments on phytoplankton populations in Lake Michigan. C. L. Schelske, E. Callender, and E. F. Stoermer. MS. October 1969.

C00-2003-3

Survey of phytoplankton productivity and nutrients in Lake Michigan and Lake Superior. C. L. Schelske and E. Callender. Proc. 13th Conf. Great Lakes Res. 1970. pp. 93-105.

C00-2003-4

Progress Report, November 1, 1969 to July 31, 1970. C. L. Schelske, E. F. Stoermer, and E. Callender. MS. July 1970.

C00-2003-5

Phosphorus, silica, and eutrophication of Lake Michigan. C. L. Schelske and E. F. Stoermer. Symposium on Nutrients and Eutrophication, Spec. ASLO Symp. Vol. 1. pp. 157-171.

C00-2003-6

Phytoplankton assemblage differences at inshore versus offshore stations in Lake Michigan, and their effects on nutrient enrichment experiments. E. F. Stoermer, C. L. Schelske, and L. E. Feldt. Proc. 14th Conf. Great Lakes Res. 1971. pp. 114-118.

C00-2003-7

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

C00-2003-8

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

C00-2003-9

Ecological implications of fallout radioactivity accumulated by estuarine fishes and mollusks. C. L. Schelske, D. A. Wolfe, and D. E. Hoss. Radionuclides in Ecosystems. Proc. 3rd Nat. Symposium on Radioecology. 1971. pp. 791-806.

C00-2003-10

Ecological concept of the coastal zone in the Great Lakes. C. L. Schelske. Proc. Conf. on Coastal Zone and Shoreline Management in the Great Lakes. 1971. Unpublished manuscript.

C00-2003-11

Silica and nitrate depletion as related to rate of eutrophication in Lakes Michigan, Huron and Superior. C. L. Schelske. In Coupling of land and water systems, A. D. Hasler (ed.), Springer-Verlag New York Inc. 1975. pp. 277-298.

C00-2003-12

Progress Report. Vol. 1, 1968 to Oct. 31, 1971. Nutrient enrichment and eutrophication of Lake Michigan. C. L. Schelske. MS. October 1971.

C00-2003-13

Nutrient enrichment and its effect on phytoplankton production and species composition in Lake Superior. C. L. Schelske, L. E. Feldt, M. A. Santiago, and E. F. Stoermer. Proc. 15th Conf. on Great Lakes Res. 1972. pp. 149-165.

C00-2003-14

Spring phytoplankton abundance and productivity in Grand Traverse Bay, Lake Michigan, 1970. E. F. Stoermer, C. L. Schelske, M. A. Santiago, and L. E. Feldt. Proc. 15th Conf. on Great Lakes Res. 1972. pp. 181-191.

C00-2003-15

Nutrient inputs and their relationship to accelerated eutrophication in Lake Michigan. C. L. Schelske. In Biological effects in the hydro-biological cycle, E. J. Monke (ed.), Proc. of the 3rd Internat. Symp. for Hydrology Professors, Purdue Univ., Dept. of Agricultural Eng. 1971. pp. 59-81.

C00-2003-16

Fallout Mn-54 accumulated by bay scallops *Argopecten irradians* (Lamarck) near Beaufort, North Carolina. C. L. Schelske. In Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment, International Atomic Energy Agency. 1973. pp. 331-346.

C00-2003-17

Progress Report. Nutrient enrichment and eutrophication of Lake Michigan. November 1, 1968 to July 31, 1972. C. L. Schelske, July 1972.

C00-2003-18

Limnological survey of Lakes Michigan, Superior, Huron, and Erie. C. L. Schelske and J. C. Roth. 1973. Univ. Mich., Great Lakes Res. Div., Pub. 17, 108 p.

C00-2003-19

An automated method for sulfate determination in lake water. M. A. Santiago, S. Fielek and C. L. Schelske. Water Quality Parameters, ASTM STP 573, Amer. Soc. for Testing and Materials, pp. 35-46. 1975.

C00-2003-20

Occurrence of morphologically abnormal *Synedra* populations in Lake Superior phytoplankton. L. E. Feldt, E. F. Stoermer and C. L. Schelske. Proc. 16th Conf. Great Lakes Res. 1973. pp. 34-39.

C00-2003-21

Responses of phosphorus limited Lake Michigan phytoplankton to factorial enrichments with nitrogen and phosphorus. C. L. Schelske, E. D. Rothman, E. F. Stoermer and M. A. Santiago. Limnol. Oceanogr. 19: 409-418. 1974.

C00-2003-22

Progress Report. Nutrient enrichment and eutrophication of Lake Michigan. C. L. Schelske. April 1974.

C00-2003-23

Storm induced relationships among chemical conditions and phytoplankton in Saginaw Bay and western Lake Huron. C. L. Schelske, L. E. Feldt, M. A. Simmons, and E. F. Stoermer. Proc. 17th Conf. Great Lakes Res. 1974: 79-91.

C00-2003-24

Phytoplankton responses to phosphorus and silica enrichments in Lake Michigan. C. L. Schelske, M. S. Simmons, and L. E. Feldt. Presented at 19th SIL Congress, Winnipeg, Manitoba. Aug. 22-29, 1974.

C00-2003-25

Progress Report. Nutrient enrichment and eutrophication of Lake Michigan. November 1, 1971 to June 30, 1975. C. L. Schelske. April 1975.

C00-2003-26

Progress Report. Nutrient enrichment and eutrophication of Lake Michigan. November 1, 1971 to June 30, 1976. C. L. Schelske and C. O. Davis. March 1976.

C00-2003-27

Progress Report. Nutrient enrichment and eutrophication of Lake Michigan. November 1, 1971 to September 30, 1977. C. L. Schelske. July 1977.

C00-2003-28

Population responses of Lake Michigan phytoplankton to nitrogen and phosphorus enrichment. E. F. Stoermer, B. G. Ladewski and C. L. Schelske. Hydrobiologia 57: 249-265. 1978.

C00-2003-29

Detecting trends in Great Lakes water quality. C. L. Schelske. Water Quality Bulletin. In press.

C00-2003-30

Laboratory procedures: water chemistry and phytoplankton. C. O. Davis and M. S. Simmons. Great Lakes Res. Div. Spec. Rep. In press. NOTE: this report includes methods currently in use in our studies at the Great Lakes Research Division. It has been prepared to serve as a field and laboratory manual for internal use and as a reference source for other investigators.

APPENDICES

1. Davis, C. O., C. L. Schelske and R. G. Kreis, Jr. Nutrient and phytoplankton distributions in nearshore waters of Lake Huron during spring thermal bar conditions.
2. Schelske, C. L. Unique nutrient and phytoplankton relationships in the nearshore zone of large lakes with special reference to phosphorus loading in Lake Michigan.
3. Davis, C. O., C. L. Schelske and L. E. Feldt. Nearshore physical-chemical conditions in southeastern Lake Michigan, 1976.
4. Feldt, L. E., C. O. Davis and C. L. Schelske. Nearshore phytoplankton distribution in southeastern Lake Michigan, 1976.
5. Moll, R. A., C. O. Davis and C. L. Schelske. Phytoplankton productivity and standing crop in the Lake Huron-Saginaw Bay mixing zone.
6. Schelske, C. L., E. F. Stoermer, J. E. Gannon and M. S. Simmons. 1976. Comparison of phytoplankton and nutrients in northern Lake Michigan and the Straits of Mackinac, p. 191-203. *In* Biological, chemical and physical relationships in the Straits of Mackinac, Section VIII. Ecol. Res. Series, U.S. Environmental Protection Agency, Duluth, MN, Rep. No. EPA-600/3-76-095.
7. Schelske, C. L., L. E. Feldt and C. O. Davis. Phosphorus and river water: their effects on deep-living phytoplankton in Lake Michigan.
8. Peterson, T. P. A test of Bannister's quantum yield hypothesis in the thermocline and hypolimnion of Lake Michigan. Submitted to Limnol. Oceanogr. 1978.
9. Schelske, C. L. In press. Detecting trends in Great Lakes water quality. Water Quality Bulletin, 1978.
10. Schelske, C. L. Recent changes in silica relationships in the upper Great Lakes: ecosystem responses to phosphorus loadings.
11. Schelske, C. L., L. E. Feldt and M. S. Simmons. Phytoplankton and physical-chemical conditions in selected rivers and the coastal zone of Lake Michigan, 1972.