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CAPABILITIES OF VARIOUS RESEARCH ORGANIZATIONS TO PROVIDE INFORMATION ON GREAT LAKES WATER QUALITY

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CAPABILITIES OF VARIOUS RESEARCH ORGANIZATIONS TO PROVIDE INFORMATION ON GREAT LAKES WATER QUALITY*

Eugene J. Aubert

This report presents information on the nature of Great Lakes water quality problems that should be addressed over the next decade by research organizations that support the Great Lakes water quality mission of the International Joint Commission. This information is relevant to the research programs and capabilities required by such research organizations in the United States and Canada. This analysis, based upon the perception of issues and ecosystem understanding of the author, covers the following topics: a) the nature of the Great Lakes water quality problem, b) a conceptual model of an environmental quality management system, c) the eutrophication problem, and d) the toxic organics problem. Future water quality management decisions will be more complex owing to conflicts of use, and more in-depth assessments will be required for implementation. This report is intended to put into perspective the Great Lakes Water Quality problems and to pose key questions relative to environmental research capabilities required over the next decade.

1. INTRODUCTION

This paper presents information and poses questions about the capabilities of the various State, Federal, university, and private research organizations to provide information to support the Great Lakes water quality mission of the International Joint Commission (IJC). It is part of a study to develop recommendations to be considered when the Great Lakes Water Quality Agreement (GLWQA) is reviewed in 1986. Contemplating the capabilities of these research organizations leads to the question, "Capability to do what?" There are a series of pertinent questions relating to Great Lakes water quality problems, issues, and research needs and the functional and resource requirements of the research organizations. What is the nature of Great Lakes water quality problems to be solved by the IJC? What decision-making process is being used? or should be used? What is our understanding and perception of the seriousness of the problems? What risks are there to living resources and to human health? What are the cause and effect relationships? the status of corrective actions? the options for future corrective actions? the effects, costs, and benefits of past corrective actions, and of possible future corrective actions? Do the capabilities of existing research organizations meet the requirements of the critical Great Lakes water quality issues of the decade 1986-96? Are the resources adequate to make significant progress in a timely manner on problems that require holistic approaches? Is there adequate Canadian and United States research coordination? joint programs?

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This paper, a part of the problem definition phase of this study, is intended to put into perspective the Great Lakes water quality problems and to pose some key questions (that should be pursued in greater depth in Phase II) relative to capabilities of Great Lakes research organizations required in 1986-96. Aspects of the following five topics will be addressed:

- The nature of the Great Lakes water quality problem;
- A conceptual model of an environmental quality management system;
- The eutrophication problem;
- The toxic organics problem; and
- The Great Lakes research organizations.

2. THE NATURE OF THE GREAT LAKES WATER QUALITY PROBLEM

Natural conditions make the Great Lakes susceptible to pollution. The Laurentian Great Lakes are an interconnected lakes-river basin system (fig. 1). The profile of the system (fig. 2) shows that several of the lakes are relatively deep. The bottoms of four Great Lakes are below sea level. The Great Lakes have a long retention time for water and pollutants. The hydrologic retention time ranges from about 1 year in Lake Erie to over a century in Lake Superior. In addition, sediments are sinks for many contaminants that have an affinity for particles.

Two classes of contaminants--nutrients and toxic organic chemicals--cause major Great Lakes pollution problems. Excessive nutrients cause eutrophication, which influences the composition of organisms and the health of the ecosystem. Toxic organic contaminants degrade the health of the Great Lakes living resource, and low quality seafood and drinking water can be risks to human health. Major stresses come from the large population living near the lakes; industrial and manufacturing concentrations in the basin and upwind (many chemicals are produced, used, and transported here); and the use of fertilizers, herbicides, and insecticides by the large agribusiness in the basin. Great Lakes pollutants come not only from Great Lakes users, but also from land users in the basin and users of the free atmospheric resource within the Great Lakes Basin and probably beyond.

Spatial scales of pollutant stress depend upon the problem and cover the dimensions from the source to the effects. For point source problems, the scale is usually local; for nonpoint source problems, the contaminant source may be within or outside the basin, and the scale can be large (thousands of kilometers). Temporal scales depend on the hydrologic residence times, the time constants associated with sediment-water interaction (seasonal to decades), and the rates of decomposition of the contaminant within the system.

Do we know how to clean up the Great Lakes? Decisions are being made on the basis of insufficient knowledge and information. A recent workshop on Great Lakes water quality resulted in the following recommendation: "Develop

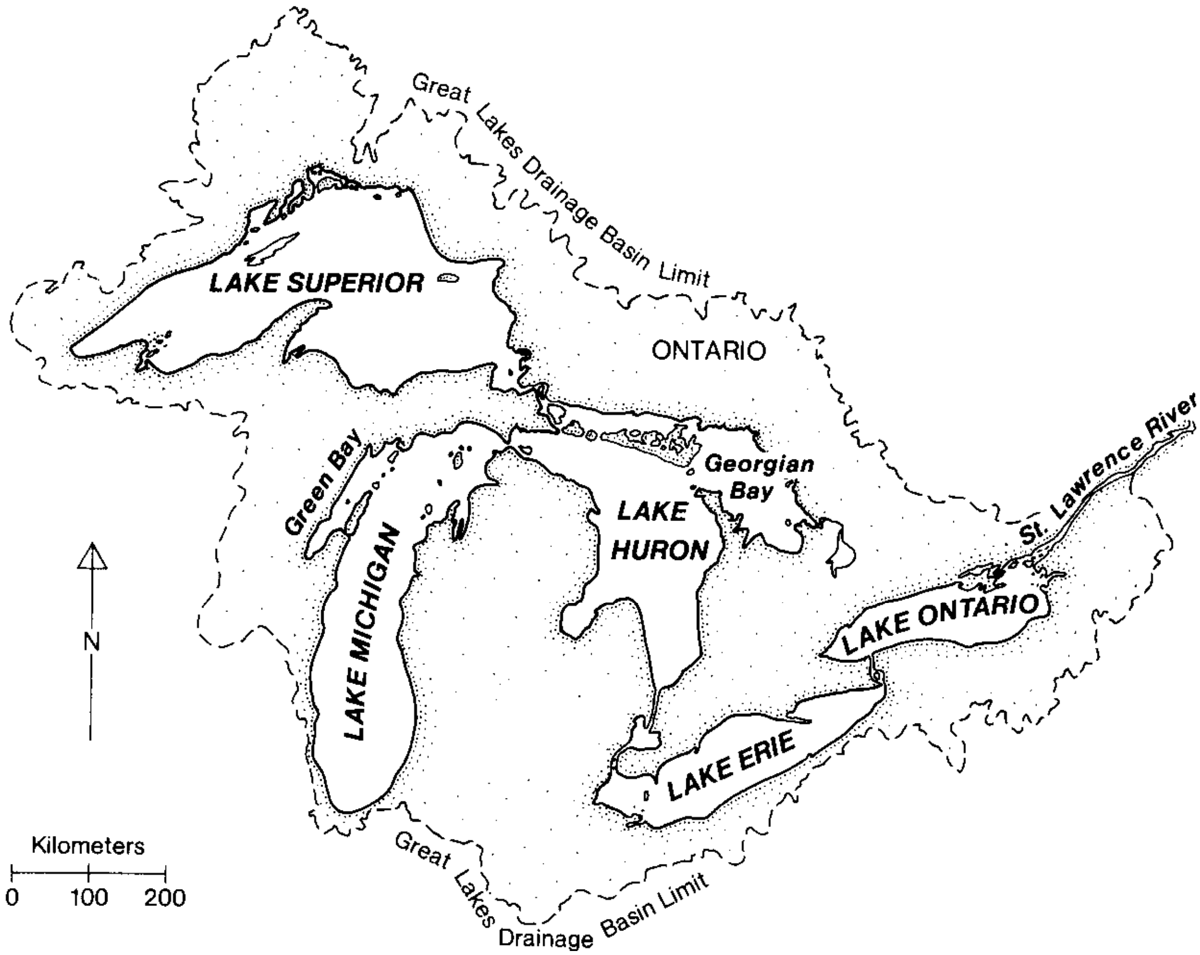
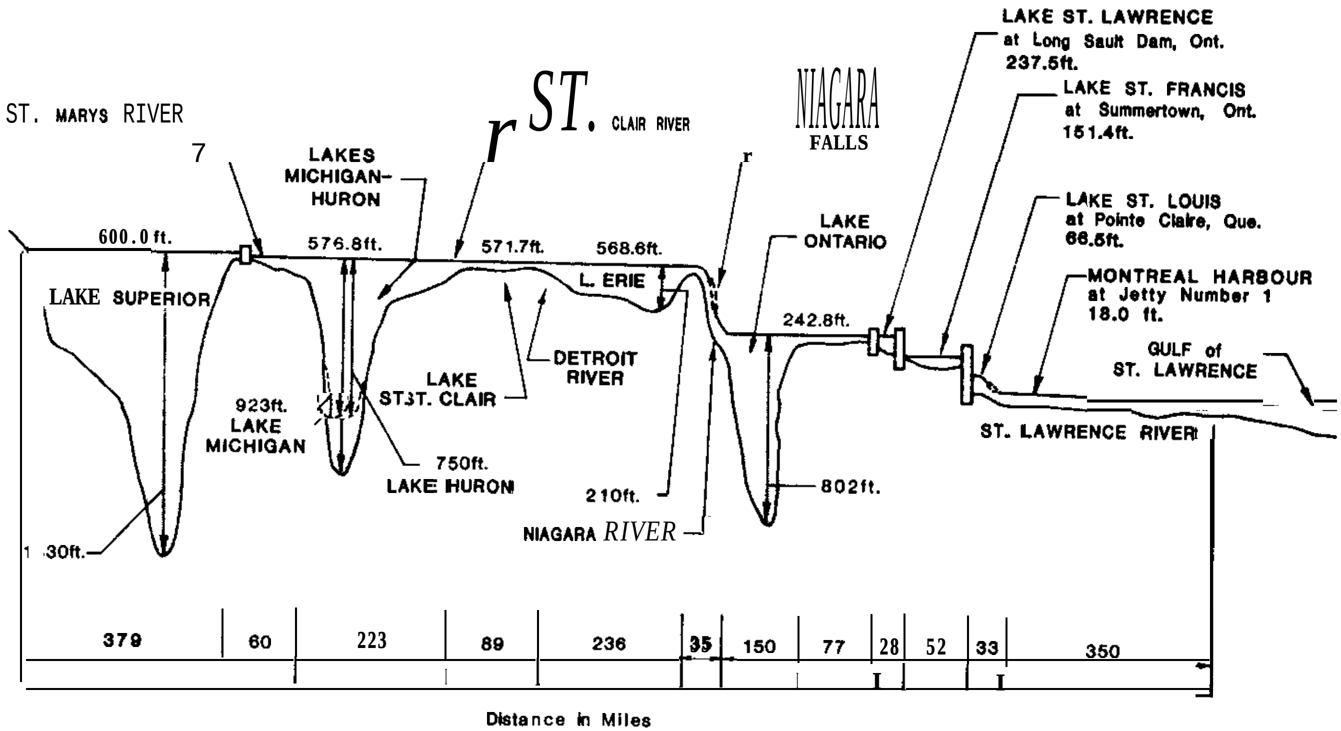


FIGURE 1.--*The* Great *Lakes.*

an increased understanding of how the Great Lakes ecosystems function in order to evaluate their response to various stresses and corrective measures," (NOAA, 1980). There is general agreement that quick fixes are not feasible, and that a holistic, ecosystem approach is needed. In its 1982 annual report, the IJC Science Advisory Board made specific recommendations for increased Great Lakes research efforts.

3. A CONCEPTUAL MODEL OF AN ENVIRONMENTAL QUALITY MANAGEMENT SYSTEM

My perception of the challenges facing Great Lakes management for the next decade relates to my understanding of Great Lakes problems and the Great Lakes ecosystem, and *my* concept of the management system. I will describe a conceptual model of an environmental quality management system (fig. 3) that puts in perspective the major subsystems and components. This model is not unique. Central is the Great Lakes ecosystem, which is influenced by



Elevations of the lake surfaces are given at low water datum, expressed on International Great Lakes Datum (1955). Horizontal and vertical scales have been distorted to convey visual impression.

FIGURE 2.--*The Great Lakes profile.*

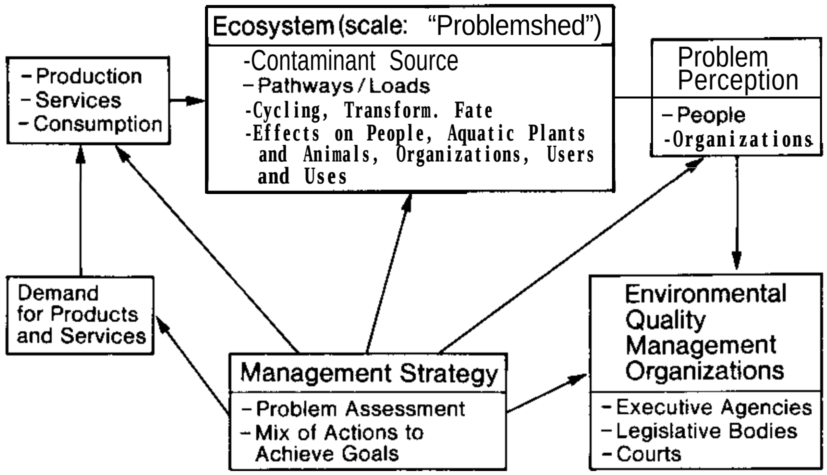


FIGURE 3.--Conceptual model of *an environmental quality management system.*

contaminants, like **PCBs** or nutrients. These are the result of various human activities of production, services, or consumption, which are responses to societal demands. Contaminants are discharged or *may* spill or leak directly onto or into the water, onto or into the land, or into the atmosphere. *Contaminants* find their way to the lakes either directly or via pathways of land drainage and streamflow or atmospheric transport and deposition. Contaminants cycle in and through the lakes, are transformed, and have some ultimate fate. Contaminants may affect people (health, aesthetics, economics), aquatic plants and animals, and uses of the Great Lakes (e.g., fishing, water supply, recreation, tourism, shoreline property). The term "problemshed" has been used as a measure of the scale of the stress; it is the region that spans the contaminant source to the affected area. It can be larger than the Great Lakes watershed. Depending upon the perception of problems by people and organizations, policies and laws are established by legislative bodies, rules and regulations are established and carried out by executive agencies, and disputes are settled in courts. Management *strategies* based upon an assessment of the ecosystem problem (i.e., identification of effects and the sources, pathways, and loads to the lake and determination of the contaminant cycling, transformations, and fate) and an assessment of feasible options to ameliorate the problem provide a mix of actions necessary to achieve ecosystem goals. Ecosystem goals relate to the acceptable uses of the Great Lakes resources or common property and to the balance of benefits, acceptable risks, and acceptable costs to Great Lakes users and to society. The adoption of ecosystem goals for the Great Lakes acceptable to all jurisdictions represents *a* significant political problem.

4. THE EUTROPHICATION PROBLEM

4.1 What is cultural eutrophication?

Eutrophication is the overproduction of undesirable plant life caused by excess limiting nutrients. In the Great Lakes, the nutrient limiting total phytoplankton growth is usually phosphorus; however, the production of desirable species of phytoplankton, e.g., diatoms, are often limited by silica. Eutrophication effects, depending upon the severity of the problem, can include: increased turbidity, aesthetic nuisance (e.g., cladophora on beaches), clogged water intake filters, drinking water taste and odor problems, dissolved oxygen depletion in bottom waters, and a shift in species distribution of biota.

A eutrophication model developed by Chapra (1977) illustrates some system concepts with respect to the eutrophication problem and puts human beings into the Great Lakes ecosystem. Chapra developed a relatively simple large-scale phosphorus model (a load-driven. time-dependent mass balance of the Great Lakes system). Figure 4 depicts the model structure, a mass balance for phosphorus. It assumes that the lakes are completely mixed on an annual time scale. For each lake or lake basin, the mass balance states that phosphorus accumulation equals waste source loads plus inflow from the upstream lake minus outflow minus lake loss to sediments. Waste sources of phosphorus in the Great Lakes are

- Human wastes--phosphorus from that fraction of population served by sewers minus the phosphorus removed by treatment;

- The contribution due to household detergents;

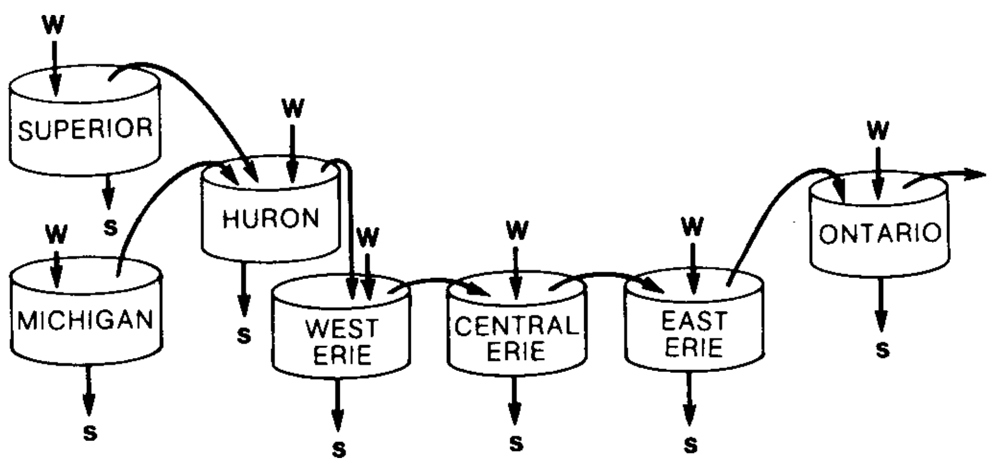


FIGURE 4.--*Phosphorus model network (Chapra, 1977). W is waste source load and s is phosphorus lost to sediments.*

- Land drainage--estimated as separate agricultural, urban, and forested land nonpoint sources; and

- Atmospheric sources.

A historical simulation of loads from 1800 to 1970 is shown in figure 5. Phosphorus budget information from 1965 to 1975 was used to calibrate the model. What does the load model show? Setting aside discussion of several critical assumptions, the model shows that Lakes Erie and Ontario have the biggest loads, that there was a big increase in human waste loads from 1870 to 1970 as the population grew, that there was a big increase in household detergents from 1940 to 1970, that there was a big increase in land runoff to Lake Erie from 1850 to 1880 because of changed agricultural practices in the basin, and that the phosphorus loads increase with time.

Model results from 1800 to 1970 (fig. 6) show that the increase in phosphorus concentration in Lakes Erie and Ontario in recent decades is large. The lakes react differently to phosphorus loads. Lake Erie will always tend to be eutrophic since the lake is shallow and its drainage basin is large.

The model was used to assess the following scenario: What if all major municipal waste treatment facilities were to reach the phosphorus objective of 1 mg/l? Figure 7 shows that a significant decrease in phosphorus concentration would be expected for Lakes Erie and Ontario with the 1 mg/l limitation. The horizontal dashed and dash-dot lines separate the phosphorus concentration into three qualitative categories of water quality: eutrophy, mesotrophy, and oligotrophy. Western Lake Erie would remain eutrophic even with a reduction in phosphorus concentration to 1 mg/l in municipal waste treatment facilities, while central and eastern Lake Erie would become mesotrophic.

4.2 What have governments done to control eutrophication?

The 1972 GLWQA focused on controlling point source discharges and set target loads by setting total phosphorus concentration at 1 mg/l for all municipal waste treatment facilities with discharges to Lakes Erie or Ontario greater than 1 million gal/day. The 1978 GLWQA extended point source limitation to all Great Lakes and recommended nonpoint source control for Lakes Erie and Ontario and for Saginaw Bay.

Government action since 1972 includes the expenditure of over $7 billion to construct and upgrade municipal waste treatment facilities in the Great Lakes Basin and reduce phosphorus loads. An IJC reference on land drainage sources was completed and showed that phosphorus loads from agricultural lands with clay soils are significant and vary according to agricultural practice.

4.3 What are the status and trends of Great Lakes eutrophication?

Figure 8 shows that phosphorus loads from municipal waste treatment facilities have been significantly reduced for Lakes Erie, Ontario, and Michigan. The ordinate is the phosphorus load in thousands of metric tons per

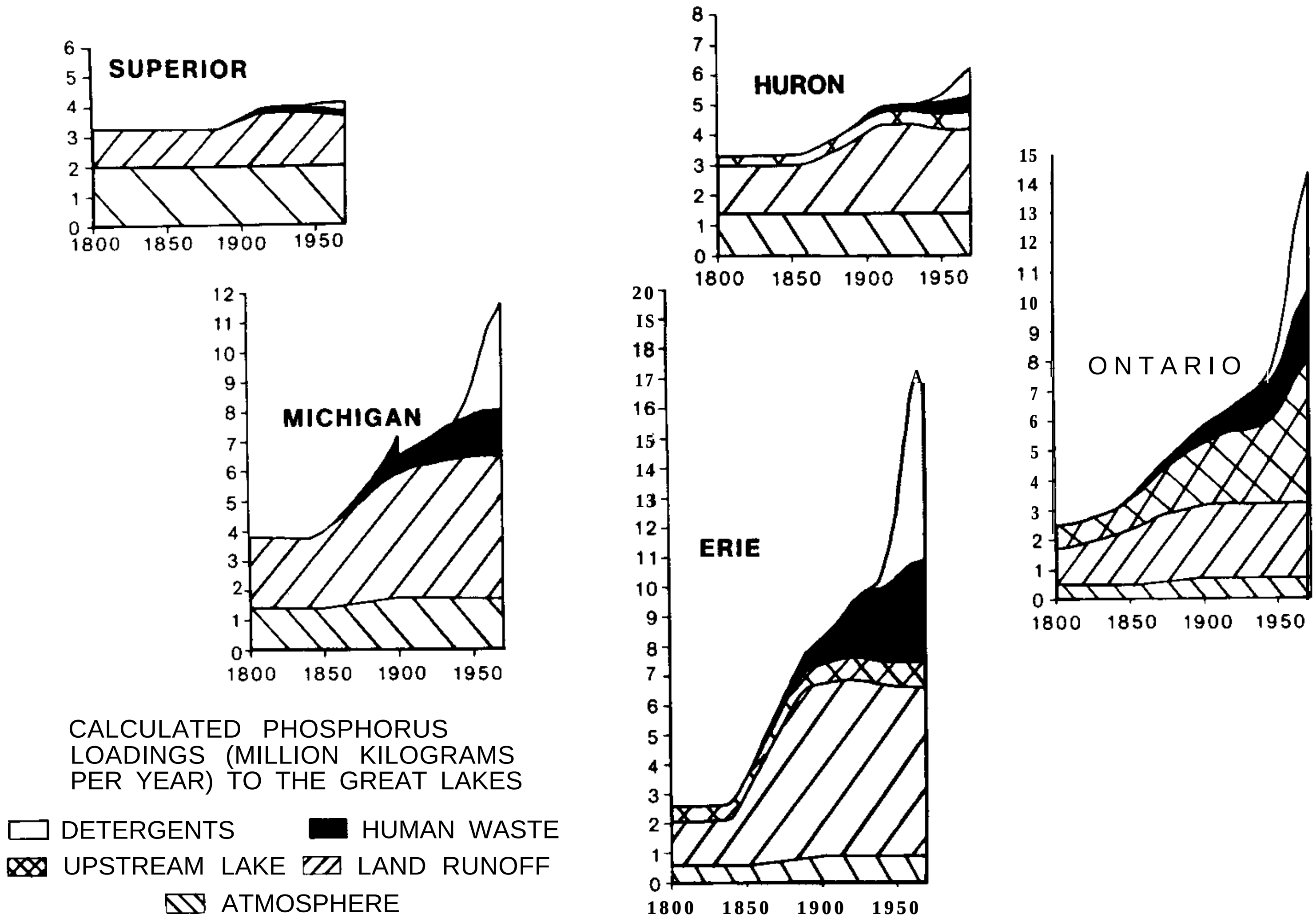


FIGURE S.--Historical *phosphorus loads (Chapra, 1977).*

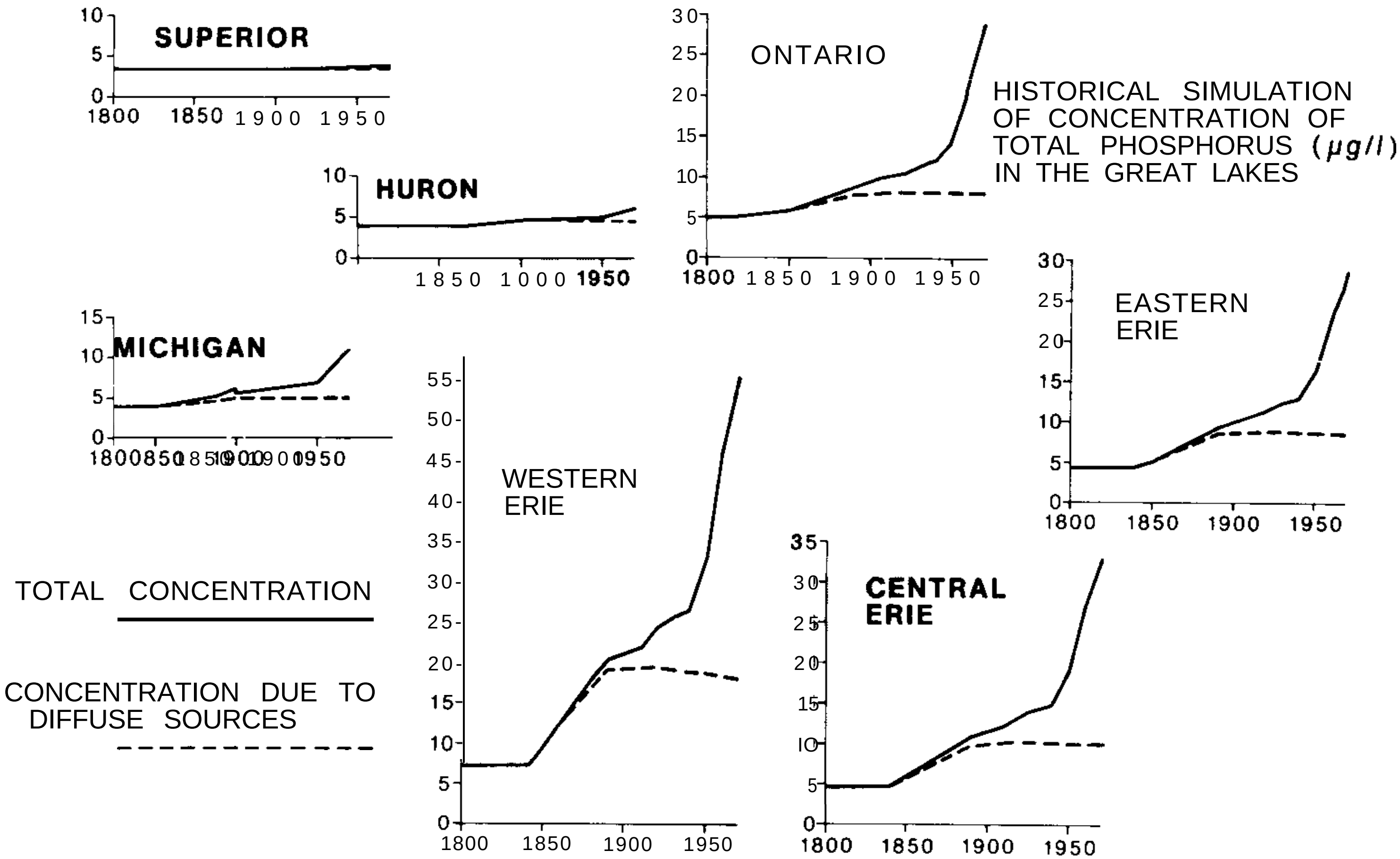


FIGURE 6.--*Phosphorus concentration* from *1800* to *1970 (Chapra, 19771.*

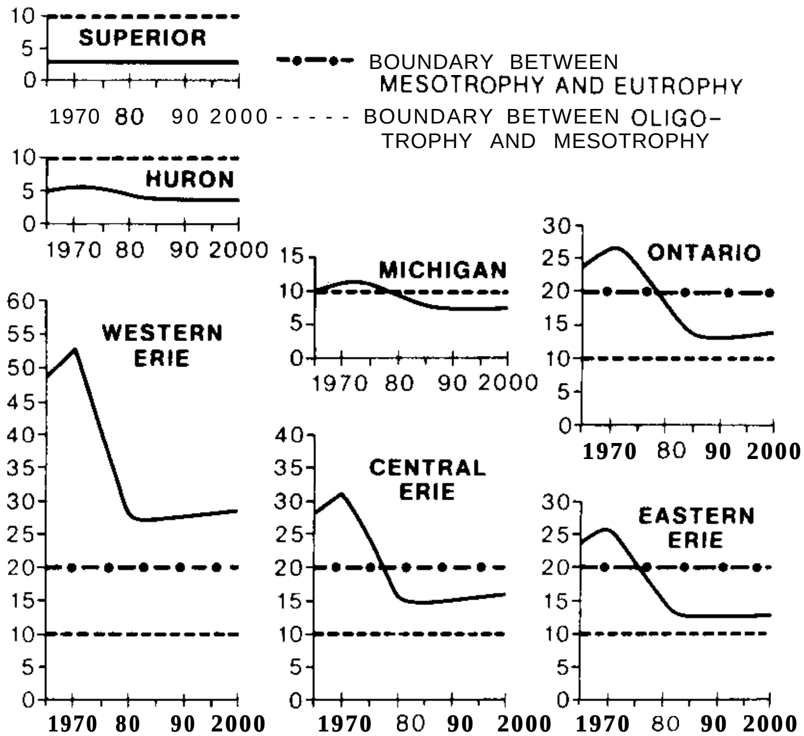


FIGURE 7.--*The 1 mg/l phosphorus load scenario (Chapra,* 1977).

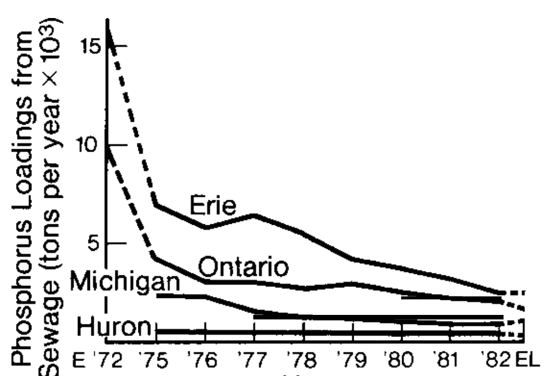


FIGURE *B.--Phosphorus loads to* four of *the Great Lakes (Great Lakes Water, Quality Board, 1983). Dashed lines (above E and EL) are estimated loads.*

year. The 1972 loads for Lakes Erie and Ontario are estimated since monitoring didn't start until 1975. The values at the right are the Agreement estimated loads. We have essentially achieved the target phosphorus loads set in the Agreement.

What are the lake effects? The 1983 Great Lakes Water Quality Board Annual Report contains the following information:

- Lake Ontario--conditions have tentatively improved. The spring lake-' wide phosphorus concentration has decreased, and a shift has occurred in open lake phytoplankton species from mesotrophic to oligotrophic types.

- Lake Erie--A tentative conclusion is that the whole-lake spring phosphorus concentration has decreased and the lakewide autumn concentration of chlorophyll a has decreased.

- Saginaw Bay--Algal species have shifted from blue-greens to diatoms and greens (indicating a shift from eutrophic to mesotrophic conditions).

Several questions are now being raised. Are the phosphorus control strategies cost-effective? Have the control strategies produced the expected results? What is the lake response to a decrease in phosphorus load? Should phosphorus from land drainage be controlled? What would be the benefits and costs? A knowledge of the ecosystem dynamics is required in order to answer these questions. The simple mass-balance model uses l-year time steps and ignores the detailed lake ecosystem processes of the annual cycle. We have apparently solved the relatively simple wastewater treatment problem with the expenditure of some $7 billion. While the effects on phosphorus loads have been dramatic, insufficient understanding of the ecosystem makes it difficult to define with confidence the beneficial ecosystem effects from these load reductions. We are now confronted with the need to assess the nonpoint source nutrient problem. Management options involving agriculture are more complex than those involving municipal waste treatment facilities, and to assess benefits and costs, we must improve understanding of the effects on the Great Lakes ecosystem of a further reduction in phosphorus. Many research questions remain. What is the nature of the cycling, transport, and fate of phosphorus forms? Are all phosphorus forms available to phytoplankton? Are sediments a sink or a source for phosphorus? Do benthos and zooplankters affect phosphorus availability and cycling? Why do particular algal species dominate? Are factors other than phosphorus, e.g., fish predation, affecting lake plankton composition and water quality?

5. THE TOXIC ORGANICS PROBLEM

5.1 What is the Great Lakes toxic organics problem?

Toxic organic contaminants come from various industrial, agricultural, and public sources. They enter the Great Lakes ecosystem by spills, leakage, atmospheric loads and pathways, land drainage, and point sources. The pollution potential in the Great Lakes Region is high: over 2,000 chemicals are produced or used here; 33 percent of U.S. hazardous wastes are generated here; over 800 major municipal and industrial dischargers are here; and billions of tons of hazardous wastes are transported here. Some toxic substances are persistent and bioaccumulate in the food chain. Various classes of toxic organic contaminants, e.g., PCBs, dioxins, PAH, have been found in the tissues of Great Lakes fish. At particular concentrations, toxic contaminants interfere with fish breeding cycles, induce deformities and death, and cause fish for human consumption to be a risk to human health as defined by the Food and Drug Administration. The following are frequently asked questions: Do toxic organic contaminants affect the fish? Is it safe to eat the fish? to swim? to drink the water?

Several remarks on toxic organic contaminants are in order. A large fraction of toxic organic contaminants loaded to the lakes from the atmosphere and tributaries sorbs onto particulate6 and settles to the sediments. Each contaminant will partition differently between the dissolved and particulate phases. The sediment-bound contaminants can be reintroduced into the water column via storm resuspension events, which are common during winter. A second and apparently important process for remobilizing contaminants out of sediments involves direct uptake by benthic invertebrates and transfer up the food chain to higher trophic levels. Thus, the large reservoir of contaminants associated with the sediments is still in intimate contact with the remainder of the ecosystem.

Figure 9 shows a PCB budget for Lake Michigan. What does it tell us? Concentrations, in metric tons (MT), are shown in three compartments; there are two compartments in the lake (identified as dissolved with 15 MT and particulate with 5 MT) and one compartment in the sediments (with 25 MT). Shown are dissolved and particulate loads to the lake (in metric tons per year) from the atmosphere, tributary streams, and sediments; the atmospheric load is 2½ times the tributary load. The sediment is both a sink and a source, with a net annual accumulation in the sediments. A large sediment resuspension or

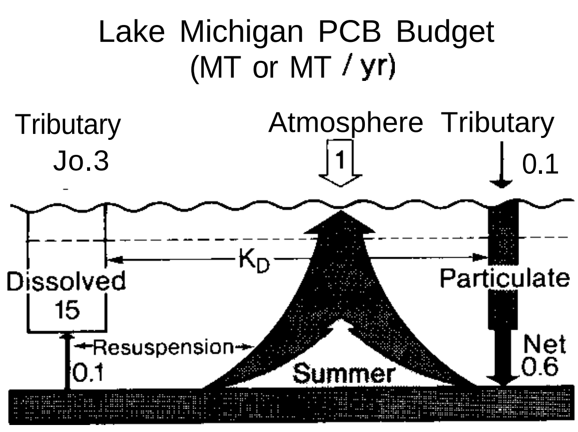


FIGURE 9.--*Lake Michigan PCB budget (Eadie, personal communication).*

load to the lake occurs in winter, when the lake is neutrally stratified. Two significant facts are apparent:

(1) The main load of new **PCBs** to Lake Michigan comes from the atmosphere; and

(2) While the sediments are a net sink, varying amounts of the large concentration of **PCBs** in the sediments are loaded back into the lake, intermittently, with the passage of storms, especially in the cold and neutrally stratified season.

5.2 What have governments done to control toxic organic contaminants?

Several government actions have been taken. The manufacture and sale of DDT has bee" banned. The manufacture of **PCBs** has been banned and its use limited by law. Most future **uses** of toxaphene have been banned, but current supplies can be used until December 31, 1986. The U.S. Environmental Protection Agency (EPA) is developing a national strategy for **dioxins.**

5.3 What are the status and trends of Great Lakes toxic organic contaminants?

The First Biennial IJC Report (IJC, 1982) after the 1978 Great Lakes Water Quality Agreement states the following: "Toxic and hazardous substances are another matter. The Great Lakes basin ecosystem suffers from 'widespread contamination and the lakes are a major sink for such substances,' and the surrounding population is exposed to toxic and hazardous substances through a variety of pathways. The impact on human and environmental health is not well understood, and this is a matter of great concern. Further studies of the transport, fate, and effects of such substances were recommended as well as the adoption of an overall strategy for toxic substances control programs."

The Great Lakes Water Quality Board 1983 Annual Report contains significant information on status and trends. Over 800 substances of potential concern have been identified in the Great Lakes ecosystem. For many of these substances, there is still insufficient information to assess hazards or risks, much less to establish a control program. Most recent 1981 and 1982 data indicate that the general decline in the concentration levels of **PCBs,** DDT, mercury, and other contaminants in fish flesh and bird eggs during the late 1970s has stopped. For example,

- Lake Superior--PCB levels in lake trout still exceed Agreement objectives.

- Lake Michigan--PCB, total DDT, dieldrin, and chlordane levels in lake trout whole fish composite samples exceed Agreement objectives.

- Lake Huron--DDT and PCB levels in lake trout whole fish composite samples still exceed Agreement objectives.

- Lake Erie--PCB levels in walleye still exceed Agreement objectives.

- Lake Ontario--PCB levels in lake trout, smelt, and spottail shiners', and DDT levels in lake trout exceed Agreement objectives.

What do we know about toxic *organic* contaminant dynamics? Simple steady-state models are available, but model research and development and comparison with data are in a very early stage.

6. THE GREAT LAKES RESEARCH ORGANIZATIONS

What are the research organizations that provide the information to support the water quality mission of the IJC through its advisory mechanisms? Detailed information is available in the Science Advisory Board 1982 Annual Report and the Research Advisory Board 1976 Directory of Great Lakes Research and Related Activities.

In Canada, the major Federal government contributors to Great Lakes water quality research are the National Water Research Institute (NWRI) and the Great Lakes Fisheries Research Branch (GLFRB), both located at the Canada Centre for Inland Waters (CCIW), Burlington, Ont.; vessel support is provided by the Bayfield Laboratory for Marine Science and Survey. In addition, several major universities pursue Great Lakes research, including the Universities of Toronto and Waterloo.

In the United States, the major Federal government contributors to Great Lakes water quality research are: the Great Lakes Environmental Research Laboratory (GLERL) of NOAA in Ann Arbor, Mich., the U.S. EPA Environmental Research Laboratory-Duluth mainly through its Large Lakes Research Station (LLRS) in Grosse Ile, Mich., and the Great Lakes Fishery Laboratory of the Fish and Wildlife Service, Ann Arbor. The Sea Grant Program (co-funded by NOAA and the states), the NOAA GLERL, and the U.S. EPA LLRS support Great Lakes water quality research at a number of universities and laboratories: Argonne National Laboratory, Case Western Reserve. Clarkson College, Duke University, Manhattan College, Michigan State University, Oak Ridge National Laboratory, Ohio State University, State University of New York, University of Michigan, University of Minnesota, University of Wisconsin, and University of Wisconsin-Milwaukee.

In addition to Federal institutions, the Province of Ontario and the Great Lakes States--Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin--maintain laboratories that participate in monitoring (with Federal financial support) and contribute in varying degrees to Great Lakes research.

The complexity of the Great Lakes water quality issues warrants an intensive program of multidisciplinary research specific to the Great Lakes resource problems. Such research should be systematic and holistic to include all first-order aspects of the Great Lakes ecosystem pertinent to the problems. Since fundamental information and tools are lacking, such research must include a long-term commitment in process research, numerical modeling research, and applied research to improve engineering assessment tools and decision making. If research is inadequate, it will be difficult to assess problems and develop alternative management options. Once problems have been identified, solutions and recovery may take decades. There is adequate latent capability in the Canadian and United States institutions, but its development and focus on Great Lakes water quality problems requires organization and long-term commitment of resources to develop the needed understanding, information, and methods of decision making. Is the Great Lakes Federal research funding commitment consistent with the threats to the valuable Great Lakes resources and, consequently, human health? Is it consistent with the long-term research needs?

7. CONCLUDING REMARKS

I perceive the primary Great Lakes water quality issues of the next decade (1986-96) to be 1) nutrient enrichment, primarily from nonpoint source tributary loads from land drainage; and 2) toxic organic contaminants from atmospheric loads, nonpoint source tributary loads, and point sources. Management decisions will be more complex owing to conflicts of use, and more in-depth problem assessments will be required for implementation. It will be necessary to have greater understanding of and information about contaminant sources, fate, and effects on the Great Lakes ecosystem, as well as improved assessments of remedial measures to ameliorate unacceptable risks, conflicts, and costs. Costs include risks to the living resource and to human health; conflicts of Great Lakes resource use, atmospheric resource use, and land use; and costs to users of the Great Lakes resource, atmosphere, and land.

The primary questions for Phase II of this study are:

- Do the capabilities of Great Lakes research organizations match those required for the critical Great Lakes issues of the next decade (1986-96) for point source loads of contaminants? for nonpoint source land drainage? for atmospheric loads from sources within the Great Lakes basin? for atmospheric loads from sources outside the Great Lakes basin?

- Do we have an adequate understanding of and information about the effects, benefits, and costs of past corrective actions? of future corrective actions?

- Do the research organizations in Canada and the United States have suitable missions, objectives, and research programs and sufficient resources (including staff, facilities, and funding) to vigorously pursue these holistic, multidisciplinary ecosystem research problems?

- Is there adequate Canadian and United States research coordination? joint research programs?

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