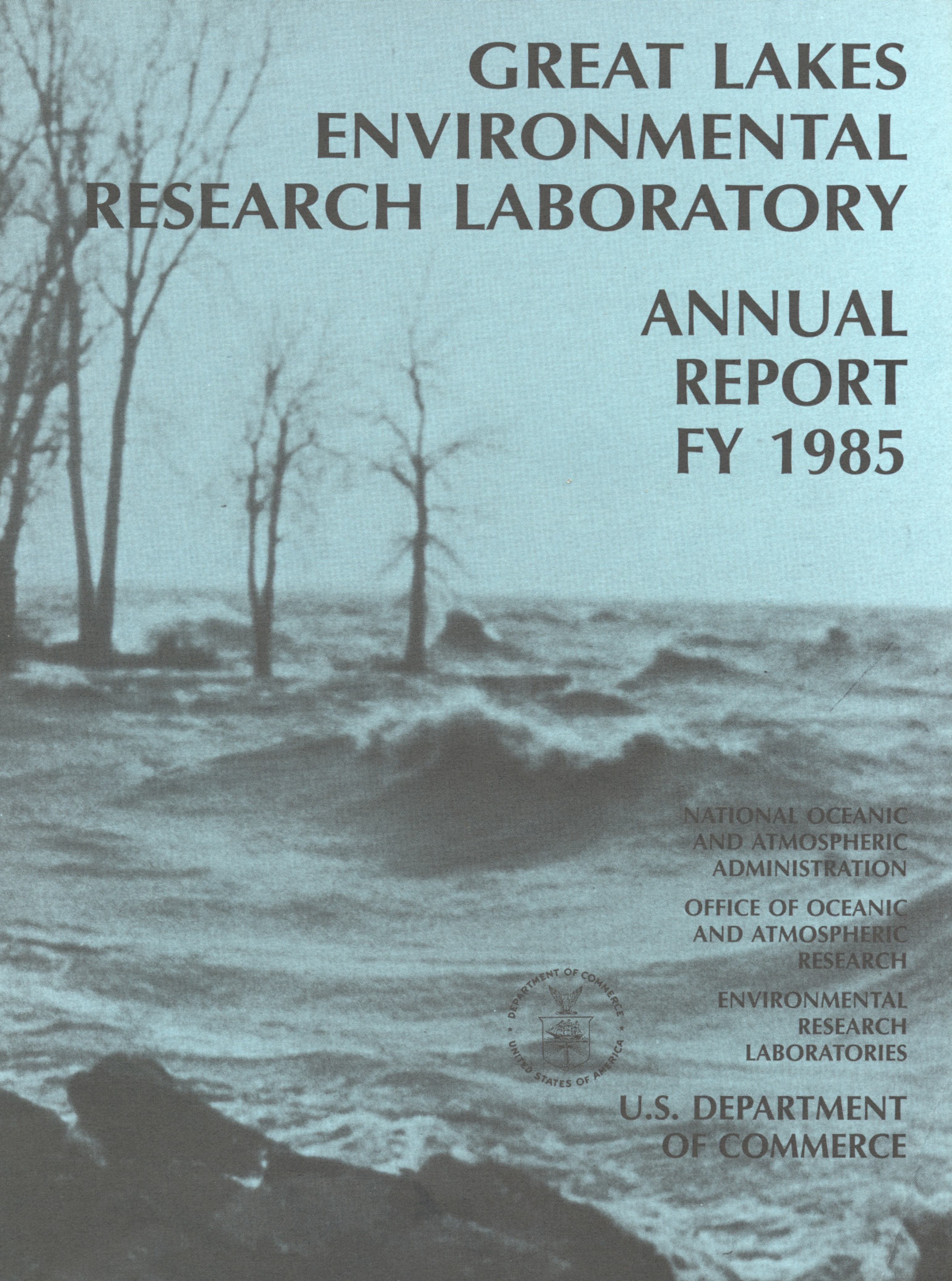


GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

ANNUAL REPORT FY 1985

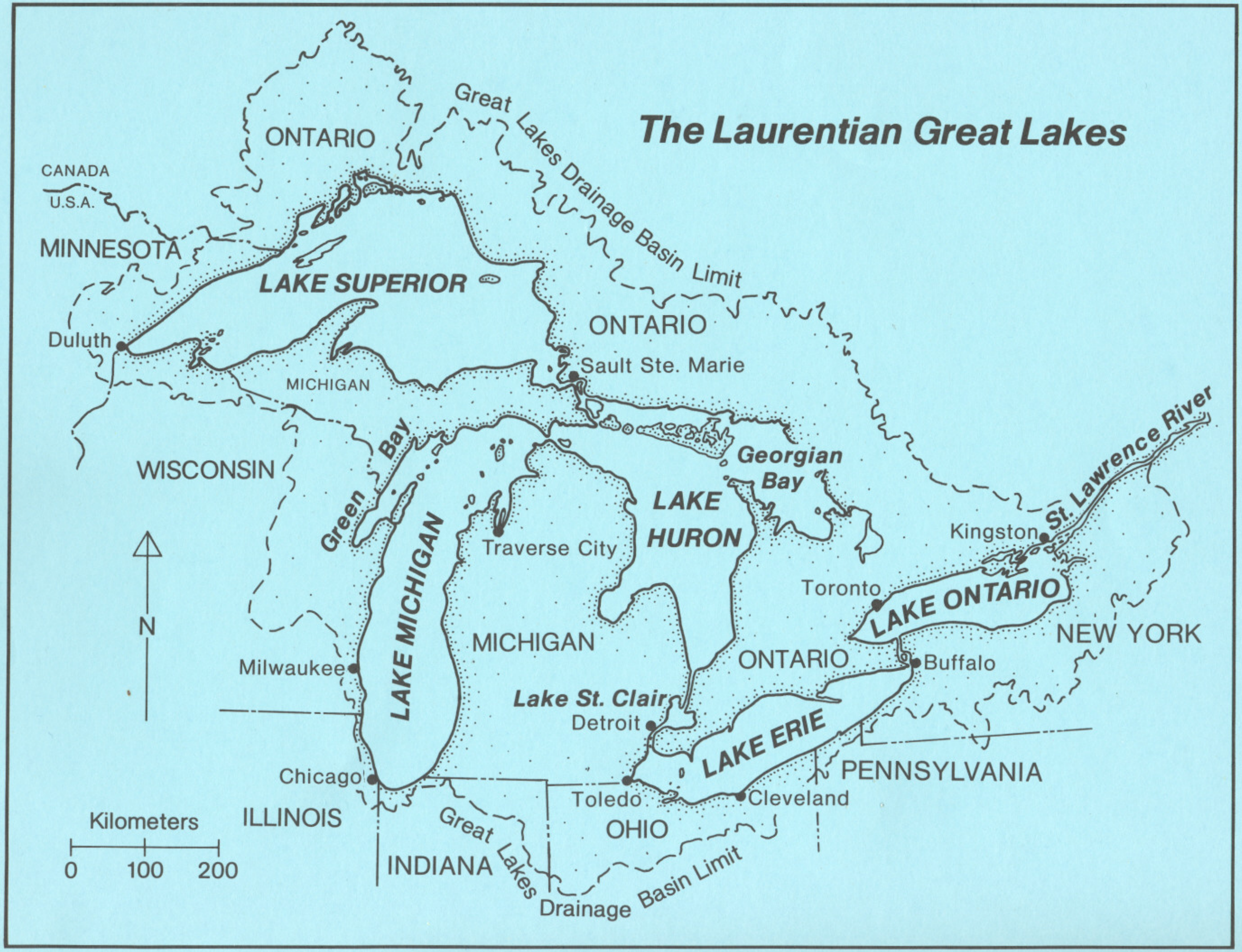
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH

ENVIRONMENTAL RESEARCH LABORATORIES

U.S. DEPARTMENT OF COMMERCE

The Laurentian Great Lakes



GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

ANNUAL REPORT FY 1985

December 1985

Eugene J. Aubert, Director

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Environmental Research Laboratories
Great Lakes Environmental Research Laboratory
2300 Washtenaw Avenue
Ann Arbor, Michigan 48104

NOTICE

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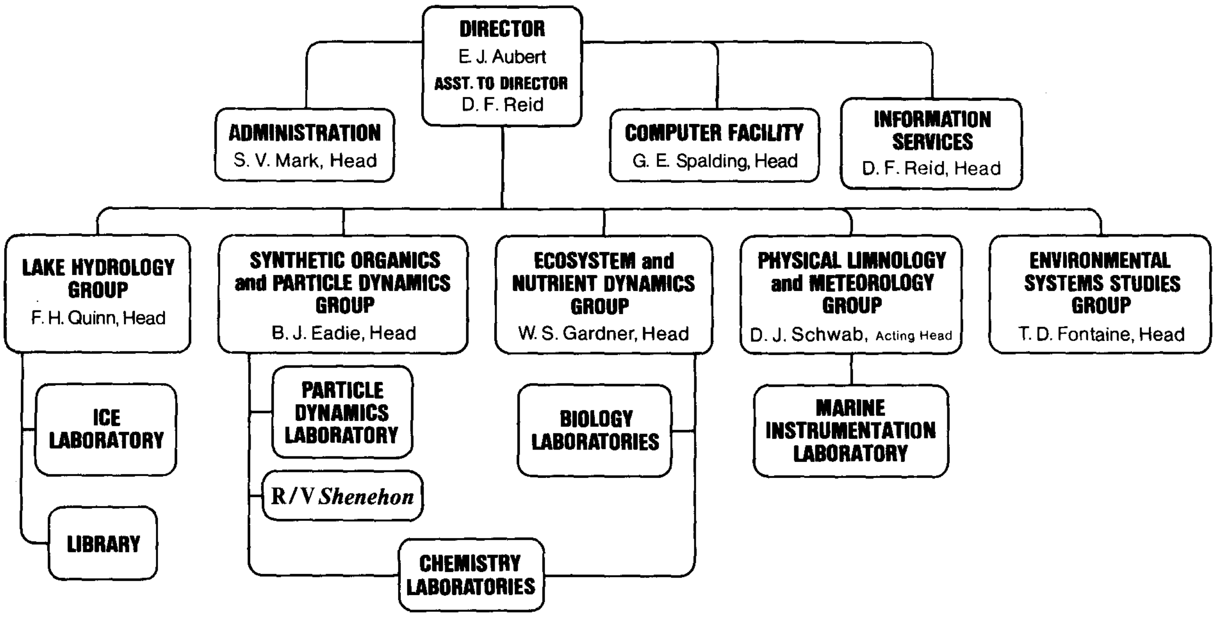
Front Cover: Water levels on the Great Lakes have been in a high regime for the past fifteen years, resulting in flooding around the perimeter and extensive damage due to shore erosion, especially during storms.

GLERL Organization Chart



Highlights

The Great Lakes Environmental Research Laboratory (GLERL) has completed its eleventh year conducting research on significant environmental processes and problems in the Great Lakes region. Research is carried out by five groups with expertise ranging from aquatic chemistry and biology to physics, hydrology, and computer modeling. GLERL's projects are interdisciplinary and integrated where feasible, to maximize utilization of operational resources in support of NOAA's Ocean and Great Lakes Prediction Research Program. GLERL is also taking part in the Upper Great Lakes Connecting Channels Study (UGLCCS), a multi-agency joint United States-Canada study of water quality and ecosystem dynamics in Lake St. Clair and the St. Clair and Detroit Rivers. The products of GLERL research are used by government, educational, and private organizations to facilitate planning and improve decision making in relation to water resources management and environmental services in coastal and estuarine waters, especially the Great Lakes. GLERL's products are disseminated as technical publications, brochures, posters, and by presentations at scientific and public meetings. During FY 1985, 69 scientific articles, reports, and books were published and 85 talks were presented by GLERL staff at scientific or public meetings.

Research

The Synthetic Organics and Particle Dynamics Group focuses on research to improve our understanding of the processes that control the movements and fates of trace contaminants, especially the synthetic organics, in the Great lakes and coastal marine ecosystems. During FY 1985:

- Hydrophobic organic contaminants (HOC) were found to associate with (e.g., partition to) a spectrum of dissolved materials, including dissolved organic matter and extremely fine particles that are "operationally" defined as being dissolved. Such partitioning significantly reduces the entry of these contaminants into the food chain in the Great Lakes.
- The partitioning of HOC in the Great Lakes between dissolved and particulate substrates was shown to undergo complicated seasonal variations that are compound dependent. The introduction of time-variable phase partition coefficients in GLERL's contaminant-fate model indicated that such seasonal variability could significantly affect the concentration of HOC predicted to remain in the water column.
- Field work for a seasonal mass flux study in Lakes Superior, Huron, and Michigan was completed with the final retrieval of long-term sediment trap moorings. The results revealed a significant increase in mass flux during the unstratified winter period in the Great Lakes, primarily due to resuspension of bottom sediments. The reintroduction of PCBs and phosphorus by resuspension was shown to equal the sum total of all other known inputs of these materials. The combination of resuspension and bioturbation (stirring of the upper sediments by organisms) thus appears to buffer the lake environment against responding rapidly to decreases in the loading of trace contaminants, thereby possibly reducing the effectiveness of remedial actions taken by resource managers.
- The presence of dissolved organic matter (DOM) from natural interstitial waters of the Great Lakes was shown to reduce the bioavailability of organic contaminants, thus confirming the results of laboratory studies performed using artificial DOM standards.
- The freshwater shrimp, *Mysis relicta*, was used in a study of the uptake of contaminants via ingestion of contaminated food versus directly from contaminated water. Results contradicted the common assumption that the contaminant body burden of an aquatic animal is enhanced by ingestion of contaminated food: in this study, the body burden of benzo(a)pyrene in *M. relicta* decreased when contaminated food was ingested.
- The GLERL non-steady-state sediment mixing model was validated against the vertical distribution of lead in cores from high sedimentation areas of the Great Lakes. The model-predicted distributions provided an extremely good fit to observed data.
- Thirty-five sediment cores were hand-collected from Lake St. Clair by divers as part of the UGLCCS. These cores will be analyzed to evaluate whether Lake St. Clair acts as a natural trap for contaminant-bearing particles from the St. Clair River and surrounding watershed. Remotely deployable instrument packages were developed for a related study of sediment resuspension in Lake St. Clair. These packages are instrumented with wave, current, temperature, and light transmission sensors and can collect and store data for up to a month between retrievals.

The Ecosystem and Nutrient Dynamics Group studies the factors that control nutrient and energy cycling, ecological succession, and long-term biological trends in the Great Lakes. Highlights of their work during FY 1985 include:

- A heat-diffusion model was developed for Lake Michigan that simulates the daily epilimnetic thermal structure, emphasizing diurnal variations in stability, mixed-layer depth, and mixing time. The model simulations compared favorably with actual observations made during 1983 and 1984.

- Carbon-14 based estimates of primary productivity in Lake Michigan were found to be in good agreement with other, independent estimates. This suggests that the carbon-14 technique may be satisfactory for limnologic work, unlike the experience of the oceanic community, which has agreed to disagree as to the validity of the technique applied to oceanic productivity. Productivity over the past ten summers was found to be relatively constant in spite of significant reductions in phosphorus loading, indicating that summer productivity is not phosphorus-limited.
- Simulations of subthermocline production in the presence of internal waves showed that conventional estimates can be significantly in error, depending on the trajectory of the phytoplankton population being affected by the wave. Productivity estimates with improved accuracy can be made if the trajectory of the phytoplankton and the resulting effects of internal waves are considered and incorporated in the estimates.
- Bacterial production can account for a significant portion of the total production in the Great lakes. During FY 1985, experiments were conducted to determine whether Lake Michigan bacteria are limited more by organic substrate availability or by predation. The results indicate that grazing pressure provides more control over the bacterial population.
- The particle size distribution of calcite crystals formed during late summer "whitings" in Lake Michigan was studied. A novel technique was used to differentiate between the carbonate (i.e., calcite) and non-carbonate part of the total size spectrum. Calcite was shown to comprise from 12 to 56% of the total particle volume during whitings, but had similar year-to-year size distributions, with a modal size of 7 microns equivalent spherical diameter. Therefore, light scattering off calcite particles is expected to have a minimal impact on the transmission of light through the water column, as scattering is most intense at 1 micron and decreases rapidly with increased particle size.
- Simulation experiments on the effects of silicon limitation on Great Lakes phytoplankton revealed that silicon limitation affects the ability of diatoms to utilize phosphorus and thus triggers the observed shift to blue-green algae during the summer.
- Measurements of the seasonal lipid (fat) content of four species of benthic invertebrates and a freshwater shrimp were completed. Those that feed on suspended material generally had higher and more variable lipid contents (and therefore are more desirable prey for small fish) than those which feed on already deposited subsurface material.
- Calculations on the areal distribution and caloric content of the major benthic species in Lake Michigan revealed that the benthic invertebrate, *Pontoporeia hoyi*, is the dominant species, constituting about 65% of the benthic biomass and containing approximately 70% of the total caloric reservoir there. Based on these findings, it is estimated that *P. hoyi* could require up to 30% of the incoming detritus to maintain this level of energy storage.
- *Pontoporeia hoyi* was found to retain most of its lipids as energy-storing triglycerides, and was observed to survive at least 80 days without food. Evidence from gut-content vs. time studies suggests that *P. hoyi* may feed sporadically rather than continuously. The ability of this organism to efficiently store energy and to go without food for long periods of time is thought to at least partly explain its ability to thrive in low-nutrient environments, such as the upper Great Lakes.
- A GLERL scientist participated in the exploration of Lake Superior using a research submersible. He used the submersible for direct evaluations of benthic sampling techniques, and to examine the microdistributions of benthic invertebrates. A major observation was the occurrence of large numbers of freshwater *Hydra* coating rocks as deep as 400 meters.

During FY 1985 the Great Lakes set record high water levels. The Lake Hydrology Group at GLERL focuses on studies to improve our knowledge of the hydrologic and hydraulic processes that affect the Great Lakes, including improving forecasting methodology, producing more accurate simulations of water supplies and lake water levels, and improving large river dynamic flow models. The hydrology program also pursues studies to improve information concerning the seasonal ice cover on the lakes, including formation, growth, movement, and decay of the seasonal ice and snow cover. During FY 1985:

- The Hydrology staff completed development of a semi-automatic software package which uses meteorologic data in near-real-time to predict water supplies to Lake Superior. Parts of this package were installed on the U.S. Army Corps of Engineers (Detroit District) mainframe computer and mini-computer, for use in forecasting Great Lakes water levels for the International Joint Commission.
- A similar forecast package was developed for Lake Champlain and installed on the computer at the National Weather Service (NWS) Northeast River Forecast Center, at their request.
- The first year of simultaneous measurements of currents in both the St. Clair and Detroit Rivers was completed. Analyses of the data showed that standard electromagnetic current meters are poorly suited for prolonged measurements in rivers which are subject to a high incidence of flowing debris, including ice and weeds. On the other hand, acoustic doppler current profilers appeared to suffer no deterioration of accuracy under the same conditions.
- A winter field program to measure and characterize the spectral reflectance of snow and freshwater ice types was continued during FY 1985. Correction fac-

tors for atmospheric attenuation and path radiance were calculated from measurements using calibration panels, snow, and open water. Application of these correction factors produced a slight increase in the average reflectance measured for a variety of Great Lakes snow and ice types.

- A temperature climatology was developed for Lake Superior and made available to NWS forecasters in tabular and graphical forms, including both hardcopy and an on-line computerized data base.
- An interactive computer program was developed on the GLERL computer for use by the NWS Weather Service Forecast Office – Ann Arbor, to allow forecasting of ice formation, ice thickness, and date of breakup at specific locations along the St. Marys River. During the 1985-86 winter season the NWS will access this forecast model on the GLERL computer on an experimental basis, to test its validity.

The Physical Limnology and Meteorology Group studies the physical processes and variables that determine and describe how the Great Lakes and coastal estuaries respond to external physical forcing, and develops improved numerical simulation and prediction methods. The primary driving processes are the wind acting on the water surface, the exchange of heat across the water-atmosphere boundary, and hydraulic flow through the system. Research conducted by this group includes studies of nearshore and lakewide circulation, seasonal changes in the current regimes, thermal structure of the water column, surface waves, and seiching and surging during storms. During FY 1985, the significant results of these studies included:

- A permanent rotational wave with a 4-day period was shown to be trapped within the southern basin of Lake Michigan, a finding that may help simplify dynamical simulations of this basin.
- The characteristics of the bottom Ekman layer in southern Lake Michigan were described in detail, and revealed that most of the Ekman veering occurs within 10 meters of the bottom. These results will be used to improve simulation models that incorporate the near-bottom or benthic boundary layer as a consideration.
- Analyses of data collected during previous fiscal years showed that, under light wind and wave conditions on the Great Lakes, the trajectory difference, or "slippage," between drifter buoys and actual water parcels tagged by dye is well described by elementary slippage theory. This allows the development of an improved drifter data base that is more useful for trajectory prediction verification.
- In connection with the UGLCCS, three week-long synoptic current surveys were made at eleven sites in Lake St. Clair. Each survey consisted of a time series of 128 measurements made at 0.5-second intervals at three depths at each site over the course of the week.
- The Pathfinder Trajectory Prediction Model was used several times by the U.S. Coast Guard and the NOAA Hazardous Materials Response Team to predict the movement of spills and similar contaminant inputs, and to focus search and rescue operations in the Great Lakes. Improvements to this model were begun during FY 1985, based on testing the model against GLERL's library of drifter records.
- The GLERL Interactive Wave Prediction Model was made available in a modified form to include an air-water temperature difference parameter at the request of the Cleveland Weather Service Forecast Office, which will evaluate the usefulness of this parameter during FY 1986.
- A joint experiment (WAVEDISS '85) involving scientists from GLERL, the National Water Research Institute of Canada (NWRI), and the Atmospheric Environment Service of Canada was started in Lake St. Clair to measure wave dissipation and the effects of waves on sediment resuspension in shallow water environments. Instrumented towers were deployed in September 1985 and will remain deployed through November 1985.
- A comparison of data from a GLERL-deployed satellite-reporting wave buoy against the wave heights reported by a NOAA NOMAD weather buoy in Lake Erie revealed slight biases in the NOMAD data at both the high and low ends of the waveheight range (0.1 – 1.9 meters).
- A study of shallow water effects on the wind wave spectrum was completed using field measurements made in Lake Erie during 1981. It demonstrated that the depth-dependent factors derived for the deep ocean environment are very effective in characterizing the depth effects of wind waves in shallow water systems.

The Environmental Systems Studies Group completed its first full year of research. The work of this group focuses on questions concerning the effects on the Great Lakes ecosystems of alternative management schemes and human-induced changes, the risks to ecosystem health posed by contaminants, and the cost-effectiveness of environmental management strategies. During FY 1985:

- An optimization and cost-effectiveness analysis of the various strategies to implement the IJC plan for phosphorus management in the Great Lakes region was completed. The results showed that the probability of attaining the stated goals varies from basin to basin, and is quite low under some strategies. An alternative least-cost strategy was described which, with a 100% probability, would lead to achievement of the desired goals in all basins.
- Coordination of the GLERL studies in relation to the UGLCCS was provided, and a phosphorus mass balance model for Lake St. Clair was developed. Devel-

opment of a similar, but more detailed, toxic contaminant model was begun.

Information Services

Staff participation on boards, commissions, task forces, and committees provides a mechanism for GLERL to define user needs and identify needed products. During FY 1985, GLERL staff were active participants on several boards, committees, and task forces under the auspices of the IJC, and in connection with the UGLCCS. Staff also participated as members of regional, federal, and international groups, such as the U.S. Ice Information Working Group, the International Association for Hydrologic Research, a planning group involving the NOAA/National Marine Pollution Program Office and the Environmental Protection Agency, the NOAA Marine Environmental Quality Task Force, the Synthetic Organics Research Subcommittee, the Habitat Modification Research Subcommittee, and the Executive Board of the International Association for Great Lakes Research. A complete description of these staff activities is found under the Information Services section of this report.

The Information Services Group ensures that GLERL products are provided to the user communities in a timely manner and in the appropriate format. During FY 1985, almost 2,800 products were distributed in response to almost 1,600 documented requests for GLERL products and related information. U.S. and foreign state and federal government requests comprised 37% of the requests, while university requests were 31%, industrial requests were 25%, and private citizens accounted for 2% of the total. GLERL also made eight significant technology transfers to outside users, as follows:

- Method for Amino Acid Analysis of Natural Waters
- Track Autoradiography Procedure
- Measurement of Primary Production in Lakes and Rivers
- The Pathfinder Trajectory Spill Model
- The Lake Champlain Water Supply Model
- The Interactive Wave Prediction Model
- The Lake Superior Water Supply Model
- Technique to Estimate Snow Water Equivalent from Gamma Radiation Measurements.

Facilities

During FY 1985, GLERL continued to occupy space in five locations around Ann Arbor, with warehousing some 60 miles away. However, significant progress was made toward obtaining new leased facilities that would consolidate all GLERL functions under one roof. The existing facilities include:

- Biology and chemistry laboratories for both general and specialized measurements and analyses, including a newly installed independent Microcinematography Laboratory for high-speed motion picture studies of biological processes. In addition, there is a self-contained Ice Laboratory which allows laboratory-based experiments to be conducted at sub-freezing temperatures.
- The Marine Instrumentation Laboratory, which is a separate unit under the Physical Limnology and Meteorology Group and provides comprehensive support for the design, calibration, repair, and deployment of instruments to collect field data.
- The Computer facility, consisting of an on-site VAX 11/780 system and access to both a mainframe Cyber 180/855 and a Cyber 205 supercomputer, the latter under the auspices of the Department of Commerce Consolidated Scientific Computing Service located in Gaithersburg, Maryland.
- The R/V *Shenehon*, GLERL's primary field platform, which is a 65.6 foot research vessel based at the U.S. Army Corps of Engineers boat yard in Grand Haven, Michigan. During FY 1985, the on-board laboratory was modernized and expanded, and a number of other improvements to the scientific facilities were made resulting in easier access and more deck and storage space.
- The GLERL Library, which maintains a research collection tailored to staff needs, and which provides specialized retrieval services when the existing collection cannot meet special staff requirements. Collection holdings include 3,100 books, 3,700 unbound periodical volumes, and 2,900 technical reports.

Introduction

GLERL Overview

This Annual Report of the Great Lakes Environmental Research Laboratory (GLERL) provides a summary of significant accomplishments and activities related to its research programs during fiscal year 1985 (FY 1985: October 1, 1984 – September 30, 1985). GLERL is an environmental research laboratory of the National Oceanic and Atmospheric Administration (NOAA), under the U.S. Department of Commerce, and has completed its eleventh year of operation in Ann Arbor, Michigan. GLERL's mission is to conduct research directed toward understanding the environmental processes and solving problems in resource management and environmental services in coastal and estuarine waters, with a focus on the Great Lakes.

Special emphasis is placed on a systems approach in problem-oriented research to develop environmental service tools. Decision makers at all levels of government require access to information and improved methods for impact assessment, resource management, and safety and economy of operations in the coastal marine environment. The Great Lakes are the largest reservoir of fresh surface water in the United States, but are also sinks for domestic and industrial wastes. Major cities, including Buffalo, Cleveland, Chicago, Detroit, Milwaukee, Rochester, and Toledo, are located along the more than 5,000 miles of U.S. shoreline, and over 30 million people in the United States take their drinking water from the lakes. Understanding the complex lake-land-atmosphere-sediment system of the areas in and around the Great Lakes and coastal and estuarine waters and the many interactions that influence the lives of those in these regions requires a team of scientists with different backgrounds working together. Field, laboratory, and analytic investigations of the limnological, hydrological, and meteorological properties of the lakes, their basins, and the overlying atmosphere are necessary. The ultimate goal of the GLERL program is to understand the system to the extent that environmental simulation and prediction models can be built that will provide sufficiantly precise information on Great Lakes and coastal and estuarine processes and phenomena to support enlightened use of the region's resources.

Research at GLERL is carried out by five groups: Synthetic Organics and Particle Dynamics, Ecosystem and Nutrient Dynamics, Lake Hydrology, Physical Limnology and Meteorology, and Environmental Systems Studies. Staff specialties include aquatic chemistry, aquatic biology and toxicology, applied mathematics, meteorology, geology, hydrology, physical oceanography, ecology, computer systems applications, instrument design and development, and experimental design and analysis. The products of GLERL's research are used by government and private organizations to facilitate planning and improve decision making in relation to water resources management.

Ocean and Great Lakes Prediction Research

GLERL's multidisciplinary program supports the Ocean and Great Lakes Prediction Research Program of NOAA. Two elements of this program provide the focus for GLERL research: Marine Ecosystems Assessment, and Marine Hazards and Lake Hydrology. The Marine Ecosystems Assessment research program at GLERL is designed to (1) improve our understanding of, and predictions related to, natural marine ecosystems, physical phenomena, and the impact of human-induced stresses on the ecosystem, and (2) help provide a sound scientific basis for management decisions pertinent to marine resources, marine pollution, and environmentally sensitive marine activities. GLERL projects in support of these program elements include investigations into the short- and long-term effects of human, agricultural, and industrial wastes on aquatic life and water quality, particularly in the nearshore zone (the area of maximum use and conflict); the structure and function of aquatic ecosystems and the effects of human activities on those ecosystems; measurement, analyses, and prediction of physical phenomena such as currents, river flows, and air-water-sediment interactions; and sedimentary fluxes and processes, especially sediment-contaminant interactions. Marine Hazards and Lake Hydrology research focuses on (1) improving prediction of environmental phenomena associated with the National Weather Service (NWS) marine warning and forecasting services and the regulation of Great Lakes water flow by the U.S. Army Corps of Engineers, and (2) providing better tools and methods for short- and long-term assessments of water resources of large lakes. GLERL research in these areas includes field and analytical investigations to develop simulation and prediction models of over-water wind and wind-waves, water surface oscillations, storm surges, and flooding; lake ice formation, growth, movement, and break-up; and hydrologic lake levels, water supplies and balance, and flows in the connecting channels. GLERL staff work closely with colleagues at the forecasting and warning service agencies to assure that GLERL products meet the needs of the operational forecasters. Products released to the user community continue to be improved by GLERL researchers, either by fine-tuning or by the addition of new tools and capabilities.

The Upper Great Lakes Connecting Channels Study

The Upper Great Lakes Connecting Channels Study (UGLCCS) is an international (United States-Canada) and interagency multiyear study of water quality and ecosystem dynamics in the upper Great Lakes connecting channels. Study areas include the St. Marys River, the St. Clair River, Lake St. Clair, and the Detroit River; all are designated by the International Joint Commission (IJC) as "Areas of Concern" in which environmental quality is degraded and beneficial uses of the water and biota are adversely affected. The goals of the study are (1) to determine the existing environmental condition of the study areas, (2) to identify and quantify the impacts of contaminant loading on human and ecosystem uses of the study areas, (3) to determine the adequacy of existing or proposed programs for ensuring or restoring beneficial uses, and (4) to recommend appropriate programs for protecting the study areas.

GLERL's involvement in the UGLCCS is research oriented and addresses a number of physical, chemical, and biological questions pertinent to accomplishing the overall study's goals. Through coordinated modeling, field, and laboratory studies, GLERL scientists seek answers to questions, such as, given a contaminant loading, where will the contaminant ultimately go, how long will it remain there, what will its concentration be, and what risk will it pose to the ecosystem? In order to answer these questions GLERL scientists are developing current, wave and particle transport models for the study area, studying the toxicokinetics of organic contaminants in biota, researching sediment and sediment-adsorbed contaminant dynamics, examining ecosystem processes that affect contaminant dynamics, and developing contaminant fate and exposure models for determining the risk to ecosystem health that might result from a variety of management or contaminant loading scenarios.

Synthetic Organics and Particle Dynamics

The Synthetic Organics and Particle Dynamics Group concentrates on understanding the processes that control the movement and fate of trace contaminants in the Great Lakes and coastal marine ecosystems. Ongoing work focuses on factors controlling contaminant partitioning to particulate matter, lake particle flux dynamics, the role of benthic invertebrates in contaminant cycling, and early diagenesis and mixing processes in sediments.

Contaminants, particularly the organic xenobiotics (i.e., organic compounds foreign to the biota), have been identified at many levels as a critical problem on regional, national, and global scales. This is particularly true for the Great Lakes and estuarine areas which receive high loads, have limited flushing, and support extremely valuable yet fragile ecosystems. Any attempt to understand the transport, fate, and effects of toxic contaminants in an aquatic ecosystem must consider details of the physics, hydrology, nutrient cycling, chemistry, ecology, and organism physiologies for the system under study. Such information must be provided at a level of temporal and spatial detail consistent with the questions being addressed. Only then can a framework be developed for determining the movement and speciation of contaminants as well as for estimating exposure, bioavailability, and effects.

Contaminant cycling in an aquatic ecosystem can be divided into five major areas of study: (1) environmental monitoring for *load* estimates, and validation and calibration of models, (2) physical, chemical, and biological processes affecting the *fate*, transport, and degradation of contaminants, (3) *exposure*, bioavailability, toxicokinetics, and biodegradation of contaminants, (4) acute and chronic *effects* and development of biochemical and biological early warning indicators, and (5) system *assessments* and predictive simulation modeling.

GLERL has focused its program on those processes with characteristic time scales of seasonal or greater lengths that affect the long-term behavior and fate of contaminants. This program is now five years old and significant progress has been made in the development of tools for the simulation of lake scale, long-term contaminant behavior. Other problems exist for which shorter-term processes (day-week) must be simulated. These include limited nearshore systems, shallow systems of any areal extent, estimates of effects on particular life history stages, etc. Although much of what we have learned will be transferable, the decrease in temporal and spatial dimensions by an order of magnitude vastly increases the effort required to develop simulations with the same precision achieved for whole lake systems. Program efforts are now focusing on the sediment-water-benthos subsystem, which has been identified as the area with major impact on long-term contaminant behavior, and which has a direct link to humans (Fig. 1).

Particle-Contaminant Interactions

In lakes and estuaries, the partitioning of hydrophobic organic contaminants (HOC) onto particles followed by settling and eventual burial is commonly the major internal process controlling the residence time and concentration of these compounds in the water column. Over the past few years, several laboratory studies have shown that partitioning between the dissolved phase and particles is inversely proportional to the solubility of the HOC and to the substrate concentration, and is proportional to the organic carbon content of the substrate. Total suspended particulate matter (TSM) plays a vital role in the solution chemistry of the Great Lakes by sorbing pollutants from the water, thus providing a potential mechanism for cleansing the lakes through sedimentation. In some cases, however, the sediments serve as only a temporary reservoir for the sorbed contaminants, later releasing them to the overlying water and exposing the ecosystem to "trapped" contaminants through the processes of diffusion, sediment resuspension, or food web transfer upward from the benthos.

Investigations in our laboratory have recently shown that HOC also form an association with the spectrum of materials operationally defined as dissolved, which includes very fine particles and dissolved organic matter (DOM). The partitioning of HOC to TSM or DOM

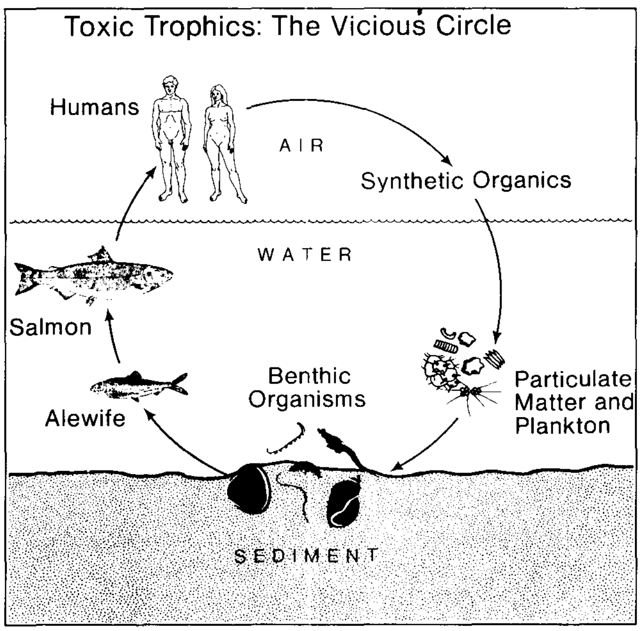


Figure 1. A conceptual representation of the cycling of trace contaminants in the Great Lakes and the closed-loop relationship to human beings.

appears to significantly reduce the bioavailability of these compounds to Great Lakes benthic organisms.

A perceived shortcoming of most laboratory studies of phase distribution is the use of artificial media, usually with grossly elevated substrate concentrations. Since substrate concentration affects HOC distributions, the results of these experiments are difficult to extrapolate to field conditions for modeling purposes. Previous laboratory measurements of the partitioning of a variety of radiolabeled organic contaminants to 11 samples of sediment trap material, collected at approximately monthly intervals from a 15-meter depth at a station in the center of southern Lake Michigan with a bottom depth of 146 meters, showed an order of magnitude range in K_p, the ratio of particle associated to dissolved contaminant concentrations. This seasonal signal was shown to have a significant effect on contaminant concentrations predicted by our fate models. During FY 1985 a more temporally detailed study was completed. Freshly collected Great Lakes waters were inoculated with a suite of radiolabeled HOC and were phase separated after equilibration, to measure the concentration of freely dissolved HOC versus the concentration of HOC associated with TSM and DOM. The study examined the effects on compound phase distribution of both the seasonal changes and differences in ambient conditions among the Great Lakes. Results indicate a complicated seasonal pattern that is compound dependent (Fig. 2). Benzo(a)pyrene (BaP) is predominantly particle bound early in the year, eventually becoming primarily dissolved by early summer. DDT shows almost the inverse behavior, while pyrene distribution remains essentially constant throughout the year. The measured seasonal values of the K_p for BaP were used in our contaminant fate model and the outputs (assuming constant load and steady state) indicate that the values significantly affect the predicted water concentration. At present there are insufficient data to validate these results. This work is being continued.

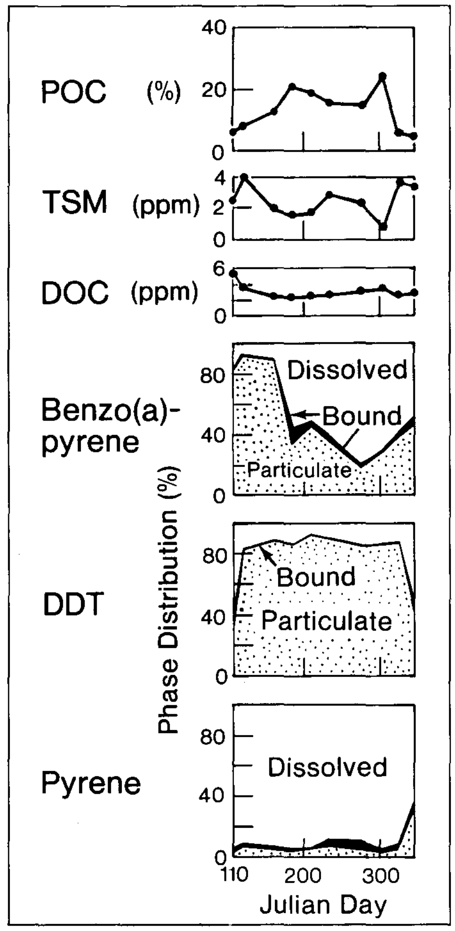


Figure 2. Results of trace organic phase distribution experiments using Lake Michigan waters. The particulate organic carbon in the samples ranged from 5 to 24%, TSM ranged from 0.8 to 4.1 ppm, and DOC remained relatively constant. BaP is over 80% particle associated in the spring, but declines to about 25% in summer. DDT shows the reverse seasonal partitioning behavior while pyrene partitioning is essentially constant for all samples.

Surficial sediments, with their sorbed contaminants, are mixed by animal activity (bioturbation) and are reintroduced to the water column via resuspension. In order to study the role of resuspension in the Great Lakes, GLERL has been measuring the fluxes of particulate matter using sediment traps moored in vertical arrays in the water column. Past results from Lake Michigan indicated that resuspension follows a seasonal pattern, with a maximum in the winter. This process was shown to influence the observable characteristics of both the sediments and the water column. By providing a mechanism for intimate contact between recent sediments and overlying water, resuspension appears to play a significant role in the cycling of nutrients and contaminants.

In a continuation of these studies, vertical arrays of sediment traps (5 – 7 per array) were deployed in July 1984 at four stations each in Lakes Superior, Huron, and Michigan. The traps were retrieved, sampled, and redeployed in September 1984 and retrieved for the last time in July 1985. Thus there were two samples from each trap, one representing fluxes during the period of thermal stratification (summer) and one when the lakes were unstratified (winter). The deployments in Lake Michigan were at locations that had been sampled in prior years and these served as controls. The fluxes measured in 1984 – 85 were within the range of values previously measured, indicating that we had collected during a "typical year." A total of 162 samples were recovered; two were lost when a mooring-wire parted.

Summer particle mass flux data from one station in each of the three lakes are shown in Figure 3 (note that stations are of similar depth). The fluxes in Lakes Michigan (average lake depth (Z) = 86 meters) and Huron (Z = 59 meters) were similar and significantly greater than

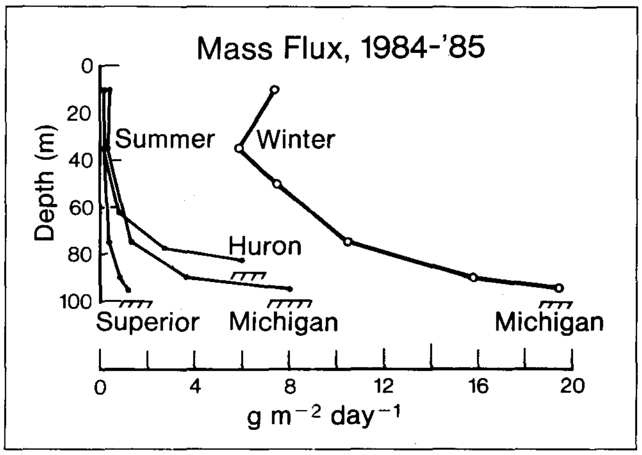


Figure 3. Particle mass fluxes measured using sediment traps at offshore stations in Lakes Michigan, Huron, and Superior. A winter profile from the Lake Michigan station provides a comparison of the magnitude of this process during stratified (summer) versus unstratified (winter) periods.

the flux measured in Lake Superior ($Z = 149$ meters). The winter flux profile from the Lake Michigan station shown in Figure 3 reveals a significant increase in the mass flux during the unstratified winter period.

Primary flux (e.g., flux of new material) was calculated using the data from the near-surface traps during the stratified period, and ranged from 0.1 to 1 gram per square meter per day. Resuspension was calculated as the integral of the flux profiles (divided by depth) minus the primary flux. Values in the three lakes ranged from 0.2 to almost 10 grams per square meter per day. These data are being used in GLERL's contaminant fate models that include the reintroduction of contaminated sediments by resuspension. From moored sediment trap collections, we have shown that in Lake Michigan the reintroduction of (1) sedimentary PCBs and (2) phosphorus and other contaminants by resuspension is equal to the sum of all other inputs of these materials. There is a long time constant (on the order of decades) associated with this internal recycling, proportional to the ratio of the thickness of the sediment-mixed layer to the rate of sediment accumulation. Thus, the combination of the bioturbation and resuspension processes buffers the lake system from responding to changes in loading of trace contaminants. These processes must be quantitatively understood in order to predict system responses to potential remedial alternatives.

Benthos-Sediment Interactions

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. Previous benthos-sediment interaction studies have examined the uptake, depuration, and biotransformation rate constants for various toxic organics in Great Lakes invertebrates and the empirical relationships between the rate constants and environmental parameters such as temperature, pollutant concentration, and sorption to dissolved and particulate matter. During the past year GLERL research focused on changes in bioavailability due to the presence of DOM.

DOM in aquatic systems has been shown to reduce the bioavailability of heavy metals. Past studies have demonstrated similar reductions in the bioavailability of organic contaminants in the presence of Aldrich humic acid, a laboratory standard for DOM. The mechanism for reduction was partitioning to the DOM, which reduced the "freely dissolved" bioavailable concentration of the contaminant. During FY 1985 this mechanism was also found to affect organic contaminants in the presence of DOM from natural interstitial waters. Partitioning of organic contaminants to DOM in waters from several geographical sources ranged over several orders of magnitude for an individual compound. A reverse-phase separation technique was used to measure the bound or sorbed xenobiotic, and by difference from the total, the freely dissolved concentration of a contaminant. The reverse-phase partition coefficient to DOM (K_{rp}) was well correlated ($r \doteq 0.86$) with bioavailability as measured by the uptake rate constant (K_b) of the organic xenobiotics to the amphipod *Pontoporeia hoyi* (the major benthic invertebrate in the Great Lakes) in the presence of DOM. K_b decreased over a range of three orders of magnitude in measured partition coefficient for individual organic contaminant compounds in the presence of DOM from different sources (Fig. 4). While sorption to DOM results in reduced bioavailability over the short term, the stabilization of nonpolar xenobiotics with time in the water column will likely produce enhanced dispersion and result in long-term, low level exposure of aquatic organisms to organic xenobiotics.

Data showing the accumulation of polycyclic aromatic hydrocarbons (PAH) from sediments by benthic organisms, specifically *Pontoporeia hoyi*, continue to exhibit considerable complexity. There appear to be several parameters that affect the bioaccumulation of PAH from sediment: sediment composition, the amount of material ingested by the organism, and the characteristics of the compound under investigation. Recent studies of *P. hoyi* indicate that this benthic invertebrate does not feed continuously and that the percent of the population that is feeding varies with size of the animals. *P. hoyi*, exposed in small static systems to sediments taken from the high-sedimentation area near Benton Harbor, Michigan, and treated with radiolabeled PAH, exhibited 100% mortality within 2 weeks. The *P. hoyi* were generally found to be free-swimming, thus avoiding the sediment. Another experiment, employing PAH-treated artificial sediment consisting of quartz and 1% trout chow by weight, in the same size system, also resulted in 100% mortality within

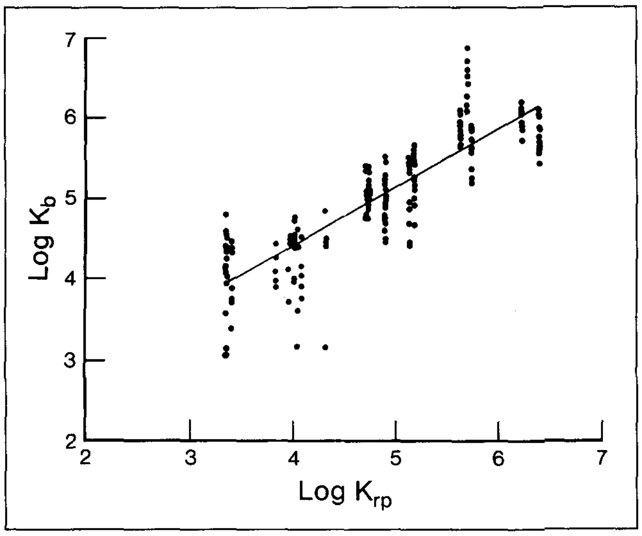


Figure 4. Plot of log K_b (biologically measured partition coefficient to DOM) versus log K_{rp} (reverse-phase partition coefficient to DOM) yields a strong positive correlation ($r = 0.86$). This will permit the mean log K_b to be predicted within ± 0.11 log units at the 95% CV from log K_{rp}.

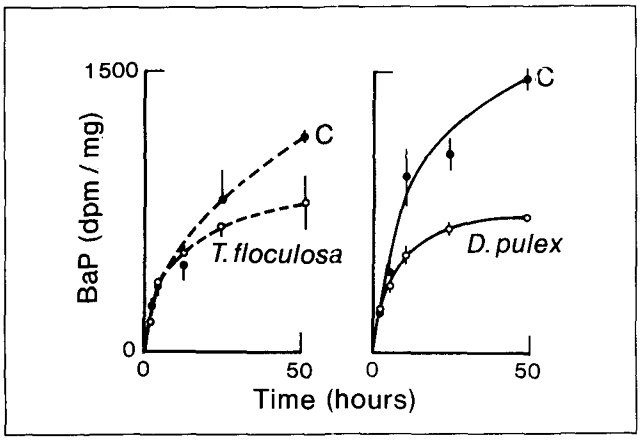


Figure 5. Uptake by *Mysis relicta* of BaP from contaminated water (line C) and two food-water combinations. The food sources used were the algae *Tabellaria floculosa* (left) and the zooplankton *Daphnia pulex* (right).

4 days. However, in the artificial substrate the problem appeared to be a bacterial bloom, and the *P. hoyi* did not appear to avoid the sediment. A sediment avoidance study was performed using fresh Lake Michigan sediment from the Grand Haven, Michigan, area as one control and quartz sand as a second control. Dried sediment from the Benton Harbor area and dried sediment from the Grand Haven area that had been used in previous experiments, were compared to the two controls. Both the quartz sand and the fresh sediment were found to be equally acceptable to the organisms, while the Benton Harbor sediment was the least acceptable (Table 1). Contaminant uptake rates were measured using Lake Michigan sediment collected from the Grand Haven area. The initial uptake rates were proportional to the water solubility of the xenobiotic, with the low water solubility compounds yielding the slowest rates. However, the high water solubility compounds appeared to become unavailable after several days, indicated by a decrease in the rate of uptake with time, while the sediment xenobiotic concentration and composition did not change. In the case of phenanthrene, the bioaccumulated level actually decreased after several days. Studies with flowing water systems are currently being used to further define the processes that are affecting bioaccumulation from sediment sources. This area will require considerable work to develop an understanding of the role of sediment in the accumulation of xenobiotics by benthic organisms.

TABLE 1. Sediment avoidance by *Pontoporeia hoyi*.

Sediment	Number of *Pontoporeia hoyi* per 25.5 square centimeters Mean	($\pm$1 SD)
Benton Harbor (dried)	2.22	(2.54)
Grand Haven (dried)	5.65	(4.33)
Grand Haven (fresh)	10.89	(6.05)
Sand	15.89	(12.59)

The freshwater shrimp *Mysis relicta* constitutes a large percentage of the food source for young Great Lakes fish and also consumes many types of food (i.e., phytoplankton, zooplankton, and detritus). For these reasons, a study of contaminant transport in *M. relicta* will help in understanding the dynamics of contaminant transport via food consumption in the Great Lakes. *M. relicta* has been exposed to BaP in (1) water and (2) a natural food source plus water. The consumption of BaP-enriched food reduces the body burden of BaP in this animal (Fig. 5). This finding is contrary to the commonly held notion that the contaminant body burden of an aquatic animal is enhanced by the consumption of contaminated food. These results may be due to increased elimination of contaminants in the presence of food.

If this phenomenon holds in the field, the PAH body burden of *Mysis relicta* is likely to be high when food supplies are low (i.e., winter months) and low when food supplies are abundant (i.e., summer months). Field samples of *M. relicta* are presently being analyzed for BaP content to test this hypothesis.

Because the toxicokinetics of organic xenobiotics can be modified by induction resulting from exposure to certain specific compounds, the toxicokinetics of *Pontoporeia hoyi* collected at the Benton Harbor high sedimentation area are being compared with *P. hoyi* collected off Grand Haven. The Benton Harbor area has a higher concentration of organic xenobiotics by approximately an order of magnitude compared to Grand Haven. Preliminary results indicate a statistically significant reduction in the uptake rate constant for the *P. hoyi* collected at the Benton Harbor high sedimentation site compared to those collected the same day from the Grand Haven area. This reduction could be accounted for by the difference in the mass of the organisms from the Benton Harbor area, which were, on the average, 33% larger per animal. No differences in the depuration rates or biotransformation rates (no measurable biotransformation in either population) of the two populations were found. The above data suggest that no induction is occurring.

In conjunction with scientists at Ohio State University, studies were begun using an *in vitro* aryl hydrocarbon hydroxylase (AHH) assay to compare bullheads from the Black River, which have exhibited high levels of tumors, to fish from Old Woman Creek National Estuary; the latter acting as a control site. Initial results indicate approximately a two-fold induction of AHH activity in the contaminant-exposed Black River fish compared to the control fish. These fish also seem to have a rapid conjugation system for phenolic metabolites. The goal of this research is to develop a field technique to measure exposure to organic xenobiotics.

Bioturbation and Burial

In an attempt to determine the rates of introduction of trace contaminants into the sediments and the postdepositional behavior of these contaminants, GLERL scientists collected and analyzed sets of sediment cores from the areas of maximum accumulation in each of the five Great Lakes. This was accomplished with ship and technical support provided by the Canada Centre for Inland Waters (CCIW). Twenty cores were carefully subdivided and distributed among 23 researchers for analyses, which are complete. Data interpretation will be completed during FY 1986.

Results to date have supported previous reports of a near-surface layer of mixed sediments. A major advance has been the development of a nonsteady-state sediment mixing model that provides information on the rate of mixing in this mixed layer. This is necessary to simulate the movement of sediment-associated contaminants into and out of the region subject to resuspension and interaction with benthic organisms. The model takes account of (1) sediment accumulation, (2) compaction, (3) depth-dependent biodiffusion of particle and solution phases, (4) molecular diffusion, (5) advective transport and surface redeposition of tracers and contaminants due to depth-dependent feeding of conveyor-belt feeders, (6) radioactive decay, and (7) time-dependent fluxes to the sediment surface. What makes the model unique and yet applicable to both freshwater and marine systems is the treatment of sediment redistribution by the conveyor-belt deposit feeders. These organisms, prevalent in both marine and fresh water, ingest sediments over a range of depths in the upper sediments, while depositing gut contents from tails protruding above the sediment surface. This action transfers buried materials to the sediment surface and accelerates the rate of sediment and pore water burial within the feeding zone. Since this process is particle selective, it represents a mechanism for enhanced transfer of contaminants to the vicinity of the sediment-water interface. In the model, particle selectivity is handled by applying mass conservation separately to tracers and bulk sediments.

The vertical distributions of lead in sediment cores illustrate the relationship between anthropogenic sources and deposition in the lake. Because geochemical evidence indicates that lead will be relatively immobile in these sediments, the shape of the observed profiles should be the result of lake processes and the history of lead emission within the Great Lakes region. In contrast to lead profiles in earlier (1971 – 73) cores from Lake Ontario in which the lead concentration peaked at the sediment-water interface, the lead concentrations in two cores collected during 1981 increased with depth to a subsurface maximum before decreasing to pre-cultural concentrations. In both cores, the lower lead concentrations in the upper few centimeters of sediment reflect the declining use of lead in the Great Lakes region.

A correspondence between lead emissions and lead profiles can be illustrated quantitatively by independent determination of the loading of lead to the lake from regional records of coal and gasoline consumption. These two sources constitute the major environmental burden of lead. As the residence time of lead in the waters of the lakes is expected to be short (roughly 1 year), profiles of lead should be congruent with the historical loading (source function). Since peak production, there has been a substantial reduction in the amount of atmospheric lead. This reduction should be apparent in areas of the Great Lakes where sediments accumulate rapidly and provide good time resolution. The results of using this source function in the steady-state mixing model with the sedimentation parameter fixed from lead-210 data are shown in Figure 6 as the dashed lines. The excellent quality of the fits supports the validity of the approach, suggesting a common time-dependent lead flux to the lake and a very limited mobility of lead in the sediments. The model (and data) indicate that the average lead flux in Lake Ontario increased 680% from the early 1800s to the time of maximum lead in the mid-1970s.

Upper Great Lakes Connecting Channels Study

As part of our cooperative research program with Region V, U.S. EPA, sediment samples were collected for radiometric and selected trace metal analyses (Fig. 7). These cores were hand-collected by divers in conjunction with CCIW. Analyses of the cores are currently

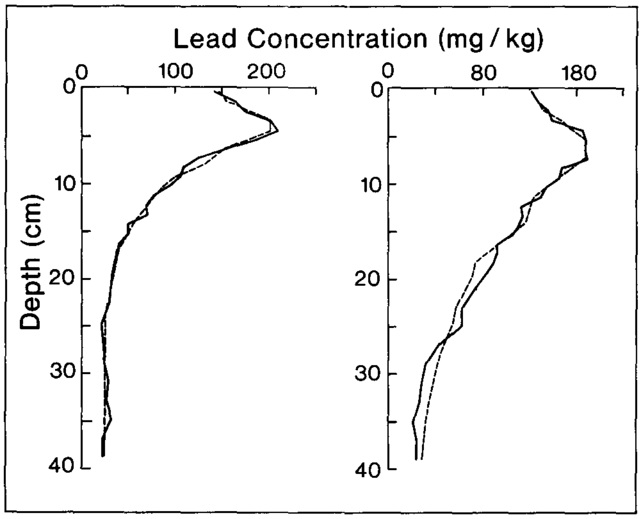


Figure 6. Vertical distribution of stable lead in the Lake Ontario cores. The solid lines connect data points, while the dashed lines are the distributions predicted on the basis of lead atmospheric emissions inventories and the steady-state mixing model. The sedimentation rate is fixed in each case by the lead-210 data. Recent decreases in the use of leaded gasoline are reflected both in the emissions inventory and in sediment lead profiles. The excellent fit of the model simulations encourages use of refined models to treat distributions of contaminants with less well-known loadings and more complex sedimentary behavior.

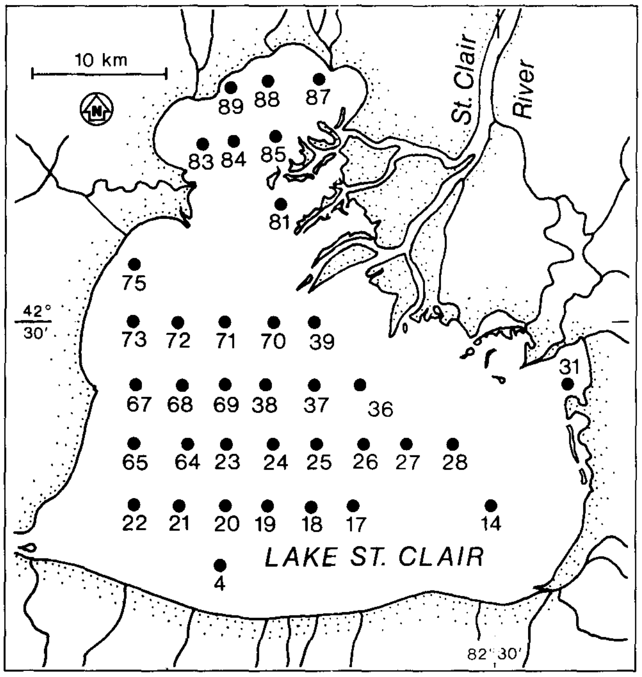


Figure 7. Sediment sampling locations for the Upper Great Lakes Connecting Channels Study in Lake St. Clair.

underway, with completion scheduled for 1987. The main objective of this portion of the international study is to determine the extent to which Lake St. Clair acts as a sediment trap for particle-associated contaminants entering from the St. Clair River system and other tributaries. The time constant for transport through this system into Lake Erie is a critical parameter in our Great Lakes modeling efforts.

A second, particle-related study involves the *in situ* measurement of sediment resuspension in this shallow (Z = 7 meters) lake. Remotely deployable instrumented packages were developed and tested during the past year. One monitors wave action, current velocity, temperature, and water transparency for periods of up to a month. By comparing these data with weather information we will be able to determine what meteorological events are likely to produce resuspension in the lake. The limited number of instrumented packages makes it impossible to monitor more than a few sites in the lake, so we are supplementing these measurements with measurements of resuspension rates using a bottom-resting flume through which water is drawn at controlled speeds. By measuring erosion rates of various substrates as a function of current velocity we will be able to extrapolate the results to other parts of the lake.

Ecosystem and Nutrient Dynamics

An understanding of and ability to predict the dynamics of Great Lakes ecosystems are needed to make wise decisions for management of the lakes in relation to both water quality and fishery resources. The "health" of the Great Lakes is evidenced by the abundance and composition of their biota. Benthic organisms can indicate long-term trends in water quality, whereas pelagic biota reflect present water quality. Because invertebrates from both zones are important prey for small fish, the amounts and composition of these small animals can affect total fish production in the Great Lakes. Planktonic phytoplankton are important because they affect water quality directly and also serve as the base of the aquatic food web. The ability to quantitatively predict the types and amounts of these organisms is needed to assess potential effects of human activities or natural changes in lakes or marine coastal ecosystems. Basic research is necessary to identify and understand critical first-order processes controlling: (1) the flow of nutrients and energy through the ecosystem and (2) the composition and successional patterns of biota in the lakes. Both of these phenomena are affected by complex interactions between physical (e.g., light, temperature, ice cover, water movements), chemical (e.g., nutrient supply and availability, toxic substances), and biological (e.g., food web dynamics, predation, and nutrient uptake and regeneration) factors.

Critical factors affecting the biota must be recognized and quantified as parts of mathematical models to accurately predict the effects of human activities on the Great Lakes system. Conceptual and mathematical models developed at GLERL and elsewhere have demonstrated that nutrient limitation is a major factor controlling the quantity and composition of plankton in photic zones of the Great Lakes. Mechanisms controlling nutrient cycling must therefore be understood before changes in the biota and water quality of the lakes can be predicted. The close interrelationships between nutrients, phytoplankton, and aquatic invertebrates require an interdisciplinary research program to quantify and integrate these critical processes into simulation and prediction models. The Ecosystem and Nutrient Dynamics Group is investigating factors that control nutrient and energy cycling, ecological succession, and long-term trends in the Great Lakes. The long-term goal is to integrate experimental results into ecosystem models applicable to the Great Lakes and other freshwater and coastal marine ecosystems.

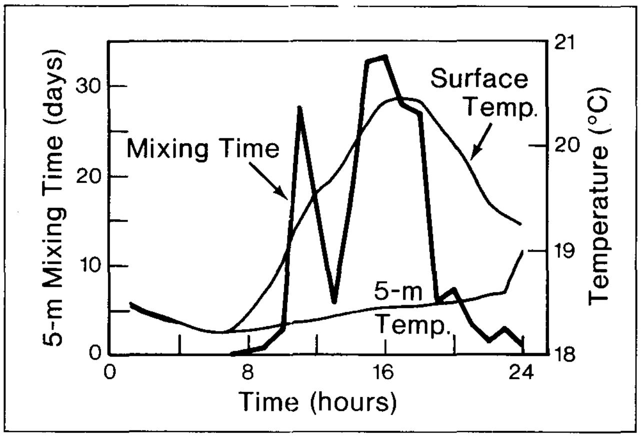


Figure 8. Simulated 5-m mixing time (days) and epilimnetic temperatures (°C) on 15 July 1972 generated using a fine-scale heat-diffusion model for Lake Washington. Mixing time is defined as the time to transport particles (e.g., phytoplankton) from the surface down to a depth z via turbulent diffusion, and is directly related to the depth z and stability of the water column and inversely related to surface wind speed. Given uniform winds, the 5-m mixing time ranges from near instantaneous during nocturnal convection events to tens of days during post-noontime heating.

Ecosystem Modeling

A major problem in developing and testing the effectiveness of ecosystem models is the limited amount of comprehensive long-term field data available for aquatic ecosystems. Physical and chemical data collected from Lake Washington over the last 20 years were used to develop and test a physical model for natural waters, including the Great Lakes. Last year, development of a Lake Washington heat-diffusion model showed that the theoretical mixing time required to transport particles (e.g., phytoplankton) from the surface down to 5 meters via turbulent diffusion ranges from near instantaneous during nocturnal convection events to tens of days during post noon-time heating (Fig. 8). This phenomenon, coupled with the daily cycle and vertical extinction of incoming solar radiation, and the time-scale of photoinhibition, could have a great impact on the fate and transport of seston and thus on epilimnetic primary production and other light-sensitive processes in lakes.

A model similar to the Lake Washington heat-diffusion model was developed for Lake Michigan. The study focused on a column of water extending from the surface to the lake bottom, representing the column of water tracked by drifter buoys during the Lake Michigan Ecosystem Experiments of 1983 and 1984. The model simulates the daily epilimnetic thermal structure with emphasis on diel variation in stability, mixed-layer depth, and mixing time (Fig. 9). The model was calibrated and tested with temperature data from bathythermograph profiles, thermistor strings, the NDBC007

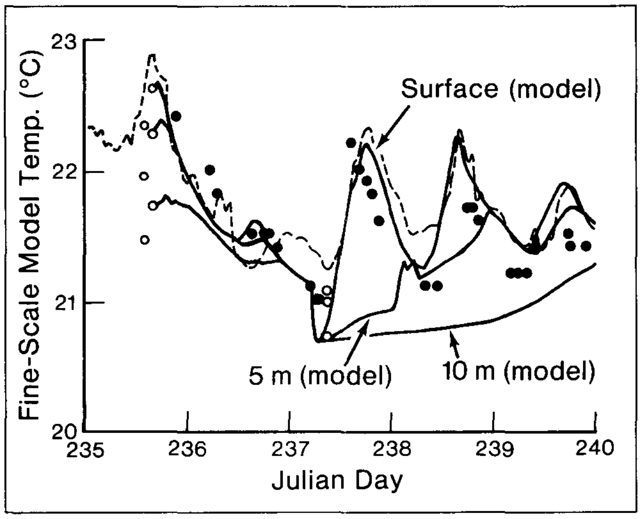


Figure 9. Epilimnetic temperatures (°C) for 22-27 August 1984 simulated by a fine-scale heat-diffusion model for Lake Michigan. Model temperatures at 0, 5, and 10 m (solid lines) are compared with drifter buoy surface temperatures (solid circles), data buoy surface temperatures (dashed line), and 0-, 5-, and 10-m BT temperatures (open circles). The daily epilimnetic heating cycle, illustrated by both the model and the data, causes the formation and erosion of a diel thermocline at a depth shallower than the seasonal thermocline.

meteorological buoy in Lake Michigan, and a satellite-tracked drifter buoy deployed by GLERL. The model accurately simulated the daily heating cycle and formation of a diel thermocline at a depth shallower than the seasonal thermocline. Such diel stratification increases the stability of the water column and restricts the vertical movement of phytoplankton populations, thus exposing portions of the population to higher irradiances during incubation periods.

Ecosystem Dynamics Field Studies

Previously, a 10-year data set for the region of Lake Michigan offshore from Grand Haven was reviewed and updated to examine the effects of meteorological conditions and ecological dynamics on water quality. This work involved collating phosphorus, temperature, transmissivity, light-extinction coefficient, Secchi depth, chlorophyll, zooplankton, and fish data from diverse and often marginally compatible sources. It revealed a slight improvement of water quality in the southern basin over the 10 years, and 2 years of particularly clear water and low chlorophyll that were attributed to severe ice-cover (1977) and ecological shifts in the zooplankton caused by the decline in alewife abundance (1983).

Field data from the same area of Lake Michigan were collected during the last 3 years, including information on phytoplankton production, zooplankton grazing, light-extinction, incident radiation, phytoplankton biomass, and phytoplankton carbon content. In contrast to similar measurements in oceanic environments, carbon-14 based estimates of primary productivity were in good agreement with other, independent estimates. This suggests that the difficulties with the carbon-14 technique experienced by the oceanic scientific community do not necessarily extend to the limnologic regime. Previous studies of Lake Michigan revealed significant reductions in the concentrations of total phosphorus and chlorophyll over the past 10 years, yet estimates of water column productivity during the summers of 1983 and 1984 were not significantly different from estimates made in 1970 and again in 1975. These findings indicate that summer productivity is, to some degree, insensitive to decreases in phosphorus loading.

Primary production below the thermocline (subthermocline production) becomes quantitatively important to the total water column production during periods of stable thermal stratification, when nutrients are depleted in the epilimnion. During such periods approximately 50% of water column production takes place below the epilimnion. Therefore the accurate estimation of subthermocline production is important for a complete understanding of the nutrient cycle and energy flow in the Great Lakes system. During FY 1985 the effects of internal waves on the accuracy of conventional subthermocline production measurements were evaluated by computer simulation. Simulation results were significantly different from conventional estimates when the actual trajectory of the phytoplankton population was taken into consideration. Therefore, if accurate estimates of subthermocline production are desired, movements of the phytoplankton population by internal waves must be analyzed and the effects incorporated in the estimates.

Carbon-14 data were integrated over several months to study the release of dissolved organic carbon (DOC) by algae. DOC was released at a rate ranging from 0.42 to 1.54 mg of carbon per cubic meter per day (Fig. 10). The release of DOC accounts for approximately 5% of the total primary production in Lake Michigan and may provide a small portion of substrate which supports secondary (i.e., bacterial) production.

Bacterial production may account for a significant portion of the total production in the Great Lakes (Fig. 11). Therefore, information on bacterial dynamics is needed to understand and quantify the transfer of energy and nutrients through the food webs of the Great Lakes ecosystem. Analysis of 1983-84 field data indicates that bacterial growth rates range from 0.05 to 0.24 per hour and appear to be balanced by losses due to predation, at least during April and November when comparative measurements were made. Field work over the last year emphasized detailed measurements of the temporal and spatial patterns of abundance and production, and quantification of grazing losses. Substrate enrichment ex-

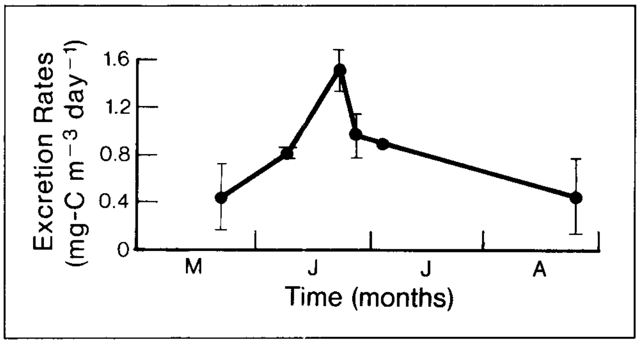


Figure 10. Release of dissolved organic carbon by algae in 1984 as measured by accumulation of ^{14}C in 0.22-μm filtrate after short-term incubations.

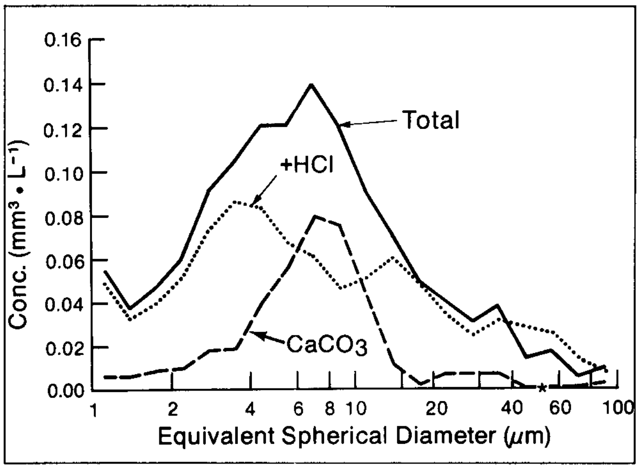


Figure 12. Particle spectra (particle concentration expressed as volume versus equivalent spherical diameter) of untreated (Total) and acid-treated (+HCL) epilimnetic water from offshore Lake Michigan. The calcite spectrum ($CaCO_3$) was determined by subtracting the acid-treated spectrum from the untreated spectrum. The acid-treated spectrum represents the food spectrum, that is, the organic seston available as food.

periments with amino acids were conducted to determine whether Lake Michigan bacteria were limited by organic substrate or controlled by grazers. The results suggest that grazers may provide more control of bacterial populations than do limiting concentrations of substrate.

Ecological Effects of Calcite "Whiting" Events

During late summer, calcite (calcium carbonate) crystals precipitate autogenically in Lake Michigan causing milky-colored water, or "whitings." Satellite imagery has shown that these whitings occur in surface waters over most of Lake Michigan as well as in Lakes Huron, Erie, and Ontario. The precipitation occurs in response to an increased activity of the carbonate ion, caused by uptake of carbon dioxide by phytoplankton, and lowered calcium carbonate solubility caused by an increase in water temperature. Calcite whitings are most intense in September, when epilimnetic temperatures exceed 20°C and pH values exceed 8.4. The abundance and size of calcite particles have not been well documented for lakes. Moreover, the ecological consequences are poorly defined, but potentially include: reduction of light transmission in the water column, sorption and subsequent sinking of nutrients and trace contaminants on the calcite particles, and reduction of zooplankton food ingestion (i.e., zooplankton ingest calcite particles as food, but they have no nutritional value and pass through the organism without being of value, thus reducing the actual volume of viable food ingested).

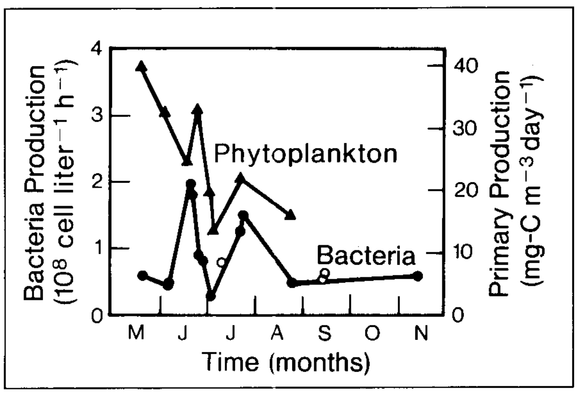


Figure 11. Bacterial cell production (solid circles) and phytoplankton net production (triangles) in the epilimnion of Lake Michigan during the 1984 Lake Michigan Ecosystem Experiment. Open circles represent bacterial production rates from preliminary experiments in 1983. Bacterial production is based on incorporation of ^{3}H-(methyl) thymidine, a precursor of DNA synthesis. Phytoplankton production is based on ^{14}C uptake.

The calcite contribution to the particle pool was determined using a novel method employing a Coulter counter. The particle-size spectrum was determined twice for each sample: once using untreated (raw) lake water, and again for the same lake water but first treated with hydrochloric acid (HCl) to dissolve the carbonate minerals. The carbonate-free spectrum was then subtracted from the total spectrum, and the resulting difference-spectrum represented the carbonate component of the total spectrum (Fig. 12). The method was carefully developed and evaluated, and was used to

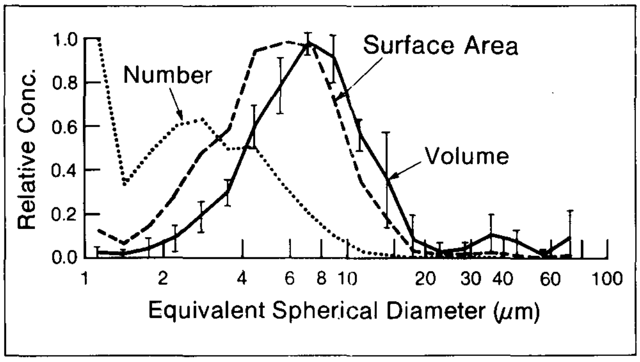


Figure 13. Mean relative concentrations of particle number, volume (± SD), and surface area of calcite in the different size categories during September 1978–83. Surface area represents the capacity of a size category to sorb nutrients and trace contaminants.

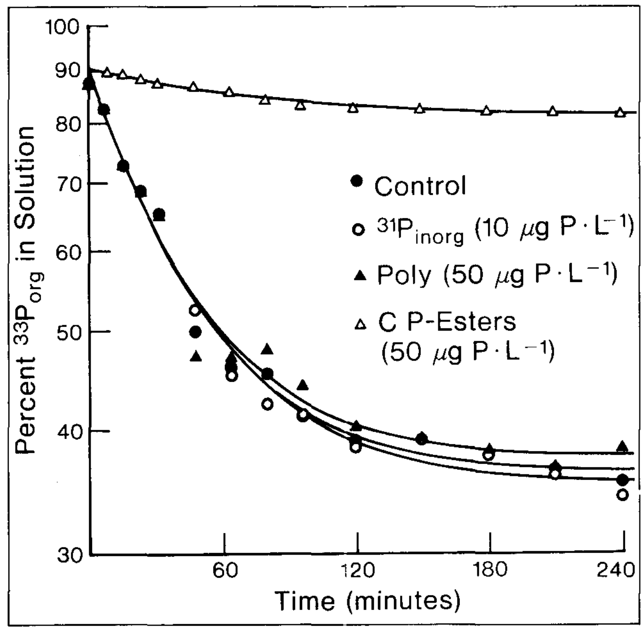


Figure 14. Results of a multiple substrate addition experiment showing that phosphorus-containing radiolabeled organic compounds ($^{33}P_{org}$) produced by algae are rapidly taken up by heterotrophic bacteria in Lake Michigan. Uptake of $^{33}P_{org}$ is unaffected by additions of inorganic phosphate ($^{31}P_{inorg}$) and condensed inorganic polyphosphate (Poly) but is severely reduced when phosphorus-containing carbohydrate esters (C-P-Esters) are added. This shows that bacteria utilize the organic rather than the inorganic dissolved phosphorus pool.

determine the calcite component during different seasons of the years 1978–83 and 1985.

Whitings were most intense during September of each year, when calcite ranged from 12–56% of the total particle volume, depending on year. This year-to-year variation is believed to reflect a variation in primary production, which drives calcite precipitation through carbon dioxide uptake. The minimum, 12% calcite by volume, occurred during September 1983 and may have resulted from abnormally low primary production in response to increased grazing pressure, the latter caused by changes in food web structure as a result of salmon stocking.

The shapes of the calcite particle size spectra from different years were similar, with the mode of the volume spectrum at 7 microns equivalent spherical diameter (Fig. 13). This conservatism will be useful for designing experiments to test the effects of calcite on zooplankton feeding and to evaluate other potential impacts. For example, the modal diameter calcite particle will sink with its sorbed nutrients and trace contaminants at a rate of approximately 3 meters per day. Light extinction from scattering off calcite particles is expected to be only modest because scattering is most intense at about 1 micron and decreases rapidly with increased size thereafter.

Nutrient and Energy Cycling

Information on the sources and fates of nutrients entering the photic zones from natural and anthropogenic sources is required for proper evaluation of the potential impact of changing these inputs to the lakes.

Modeling the phosphorus cycle requires a knowledge of the chemical composition of the dissolved phosphorus pool used by various organisms. The uptake of phosphorus by bacteria was investigated to determine if the pool for these organisms is primarily organic- or inorganic-bound phosphorus. A new approach was developed based on the use of phosphorus-33 labeled dissolved organic matter produced by algae. Bacterial uptake of the radiolabeled organic phosphorus was retarded by the addition of other organic-bound phosphorus compounds, but not by the addition of inorganic-bound phosphorus, thus indicating that bacteria use the organically-bound phosphorus preferentially (Fig. 14). These findings provide an improved basis for modeling aquatic phosphorus dynamics.

Simulation experiments on the effects of silicon limitation on phytoplankton species succession were performed to determine if limitation of this nutrient causes the shift from diatoms to blue-green and green algae in Lake Michigan. The results showed that silicon limitation affects the ability of diatoms to utilize phosphorus, and thus triggers the shift to blue-green algae during summer. These findings provide a "nutrient-based" explanation for seasonal successional patterns as well as quantitative insights into the construction of predictive multispecies phytoplankton models.

Techniques to measure denitrification (conversion of ammonium and nitrate to nitrogen gas) in lake sediments were perfected and a field program to quantify this process in Lake Michigan sediments was initiated. Denitrification rates are needed to quantify the relative importance of invertebrates versus microbes in mineralizing detrital material (i.e., converting organic nutrients to inorganic forms) in the sediments.

The lipid (fat) content of an organism is a measure of its stored energy; studies of the lipid content of lower-food chain organisms help us to follow and understand energy transformations and flow up the food chain. Measurements of the seasonal lipid content of four species of benthic invertebrates and *Mysis relicta* in southeastern Lake Michigan were completed (Fig. 15). These data were used to evaluate the role of these animals in transferring energy and organic contaminants from settling detritus to fish, and to increase our understanding of the ecological significance of these animals. *Pontoporeia hoyi*, *M. relicta*, and Chironomids, that feed on suspended material or surface detritus and microbes, tended to have higher and more variable lipid contents than the oligochaetes, tubificids, and *Stylodrilus heringianus* that feed on subsurface material. The invertebrates with relatively high lipid (energy) content are desirable prey species for small fish.

Areal caloric contents of major benthic species in southern Lake Michigan were calculated by combining mean areal biomass data, obtained from the 1980 "long-term trend survey," with mean lipid and non-lipid ash-free dry weight data for the different species. These calculations indicated that *Pontoporeia hoyi* constitutes about 70% of the total caloric content of benthic invertebrates in southern Lake Michigan. A comparison of energy requirements, needed to support this population of *P. hoyi*, with inputs measured by sediment traps the same year indicates that *P. hoyi* could be metabolizing a substantial portion (up to 30%) of incoming available detritus.

Studies to assess the importance of internal phosphorus regeneration in Lake St. Clair were begun as part of the Upper Great Lakes Connecting Channels Study. Major mechanisms being evaluated include phosphorus release from sediments and phosphorus excretion by mussels. Microcosm experiments are being conducted to assess the importance of the release of phosphorus from sediments. Mussels represent a significant part of the biomass in Lake St. Clair, and therefore, excretion by these animals could be an important mechanism for nutrient regeneration in this shallow lake. Seasonal measurement of excretion rates, combined with biomass estimates of these organisms, will allow us to estimate the quantitative importance of this process relative to other input sources.

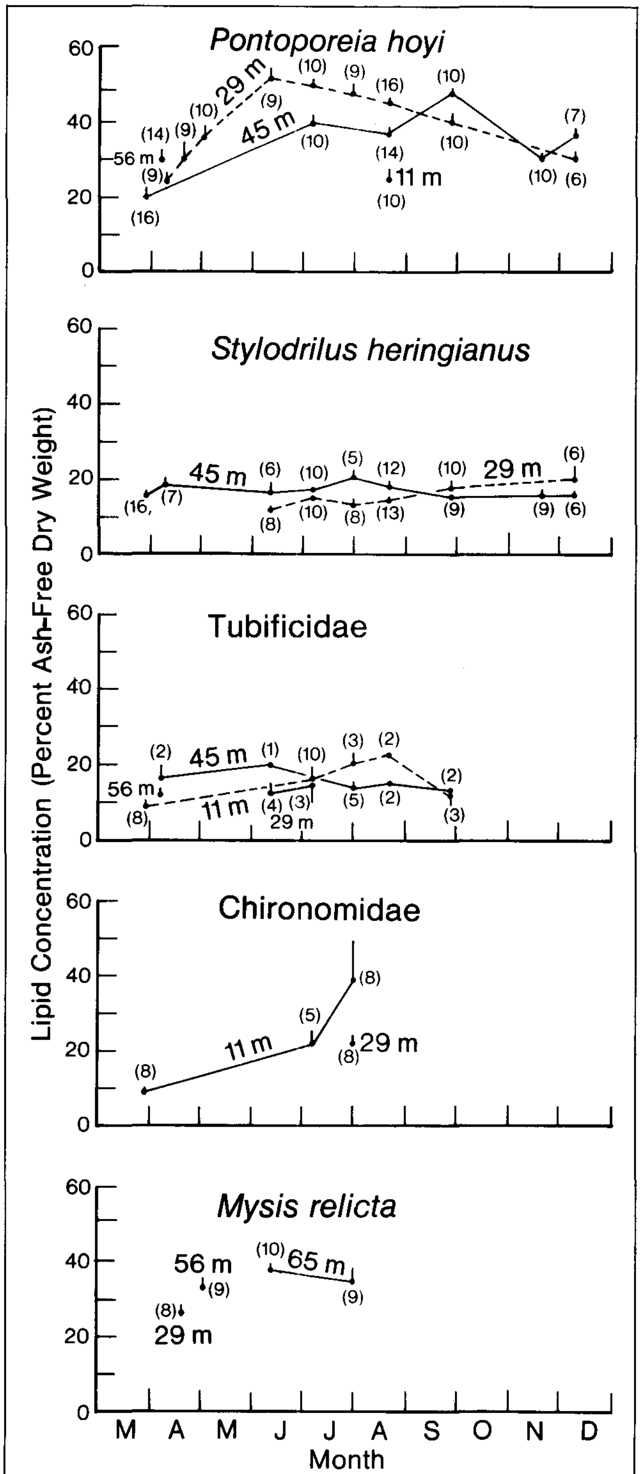


Figure 15. Total lipid content, expressed as a percentage of ash-free dry weight, in major species of Lake Michigan macroinvertebrates sampled in southeastern Lake Michigan in 1984. Range bars = standard error. Numbers in parentheses represent the number of replicate animals analyzed.

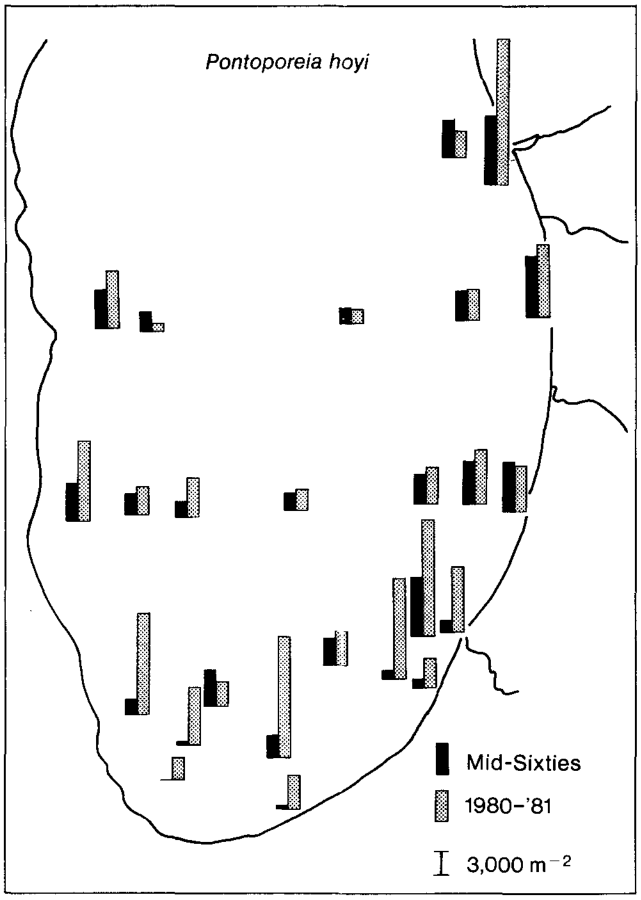


Figure 16. Abundance of *Pontoporeia hoyi* in southern Lake Michigan, based on surveys made in 1964–67 and in 1980–81. At depths less than 50 m this species increased two- to five-fold between surveys. No increase was found at greater depths.

Benthic Ecology

Data collected for a long-term trend study on the benthos in southern Lake Michigan were checked, verified, and published in a NOAA data report. Statistical comparisons with earlier data indicated a general increase in several groups of benthic invertebrates between the mid 1960s and 1980-81 (Fig. 16). This seems to indicate a general increase in productivity during this period but may also reflect decreased predation on the benthos. Data from the same study indicated that *Pontoporeia hoyi* is the dominant benthic invertebrate in southern Lake Michigan, constituting about 65% of the benthic macroinvertebrate biomass. *P. hoyi* is also a major prey organism for fish in the upper Great Lakes.

Research on the feeding habits and biochemistry/physiology of *Pontoporeia hoyi* is needed to better understand the ecology of the organism and to evaluate its role in transforming nutrients and energy from detritus to fish biomass. Studies of gut contents were conducted to gain insight into seasonal feeding habits of *P. hoyi*. The data indicate that individual *P. hoyi* often have only partially-filled guts, implying that feeding by this organism may be periodic rather than continuous (Fig. 17). Lipid extracts of *P. hoyi* and *Stylodrilus heringianus*, obtained by microextraction techniques developed at GLERL, were analyzed for lipid classes by scientists at Dalhousie University (Halifax, NS) using thin layer chromatography with flame ionization detection. These analyses indicated that most of the lipids in *P. hoyi*, but not in *S. heringianus*, were present as triglycerides, the energy storing compounds. Laboratory experiments at GLERL also indicated that *P. hoyi* could live at least 80 days without food. The ability of *P. hoyi* to store energy as lipids and to withstand long periods without food may help explain its ability to thrive in low-nutrient systems such as the upper Great Lakes. Further studies are planned to elucidate physiological characteristics of this important organism.

A GLERL scientist participated in a project to explore the bottom of Lake Superior with a submersible (Fig. 18). Research focused on the geochemistry, biology, and physical processes in deep water areas. The GLERL scientist evaluated the efficiency of benthic sampling techniques and examined microdistributions of benthic invertebrates. An interesting finding was the occurrence of large numbers of *Hydra*, a freshwater relative of sea coral and jellyfish. *Hydra* were found attached to rocks at depths as great as 400 meters, the deepest part of Lake Superior.

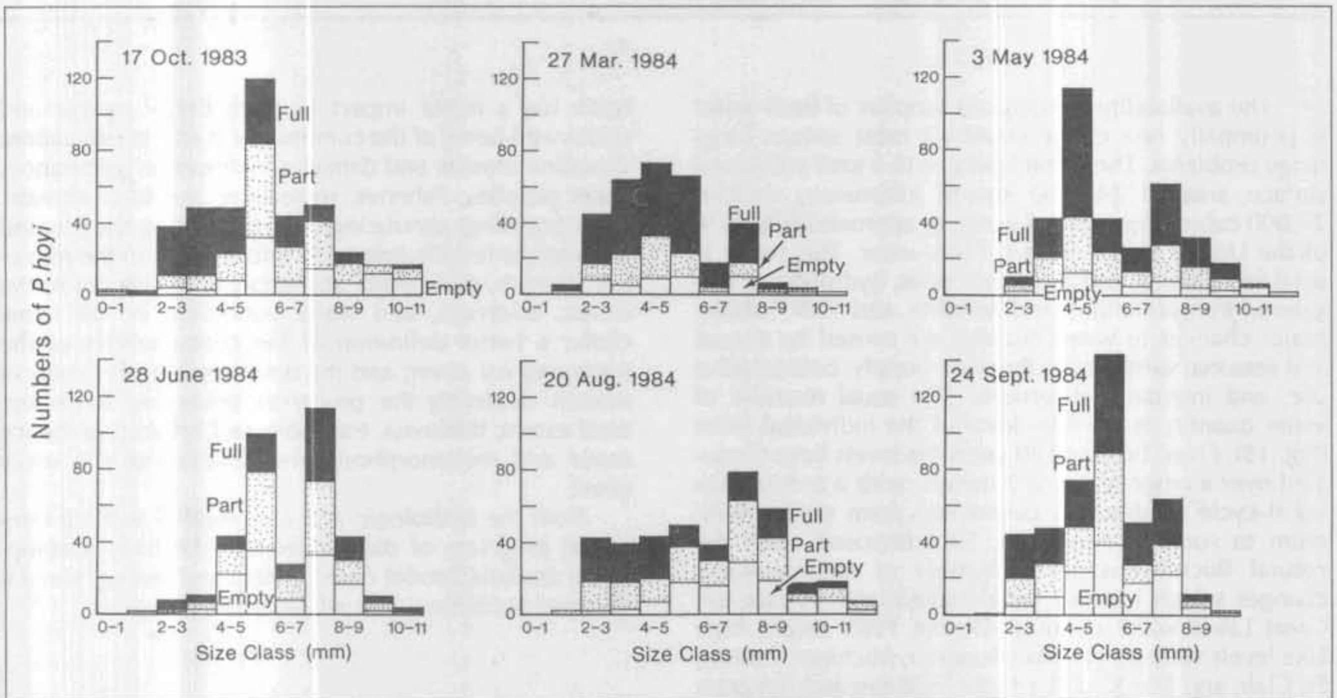


Figure 17. Results of a gut-fullness study of the amphipod *Pontoporeia hoyi* in Lake Michigan. Data indicate that the animal feeds intermittently rather then continuously as do most deposit feeding amphipods. This intermittent feeding mode may be important to the cycling of toxic organic contaminants between sediments and overlying water.

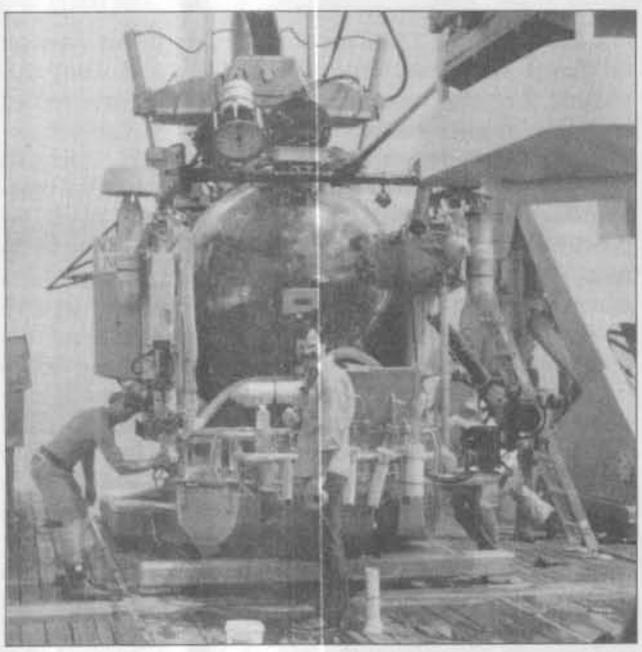


Figure 18. The *Johnson Sea-Link* was used during 1985 for a NOAA-sponsored exploration of Lake Superior using a research submersible. This marked the first time man has explored the greatest depths of Lake Superior first hand.

Lake Hydrology

The availability of adequate supplies of fresh water is potentially one of the country's most serious long-range problems. The Great Lakes, with a total combined surface area of 247,000 square kilometers, contain 23,000 cubic kilometers of water, or approximately 95% of the United States' fresh surface water. This water is used for drinking, industrial processes, hydropower, irrigation, transportation, and wildlife and fish habitat. Major changes in water quantity are caused by annual and seasonal variations in the water supply, consumptive use, and interbasin diversions. The usual measure of water quantity is the lake level of the individual lakes (Fig. 19). Over the past 120 years the levels have fluctuated over a range of about 2 meters, with a normal seasonal cycle of about 35 centimeters from winter minimum to summer maximum. Superimposed upon the natural fluctuations are a number of anthropogenic changes which have or could have major impacts on Great Lakes water quantity. During 1985 record high lake levels were set on Lakes Superior, Michigan, Huron, St. Clair, and Erie. GLERL's hydrologic research program is directed toward improving our knowledge of the hydrologic and hydraulic processes, improving methods of forecasting and simulating water supplies and lake levels, and improving large river dynamic flow models. The research assists in water resource planning and management and in the solution of problems related to water supply, water quality, shore erosion, flooding, hydropower, navigation, and recreation.

The seasonal ice and snow cover in the Great Lakes basin has a major impact on both the economic and social well-being of the community. It affects navigation, shoreline erosion and damage, hydropower generation, water supplies, fisheries, recreation, and local climate. Understanding, simulating, and forecasting the ice and snow cover require improved information on the formation, growth, movement, and decay of the ice cover; the extent, thickness, and water equivalent of the snow cover; a better definition of the characteristics of the snow and ice cover; and the development of numerical models depicting the processes governing freeze-up, areal extent, thickness, transport, and breakup of the ice cover and metamorphosis and ablation of the snow cover.

Both the hydrologic and ice research include integrated programs of data collection, database development, analysis, model development and testing, simulation and prediction, and advisory services.

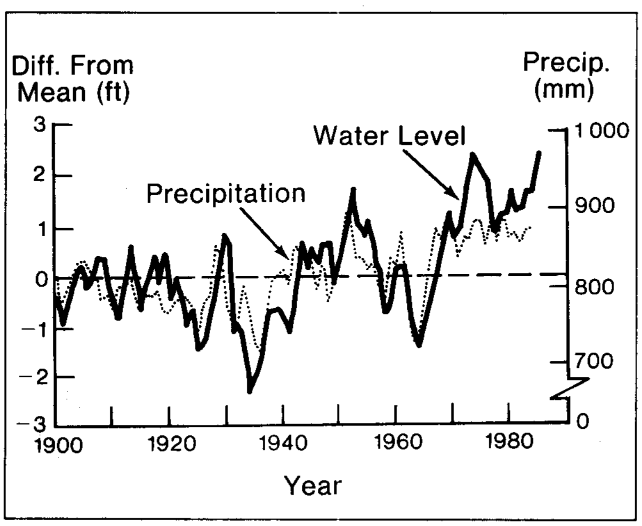


Figure 19. A plot of annual water level and precipitation on Lake Erie from 1900–1985.

Great Lakes Set Record High Lake Levels

During spring 1985, record high lake levels were set on Lakes Michigan, Huron, St. Clair, and Erie, surpassing the prior records set during 1973. New record high lake levels were again set in the fall on Lakes Superior, Michigan, Huron, and St. Clair. GLERL scientists have been deeply involved in determining the hydrometeorological factors that contribute to record levels, by providing historical perspective, and by furnishing technical information for water management. Great Lakes water levels have been in a high regime for the past 15 years, resulting in extensive damage around the perimeter of the lakes due to shore erosion and localized flooding (Fig. 20). The high levels are the result of a high precipitation regime which began about 1940, coupled with a low air temperature regime which began about 1960 (Figs. 19 and 21). Lower air temperatures result in less evapotranspiration and lower evaporation, yielding higher runoff rates than would occur during warmer conditions. During the last 15 years precipitation has averaged considerably above the long-term average with relatively little variability, leading to the current record high levels as well as the prior records set in 1973. The persistence of the current high precipitation and low air temperature regimes, coupled with the slow response of the Great Lakes system, make it likely that the current high lake levels will continue for the next several years.

Figure 20. Flooding due to a storm surge in western Lake Erie during high lake levels in 1979 (top). Erosion and damage on the eastern shore of Lake Michigan caused by the combination of record high water levels and winter storms during late 1985 (bottom).

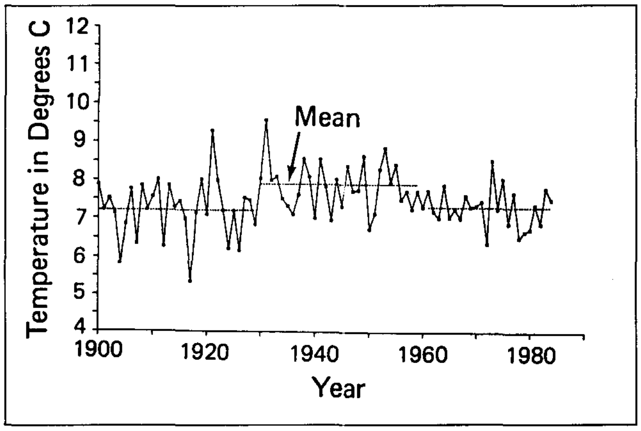


Figure 21. A plot of the mean annual air temperature over the Great Lakes since 1900.

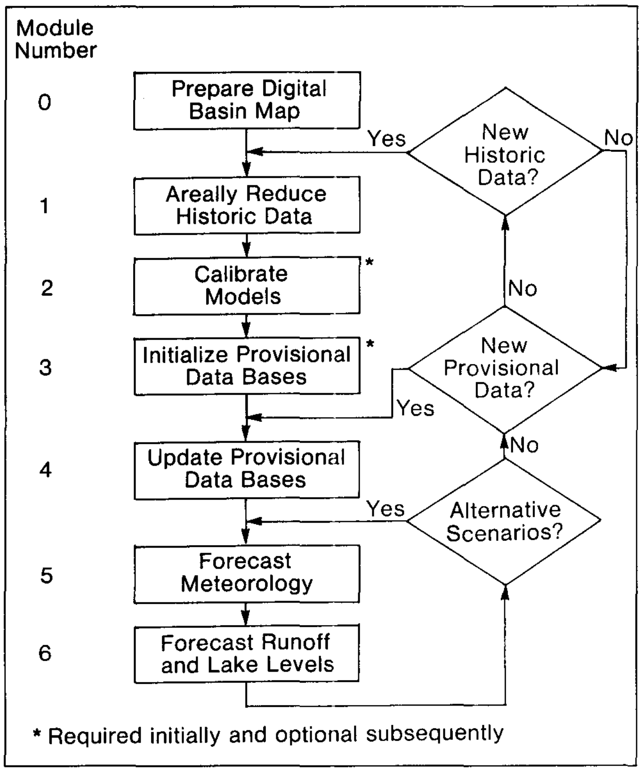


Figure 22. Conceptual logic flow chart for making water supply outlooks for a large lake. Typically, modules 0, 1, 2, and 3 are performed only infrequently on a large computer in order to prepare the models, data, and data bases for use with modules 4, 5, and 6 on other, perhaps smaller, computers in the forecast office. Modules 1 – 3 may be repeated as new historic data becomes available every 2 to 3 years; module 4 is repeated as new provisional data becomes available from the field in near-real-time every day or week; and modules 5 and 6 are repeated as new water supply outlooks are desired.

Water Supply and Levels: Forecast Development for Management

GLERL finished a semi-automatic software package which uses meteorologic data in near-real-time to predict water supplies to Lake Superior. Great Lakes water levels have been above normal for several recent years and on Lake Superior have exceeded the internationally agreed to maximum of 602 feet. The United States and Canada regulate Lake Superior outflows to directly control flooding, hydropower, and navigation on Lakes Superior, Michigan, and Huron, as well as to indirectly control the same on Lakes St. Clair and Erie. The regulation plan presently uses trend extrapolation for supply forecasts; this does not consider weather prediction nor does it account for the effects of moisture in storage.

The water supply outlook package integrates near real-time data acquisition and reduction, and conceptual modeling (Fig. 22). It incorporates National Weather Service (NWS) monthly and seasonal weather forecast outlooks and current basin moisture conditions; the latter includes snowpack water equivalents from the joint United States-Canadian aerial gamma radiation surveys. The NWS forecasts are issued each month to national and international water management agencies; experimental GLERL forecasts issued in June and July were the only ones to successfully indicate the possibility that Lake Superior could exceed the 602-foot level during autumn. GLERL developed a new algorithm and data structures for rapid reduction of meteorologic data either from archival sources (module 1) or as they become available in near real-time (module 4). For an example station network on Lake Superior, the algorithm is 93% faster than prior methods. Modules 2, 4, and 6 use GLERL's conceptual rainfall-runoff model, which produces a 0.96 correlation with actual monthly runoff for the Lake Superior basin. GLERL designed procedures to incorporate the weather forecasting expertise of the NWS (module 5) in determining forecast sequences, while preserving spatial and temporal interdependencies of meteorologic variables. The package produces 6-month forecasts of expected basin runoff, net water supplies, lake levels, and basin moisture storages, with historic quantiles for perspective.

At the request of the U.S. Army Corps of Engineers (Detroit District), GLERL installed the algorithm and data structures for rapid reduction of meteorologic data (modules 0 – 2) on their mainframe computer. Modules 3 – 6 (for making Lake Superior water supply outlooks) and other routines for reducing snow data from the joint United States-Canadian aerial gamma surveys were installed on their Harris minicomputer.

The NWS Northeast River Forecast Center (NRFC), which has forecast responsibility for Lake Champlain (New York), requested that a similar water supply and forecast model be developed for use on Lake Champlain. GLERL designed and developed a package to meet their needs and installed it on the NWS NRFC Data General Nova Eclipse microcomputer during FY 1985.

Seasonal Influences on River Flows

The field measurement program using current meters in the St. Clair River was expanded to the Detroit River (August 1984), providing the first year of simultaneous measurements on both rivers with electromagnetic meters (two on each river). The St. Clair River installation was augmented (November 1984) with the addition of a Doppler acoustic current profiler, which provided measurements of river velocities over the entire water column at 1-meter intervals. Because of a relatively mild 1984–85 winter season, there were no spectacular ice jams on the rivers and the first simultaneous winter flow measurements did not contribute significantly to the solution of winter flow problems related to the effects of ice cover and ice jams. Velocity measurements were continued in both rivers throughout the summer season in order to study the effects of weeds. These studies showed that the electromagnetic current meters are poorly suited for prolonged measurements in rivers which have high concentrations of floating debris, including weeds. These meters are oriented vertically and present a tall profile to flowing debris which accumulates around the sensor and reduces its sensitivity to water movement. We observed velocity reductions of up to 70% because of weed accumulation on these meters. In contrast, the acoustic profiler, which is oriented horizontally, presents a relatively small profile to debris and was generally not prone to debris accumulation. The acoustic profiler provided high quality velocity data over the water column (from approximately 2 meters above the bottom to 1 meter below the surface). A smooth exponential (logarithmic) distribution of vertical velocities was observed, verifying theoretical derivations.

Spectral Reflectances of Ice and Snow

Winter field work to characterize the spectral reflectance of snow and freshwater ice types was continued during FY 1985. Additional airborne reflectance measurements (400–1,100 nanometers) were made using a programmable band radiometer. With helicopter support provided by the U.S. Coast Guard, the instrument was used to make measurements of the spectral reflectance of open water, deteriorated snow, and three ice types prevalent on Saginaw Bay, Lake Huron, during clear sky conditions in the latter part of March 1985. Measurements were made from an altitude of 300 meters, at which the detected area was approximately 80 meters in diameter and approximates the area of a Landsat multispectral scanner pixel (56 meters by 79 meters). Owing to the spatial integration of reflectances obtained over heterogeneous ice types, this airborne measurement closely approximates the surface reflectance sensed from satellite altitudes. However, such measurements are subject to possible errors due to atmospheric attenuation and path radiance factors. Correction factors for atmospheric attenuation and path radiance were derived using calibration panel measurements and measurements of snow and open water made both on the ground and from an altitude of 300 meters, and applied to the data. Application of these corrections resulted in a slight increase in the average reflectance from the types of environmental surfaces measured (Fig. 23).

Satellite imagery can be used to monitor over-lake ice albedos and to identify and map Great Lakes ice types (Fig. 24). Moreover, once geometrically corrected, satellite imagery can be machine interpreted using airborne reflectance data as ground truth. Measurement sites can be located in the imagery and the digital numbers of the respective types can be abstracted and used to identify all similar types in the scene. This in turn can be used to correct satellite-derived albedos for atmospheric attenuation and path radiance, to help determine data requirements, and to direct future data collection. Future analyses will include deriving and categorizing average overlake albedos, calculating percent of lake covered by each category, analyzing the temporal and spatial changes of ice albedos, and machine-assisted identification and mapping of Great Lakes ice types.

Cooling Season Temperature Climatology of Lake Superior

A temperature climatology was developed for the surface and ten 10-meter layers along the normal ship route between the eastern and western ends of Lake Superior and for discrete areas along the ship route. The base period for the climatology includes the 1973–76 winter and 1976–79 fall seasons. Daily average temperatures and extreme temperatures for the base period were calculated, and a six-wave Fourier equation was fitted to the average temperature time series to define the temperature climatology. Products of this analysis include tabular and graphical summaries of the climatology, tabulations of the Fourier equation coefficients, and an online copy of the climatology on GLERL'S computer. The temperature data base used for analysis of the climatology is being used to evaluate the effects of the thermal expansion of Lake Superior's waters on the change-in-storage component of the water balance of that lake. These data will also have future applications to development of an operational technique to forecast water tem-

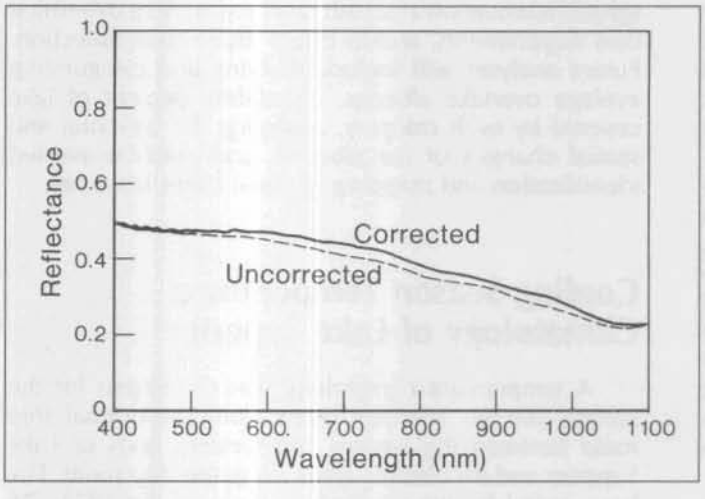


Figure 23. Old and deteriorated snow on Saginaw Bay (20 March 1985) as viewed from an altitude of 300 m (above). The averaged spectral reflectances (400 – 1,100 nm) from this image, both before and after making a correction for atmospheric attenuation and path radiance, is plotted in the graph (left). The correction resulted in a slight increase in the average reflectance.

perature decline and time of initial ice formation using the thermal structure forecast models being developed.

Operational St. Marys River Ice Forecast

A series of meetings between GLERL and the NWS Forecast Office in Ann Arbor were held during FY 1985 to identify how 10 – 20 years of ice and hydrometeorology data archived by GLERL can be used to update current NWS ice forecasting procedures and to develop new ice forecasting tools. One result of these meetings was the development of an interactive computer program to forecast the date of ice formation, ice thickness, and date of ice breakup at specific locations on the St. Marys River. This software is based on a technique developed earlier which uses site-specific heat transfer coefficients and observed water temperatures at Sault Ste. Marie, Michigan, for ice formation, a Stefan analysis of observed ice thickness and accumulated freezing degree-days (FDDS) for ice thickness, and a correlation of the observed breakup date with dates of maximum ice thickness and date of maximum FDDS for ice breakup. The NWS has access to GLERL's computer and will use

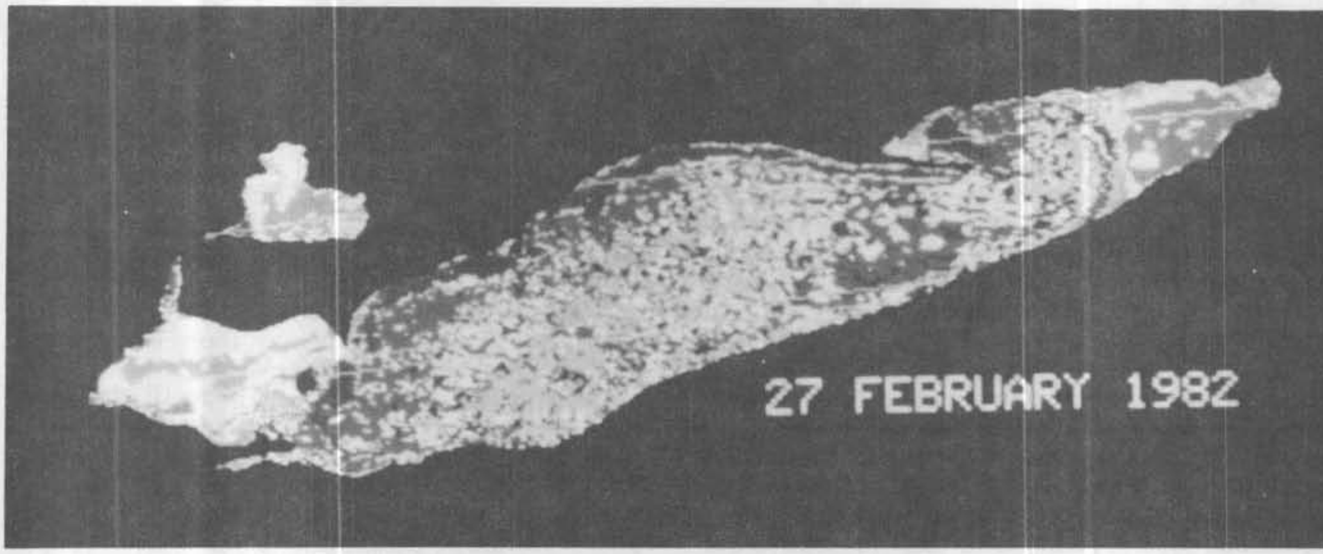


Figure 24. Unsupervised cluster analysis (machine interpretation) of ice albedos on Lake Erie, using NOAA-7 AVHRR digital imagery. Dark tones indicate low albedo, light tones indicate high albedo.

the St. Marys River ice forecasting software on an experimental basis during the 1985–86 winter season. In the future, other products will likely include improved aids for forecasts of initial ice formation and ice extent on the Great Lakes and products similar to the St. Marys River ice forecast software for specific bays and harbors and for other connecting channels of the Great Lakes.

Physical Limnology and Meteorology

The Physical Limnology and Meteorology Group studies the physical variables that describe a lake environment and the way they change with external forces, with the ultimate goal of improved prediction of water movements, physical hazards, and contaminant transport. The relevant variables are currents, temperatures, waves, and water level fluctuations. The primary driving forces are the wind acting on a lake surface, the heat exchanged between a lake and the atmosphere, and riverflows. Currents and temperatures in a lake influence biological and chemical processes and determine the distribution of pollutants. Waves and water level oscillations are hazards that may result in loss of lives and in damage to shoreline property, shipping, and recreational activities. GLERL makes measurements and develops models that improve prediction of these variables for the Great Lakes (Fig. 25). Such measurements and models will allow estimates to be made of the chemical and biological properties of the lakes that are important in waste disposal, power generation, fisheries management, and water supply planning. In addition, they will result in improved forecast models for prediction of hazards from waves and water level fluctuations.

The time scales of the variables that need to be measured and predicted range from years to seconds. The space scales range from the size of the lake down to a few meters. In view of these tremendous ranges over time and space, the various phenomena must be separated according to their scales if we are to understand and model them better. Hence, research in the Physical Limnology and Meteorology Group is in the areas of water movements and temperature, which encompass studies of lakewide and nearshore circulation, seasonal changes in circulation, thermal structure, and upwelling; and surface waves, water level fluctuations, and marine winds, which deal with wind-generated waves, storm surges, and seiches. Both areas of research involve prediction on a real-time basis as well as climatological studies.

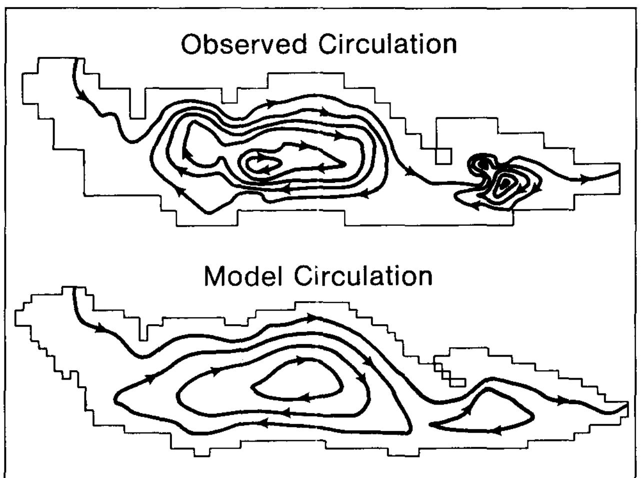


Figure 25. Comparison of observed and modeled circulation patterns in Lake Erie during a 5-day period in September 1979. Both patterns show clockwise circulation throughout the lake.

The approach used in studying the above problems is a combination of experimental (laboratory and field), theoretical, and modeling efforts. Experimental data provide information on what happens in the lake. Theoretical studies predict new phenomena and help plan new experiments. Modeling studies incorporate the important physical processes into governing mathematical equations and extrapolate the equations over time to predict the future state of the lake. Experimental data, in turn, can validate the accuracy of these predictions.

Water Movements and Temperature

Preparation continued for a special volume of the *Journal of Great Lakes Research* that will update the trophic status of Lake Erie. This volume, which is being produced jointly by GLERL and the National Water Research Institute (NWRI) of Canada, will summarize the status of the lake's ecosystem 10 years after completion of Project Hypo—the last major measurement program. It will document the interrelationships of lake physics with chemistry and biology.

Research on the basic physical variables in Lake Erie, including water temperature distribution, current velocity, and lake surface wind stress, was performed jointly by United States and Canadian scientists. Some of the contributions by GLERL scientists include development of a method for hindcasting the surface wind stress distribution from recordings of lake level variations and a description of the dominant circulation patterns in the central basin. Objectively analyzed currents have been compared with those simulated with circulation models, and methods to compare forecast and observed current trajectories were also developed. The annual temperature cycle in the central basin was documented in great detail and the results have been useful in describing temperature variations in other years when data collections were meager. Stratification and its intensity and duration control whether or not the lake experiences oxygen deficiency in the bottom water each year; the concentration of dissolved oxygen is critical in determining the health of the bottom fauna.

In another study, time-series analyses of current velocities recorded in Lake Michigan from mid 1982 to mid 1983 (Fig. 26) have revealed that a permanent 4-day-period rotational wave found earlier in the southern basin of the lake is trapped within that basin. Outside of

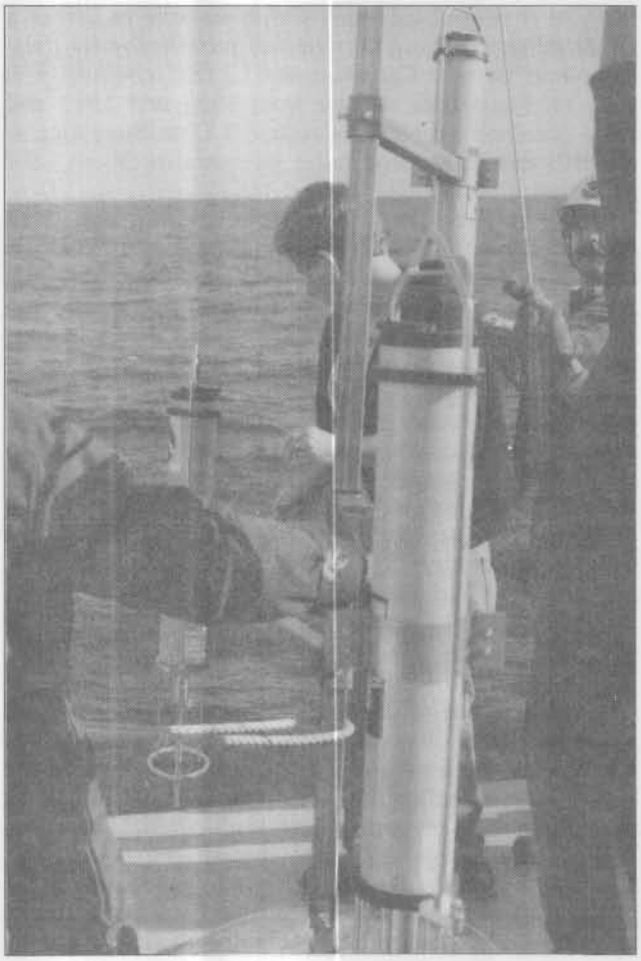


Figure 26. GLERL field party deploying an acoustic current meter in Lake Michigan.

the basin the wave-induced current oscillations of that period are either very weak or absent. Trapping of the rotational wave mode energy within the basin suggests that other lake or ocean basins may possess similar trapped oscillations of unique characteristics, and may simplify dynamical simulation of local area processes.

Studies of the bottom boundary layer have established the characteristics of a bottom Ekman layer in southern Lake Michigan. A vertical profile of current meters deployed near the bottom in 100 meters of water revealed the layer, which was about 20 meters thick. The velocity vector rotated in a counterclockwise fashion (when viewed from above) as the bottom was approached, with most of the Ekman veering occurring within the lower 10 meters. Current speed profiles were logarithmic. Simulations of sediment transport within Lake Michigan have shown sensitivity to the bottom Ekman layer structure. These observations will allow fine tuning of the estimates for physical parameters used in model development.

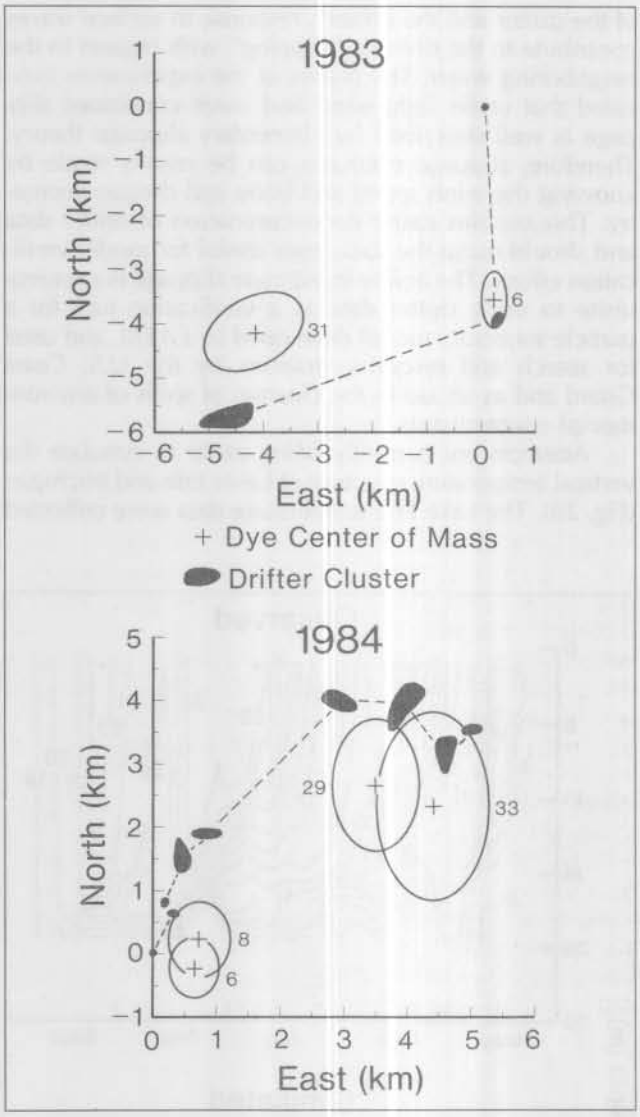


Figure 27. Idealized dye field versus drifter cluster positions during the 1983 and 1984 experiments in Lake Michigan. The length of the major and minor axes of the dye patch ellipses are equal to twice the standard deviation of the dye distribution in those directions divided by the total mass of the dye measured. Cluster positions versus time are indicated by the shaded areas.

Analyses of the experiments designed to estimate the water-following ability of satellite-tracked surface drifters were completed during FY 1985. The experiments were performed in 1983 and 1984 and consisted of monitoring the spatial separation of a cluster of drifters and a patch of fluorescent Rhodamine B dye (Fig. 27). If the drifters were to track a given parcel of water exactly, then the center of mass of a suitably tagged (dyed in this case) water parcel and the centroid of a cluster of drifters should remain coincident with each other independent of time. However, wind effects on the exposed portion of the drifter and the drifter's response to surface waves contribute to the drifter's "slipping" with respect to the neighboring water. The results of the experiments indicated that under light wind and wave conditions slippage is well described by elementary slippage theory. Therefore, slippage estimates can be readily made by knowing the wind speed and buoy and drogue geometry. This enables easier decontamination of drifter data and should make the data more useful for model verification efforts. The ability to estimate slippage is a prerequisite to using drifter data as a verification tool for a particle trajectory model developed by GLERL and used for search and rescue operations by the U.S. Coast Guard and as an aid in the cleanup of spills of environmental contaminants.

Attempts are currently being made to simulate the vertical temperature structure of Lakes Erie and Michigan (Fig. 28). The Lake Erie temperature data were collected in 1979 at several locations within the lake as part of a larger effort involving current and meteorological measurements by both Canadian and GLERL scientists. The Lake Michigan data sets are from 1981 and 1982 and were obtained by NOAA's National Data Buoy Center (NDBC) from a moored buoy in central southern Lake Michigan.

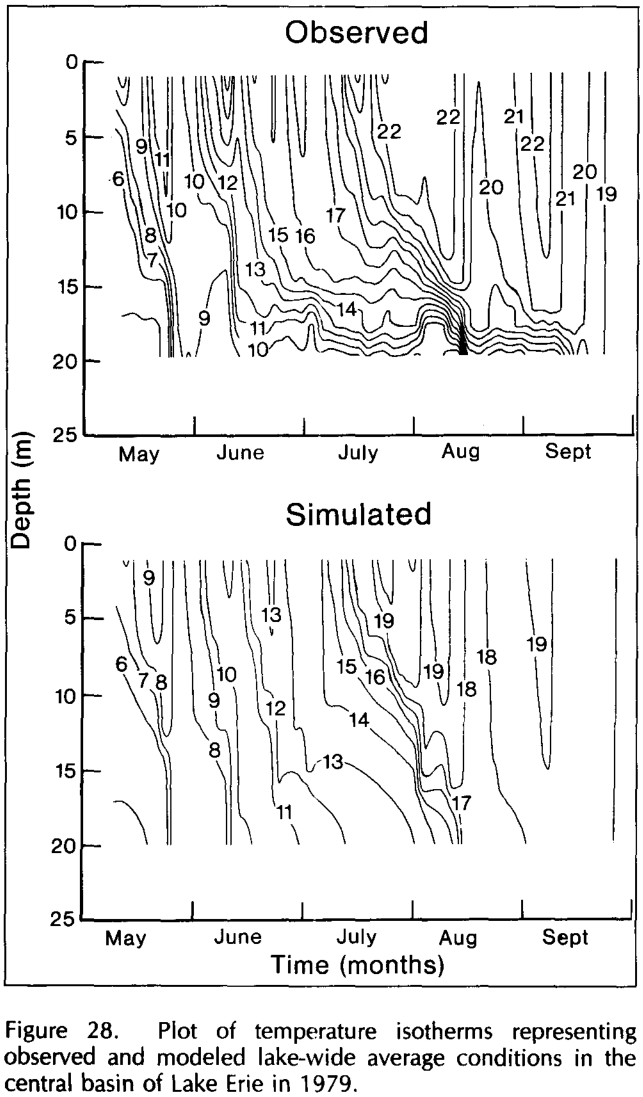


Figure 28. Plot of temperature isotherms representing observed and modeled lake-wide average conditions in the central basin of Lake Erie in 1979.

Four different one-dimensional models are being compared for their ability to simulate the temperature data from these lakes. The models span the possible mechanisms by which entrainment and thus deepening of the thermocline may occur. The potential implications of the models with respect to vertical mixing are dramatic. For example, the predicted response of a stratified lake to a storm event can vary from an isothermal water column to one that is strongly stratified, depending on the model employed. And when used in conjunction with mass balance models, large differences in the calculated mass fluxes may result, producing large biases in simulated concentration fields. Therefore, this work attempts to identify the best thermal model applicable to the Great Lakes (if one exists) and to define its limits of application based upon an understanding of the governing physics.

Much of the research on the physics of the Great Lakes has been directed toward the large deep basins, while relatively little attention has been focused on the small shallow settling basins such as Lake St. Clair. This lack of attention encompasses both theoretical developments as well as physical measurements. However, shallow basins such as Lake St. Clair form a crucial link in the Great Lakes system. Lake St. Clair is a depositional basin with the world's largest freshwater delta system and sedimentation rates which are enormous on oceanographic scales. Hence, detailed knowledge of the response of this body of water to atmospheric forcing, in terms of both its current and wave fields, is a key link to understanding the resuspension and transport of materials accumulating in this basin, which are eventually discharged to the lower Great Lakes system. It is therefore of great importance to develop a physical understanding of the processes in operation so that reliable and accurate predictions of the dynamics of this basin can be formulated.

To accomplish this goal, as part of GLERL's participation in the Upper Great Lakes Connecting Channels Study (UGLCCS), three week-long synoptic current surveys were conducted in Lake St. Clair to observe and measure flow throughout the basin under calm and storm wind conditions. The primary areas of interest were identified as the flow out of Anchor Bay, the flow in and around the shipping channel, and the flow north of Sandy Point, Ontario. Based upon predicted circulation patterns for all wind directions, a scheme of 11 current monitoring stations was devised to capture these critical flow fields. In addition, stations within Anchor Bay surrounding the St. Clair River delta and stations on transects of the shipping channel were identified and

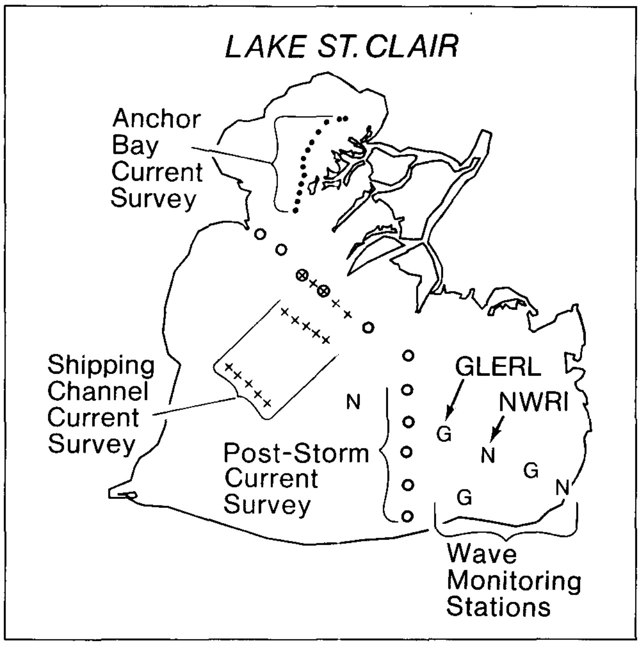


Figure 29. Locations of current measurement stations during the three synoptic current surveys of Lake St. Clair for the UGLCCS, and wave monitoring stations operated by GLERL and NWRI for the WAVEDISS '85 experiment.

sampled (Fig. 29). The surveys were conducted utilizing a Marsh-McBirny 527 electromagnetic current meter and a Hewlett-Packard data acquisition system. Time series of 128 measurements were made at 0.5-second intervals at 1 meter below the surface, at mid-depth, and 1 meter above the bottom. In areas where the depth was less than 3 meters, one mid-depth series was obtained.

Analysis of this data set will involve comparison of the measured currents to currents predicted by numerical circulation models for the wind conditions present during the surveys, as recorded by both the survey vessel and NWRI meteorological stations in place in Lake St. Clair at that time. The data will also be compared to experimental results from a table-size scale model of the lake. Suggestions for model improvement will be made based upon this analysis.

GLERL's Pathfinder Trajectory Prediction System continued to be the primary tool used by the U.S. Coast Guard and the NOAA Hazardous Materials Response Team to predict the movement of oil spills, boats, or other floating matter in the Great Lakes and to focus search and rescue operations. During FY 1985, testing of this model against GLERL's library of drifter buoy tracks was started. By systematically comparing observed tracks with the Pathfinder model's predictions, we will be able to adjust certain parameters in the model to make it a more accurate predictive tool.

During spring 1983, three drifter buoys entered an area in central Lake Michigan in which a closely-spaced network of current meters was moored. A comparison of the two different types of current measurements has revealed a surprising degree of similarity. A simple wind correction of less than 1% does a reasonable job of explaining the difference between them.

Drifter buoys have also proven quite useful in Lake St. Clair and river plume studies. As part of the UGLCCS, drifting buoys were used to measure surface currents in Lake St. Clair. The resulting tracks will be used to verify models of lake circulation and sediment transport. GLERL is also participating with NWRI in a continuing study of the physics of the Niagara River plume by deploying and tracking drifting buoys in western Lake Ontario.

Surface Waves, Water Level Fluctuations, and Marine Winds

Some of the most heavily populated and most intensely utilized areas of the Great Lakes are also the shallowest (Lake St. Clair, Green Bay, Saginaw Bay, and western Lake Erie for example). Although wave forecast methods for deep water are well-developed, shallow water wave forecasting is still in its infancy. A high-quality over-lake meteorological data system and other physical measurement systems deployed in Lake St. Clair for UGLCCS provided a perfect opportunity to measure wave dissipation and the effect of waves on resuspension in shallow water. To make these measurements, scientists from GLERL, NWRI, and the Atmospheric Environment Service of Canada planned a joint program for fall 1985 implementation entitled Wave Attenuation, Variability, and Energy Dissipation in Shallow Seas (WAVEDISS '85).

GLERL and NWRI each established three stations in the eastern half of the lake (Fig. 29). The GLERL stations consist of a single Zwarts transmission wave staff and Datawell Waverider radio transmitter. The NWRI stations consist of a triangular array of capacitance wave gauges, a cup anemometer, and a SeaData recording package. The instrumentation systems are attached to towers which are guyed to a base anchored with railroad wheels (Fig. 30). The towers were deployed along a transect parallel to the prevailing storm wind direction. One tower was deployed on a perpendicular leg to give an indication of cross-transect variability. The triangular array of capacitance gauges on the NWRI stations provided wave direction estimates in addition to the wave energy spectrum. The experiment will run from mid-September 1985 to the end of November 1985 in order to avoid the heavy boating traffic and still cover the fall storm season.

Analysis of the data during FY 1986 will include (1) selection of appropriate episodes for study of wave dissipation effects, (2) spectral analysis of wave measurements, (3) calculation of wave dissipation based on differences in the wave spectra, and (4) comparison with existing theories of wave dissipation in shallow water. In

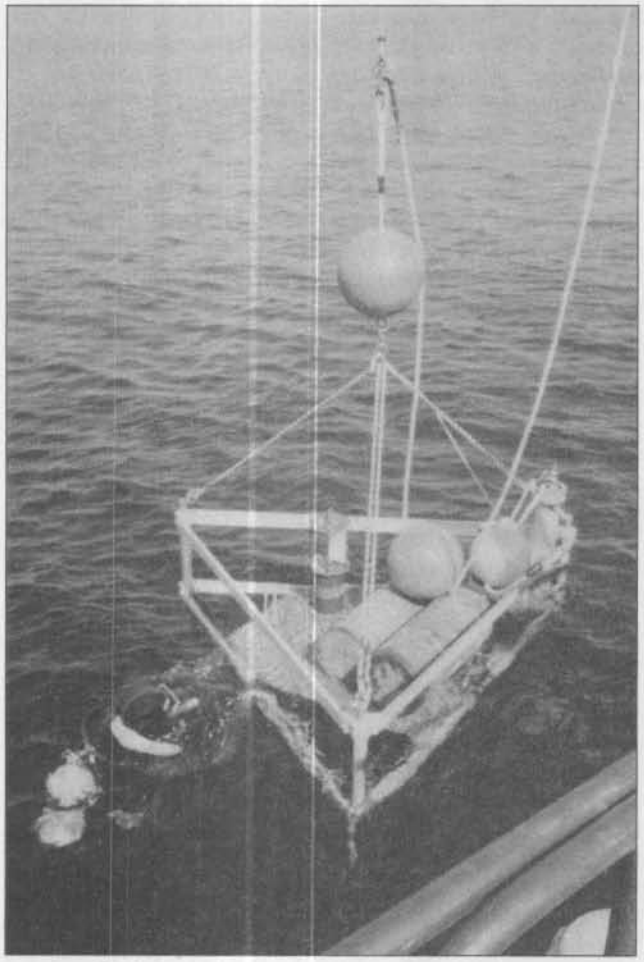


Figure 30. GLERL wave measurement tower being deployed in Lake St. Clair.

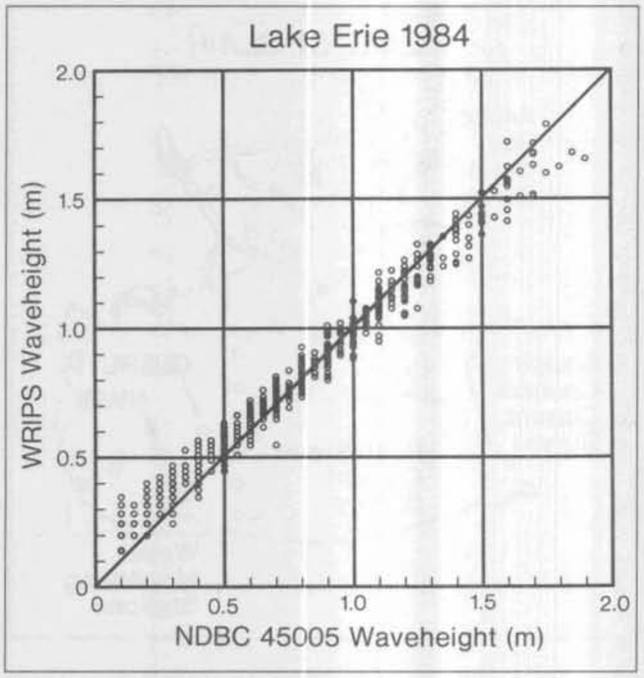


Figure 31. Comparison of significant wave heights reported by NDBC NOMAD buoy 45005 and GLERL Waverider buoy in Lake Erie during September – November 1984.

addition, comparisons will be made with deep water theory in order to explicitly determine the relative importance of shallow water effects. It is expected that these results will be incorporated into existing wave forecast models or that new models will be developed to improve wave forecasts for shallow water areas in the Great Lakes and elsewhere.

Marine weather forecasters at the NWS Great Lakes Weather Service Forecast Offices (WSFO) continued to use the GLERL Interactive Wave Prediction Model with favorable comments. At the request of the Cleveland WSFO, an air-sea temperature difference parameter was added to the forecast program; the usefulness of this additional parameter is being evaluated.

Since 1981, the NOAA NDBC has deployed eight NOMAD buoys during the ice-free season in the Great Lakes for surface wave and meteorological measurements. The NOMAD buoy has a 6-meter boat-shaped hull developed by the Navy for oceanic applications. The data collected by these buoys have been used by NWS, the U.S. Coast Guard, commercial and recreational boating interests, as well as by GLERL for research on the marine environment in the Great Lakes. In September 1984, GLERL deployed a satellite-reporting Waverider buoy in the western part of the central basin of Lake Erie within 1 kilometer of the NDBC NOMAD weather buoy 45005. The Waverider has a 1-meter spherical hull with a vertically-stabilized accelerometer for measuring waves. The Waverider system has been used extensively for wave measurements in a wide variety of environments. The Waverider buoy and the NOMAD buoy remained in close proximity for 3 months (September-November). During this period, over 1,000 pairs of wave height, wave period, and sea surface temperature observations were obtained from the two platforms (Fig. 31). In addition, several wave frequency spectra were calculated from nearly simultaneous wave data.

A detailed statistical analysis was made for all pairs of Waverider and NOMAD buoy significant waveheight reports. The correlation between the measurements is extremely high (correlation coefficient 0.99, standard error 0.05 meters). The main differences between the two measurement systems were that (1) the NOMAD buoy reported waveheights significantly lower than the Waverider buoy for waveheights less than 0.5 meters and (2) there is an indication that the NOMAD buoy reports slightly higher waveheights than the Waverider buoy for waveheights greater than 1.5 meters; there were, however, only a few measurements in the 1.5- to

2-meter range during the observation period. Accurately measuring and forecasting 0.5-meter waves may be more important in the Great Lakes than in the open seas because of the greater number of small craft that can be impacted by even these small waveheights. GLERL and NDBC are currently investigating techniques that might improve the accuracy of the NOMAD waveheight reports for low waveheights.

A study of shallow water effects on the wind wave spectrum representation was also completed during FY 1985. We made an objective assessment of three wave spectrum formulas for shallow water which are available in the literature. We compared wave spectra estimated by these formulas with those calculated from actual field measurements made in Lake Erie during 1981 in depths ranging from 1.4 to 14.0 meters. We found that the models each have various degrees of effectiveness and applicability. It appears that the form of the spectral representation remains similar at all depths, with depth affecting only the wave parameters that characterize the form of the spectrum. The choice of which model to use is basically subjective, although it may depend upon the availability of the required input parameters, which is quite different for the different models. The most encouraging result from this study however, is that the depth-dependent factors derived for the oceans are very effective in characterizing depth effects of wind waves in shallow water. This factor is especially useful in developing modifications to established deep-water wave models for shallow-water applications.

Environmental Systems Studies

Management of the Great Lakes is a complex and formidable task. Decision makers in government and private institutions are confronted with multiple goals, often conflicting, from which they must try to achieve fair and balanced policies. Among these Great Lakes goals are enhancement of commercial and sports fisheries, attainment of desired water quality, rational consumptive use and diversions of lake water, encouragement of recreation and tourism, and sensible use of the lakes for transportation, mining, hydropower, and waste disposal. The multiple-use nature of the Great Lakes necessitates that frameworks be built within which tradeoffs among goals can be examined; building such frameworks is a central focus of the Environmental Systems Studies Group. Utilizing optimization, uncertainty, and risk analysis techniques, and ecosystem-contaminant fate and behavior models, the Environmental Systems Studies Group addresses questions concerning (1) the effects of management alternatives and human-induced changes on Great Lakes ecosystems, (2) risks to ecosystem health posed by contaminants, and (3) the cost-effectiveness of environmental management strategies.

Research conducted by the Environmental Systems Studies Group is directed toward understanding and optimizing relationships between the human, economic, and ecological systems of the Great Lakes region. By necessity, this group draws heavily on the knowledge generated by other groups, both inside GLERL and from outside the laboratory. Research covers a variety of temporal and spatial scales dictated by the questions under investigation. Central to the Environmental Systems Studies approach is the premise that cost-effective management of the Great Lakes requires that they be managed as an integrated system: management actions applied to one lake or one use can affect other lakes or other uses. For example, a fisheries management plan for Lake Michigan should not be developed without taking into account the effects it will have on Lake Huron fisheries. Nor should a contaminant control program be implemented without first determining the most cost-effective method that will lead to desired objectives.

Optimization Models: An Aid to Resource Management

Optimization, uncertainty, and risk analysis techniques are important tools used by the Environmental Systems Studies Group. Although used sparingly to date, these techniques can and should play a key role in environmental decision-making processes, just as they do in the decision-making processes that lead to the safe and cost-effective design of buildings and bridges. For example, architectural engineers must design structures so that the risk (i.e., the probability) of building collapse and associated fatalities is minimized during earthquakes. Similarly, environmental managers should design cost-effective management plans that minimize the risk of decreased water quality and related harm to economically important fish species. In toxic contaminant fate and behavior models, risk comes from two sources: that attributable to the toxic effects of the contaminant and that resulting from uncertainty about the transport and interactions of the contaminant with ecosystem components. By assigning probability distributions that define the uncertainty associated with each of these areas, the output of the model will also become probabilistic. Predictions from such models indicate the probability that an undesirable event will occur for a given set of input conditions. This gives the environmental manager the option of comparing relative risks among alternative management options.

Environmental uncertainty and economic constraints must be considered when designing plans that minimize the risk of undesirable environmental events. Phosphorus management in the Great Lakes provides an excellent vehicle for demonstrating an approach which considers uncertainty and economic constraints within an optimization framework. The International Joint Commission has recommended desirable phosphorus concentrations for the Great Lakes and has also recommended a plan (1978 Agreement) to attain these concentrations. The plan suggests that a number of point and diffuse phosphorus reduction measures be implemented in each of the basins. During FY 1985 the efficacy of this plan and others was examined and compared using a coupled-basin phosphorus mass balance model that quantitatively accounts for the effects of realistic, time and space variable phosphorus loading and particle settling rates on predicted phosphorus concentrations. The results showed that the probability of attaining desired phosphorus levels varies from basin to basin and is quite low under some management strategies (Fig. 32). Management strategies tested were:

No Additional Treatment:
: maintains mid-1970 treatment levels;

Non-stochastic Optimization:
: optimal treatment capacities determined for average phosphorus loading and settling rates;

1978 Agreement:
: International Joint Commission strategy;

Maximum Projected Treatment:
: maximum capacities thought possible;

Worst Case Optimization:
: treatment capacities determined for stochastic phosphorus loading and settling rates—recommended capacities would always achieve desired phosphorus concentrations;

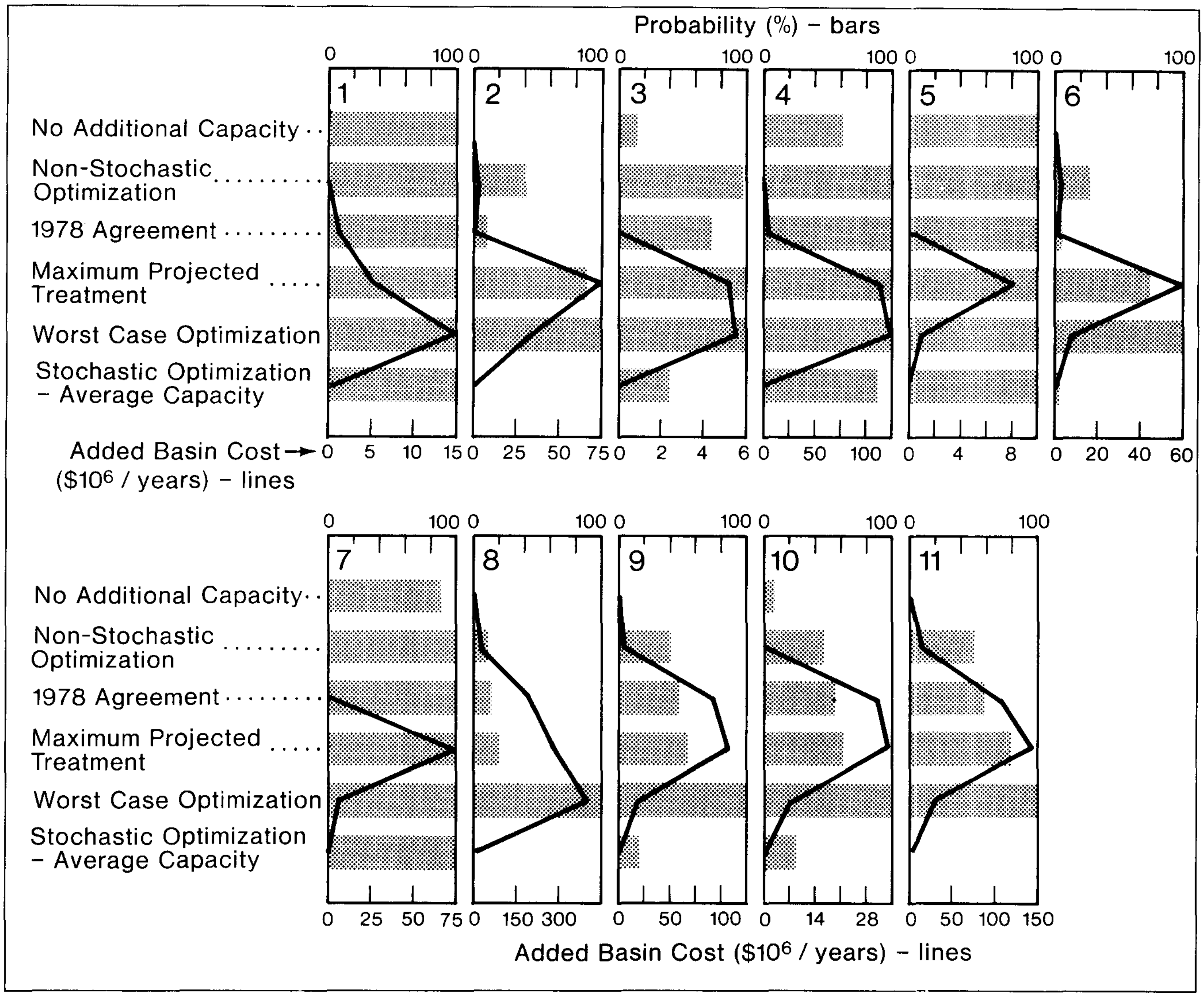


Figure 32. Probabilities (bars) of reaching desired phosphorus concentrations in each of 11 Great Lakes basins under different phosphorus treatment scenarios. Basin-specific costs (over mid-1970 levels) for each treatment scenario are indicated by lines. Basin designations are: 1—Lake Superior, 2—lower Green Bay, 3—upper Green Bay, 4—Lake Michigan, 5—Georgian Bay, 6—Saginaw Bay, 7—Lake Huron, 8—western Lake Erie, 9—central Lake Erie, 10—eastern Lake Erie, and 11—Lake Ontario.

Stochastic Optimization Average Capacity:
the average of all optimal treatment capacities that were determined for stochastic conditions.

The combination of phosphorus reduction measures and their spatial distribution needed to achieve desired phosphorus concentrations under realistic (probabilistic) environmental conditions was determined using a dynamic optimization approach. A least-cost method was identified that will, with 100% probability, lead to the attainment of desired phosphorus concentrations in all basins. This plan (Worst Case Optimization) shifts the emphasis of recommended treatment measures from those previously recommended (Fig. 33) and decreases basin-specific costs of phosphorus load reductions in some instances. However, annual costs for all of the Great Lakes would be expected to rise by 48% if 100% attainment of desired phosphorus concentrations is an unwavering goal. Studies presently underway suggest, however, that costs can be reduced even below levels required by the 1978 Agreement and its subsequent amendments, if a very small risk of sub-optimal phosphorus concentrations occurring is considered acceptable. These results suggest (1) that changes will be necessary in recommended phosphorus reduction strategies if the goal is 100% success in meeting desired phosphorus

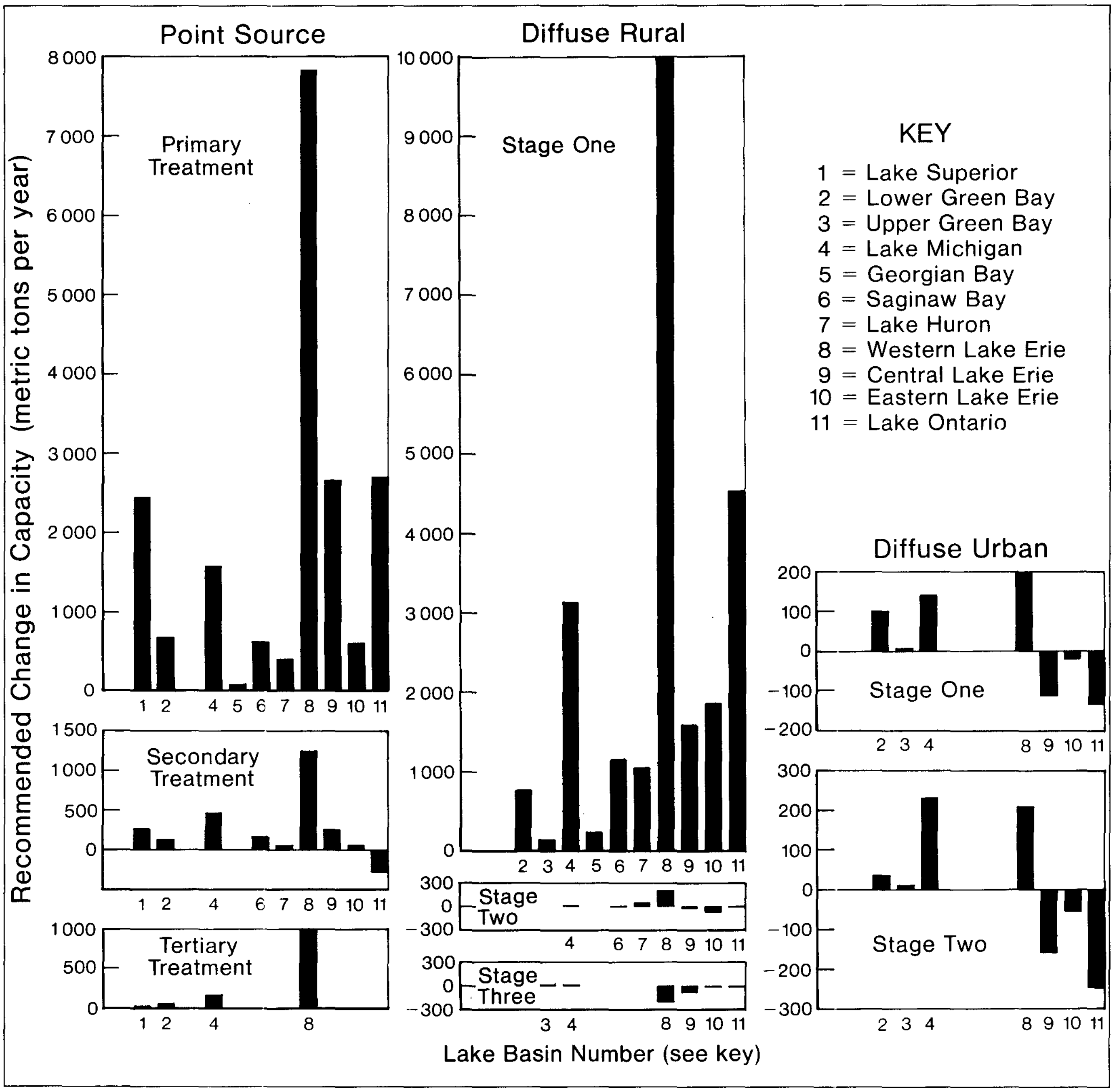


Figure 33. Recommended changes in treatment capacities in order to achieve a 100 percent probability of attaining desired phosphorus concentrations in the 11 basins. Changes recommended are relative to those capacities suggested in the 1978 IJC agreement.

concentrations in all basins, (2) that natural variability must be accounted for when deciding upon management actions, and (3) that optimization models provide an excellent tool for the design of environmental management plans. A note of caution is appropriate, however, when examining the recommendations from this optimization analysis. Phosphorus management is only one of many Great Lakes goals. It is entirely possible that the recommended increases in phosphorus treatment capacities could lead to phosphorus concentrations that might, for example, be lower than those needed to support desired fisheries. Therefore, the effects of one management strategy upon other management strategies must be considered when devising Great Lakes manage-

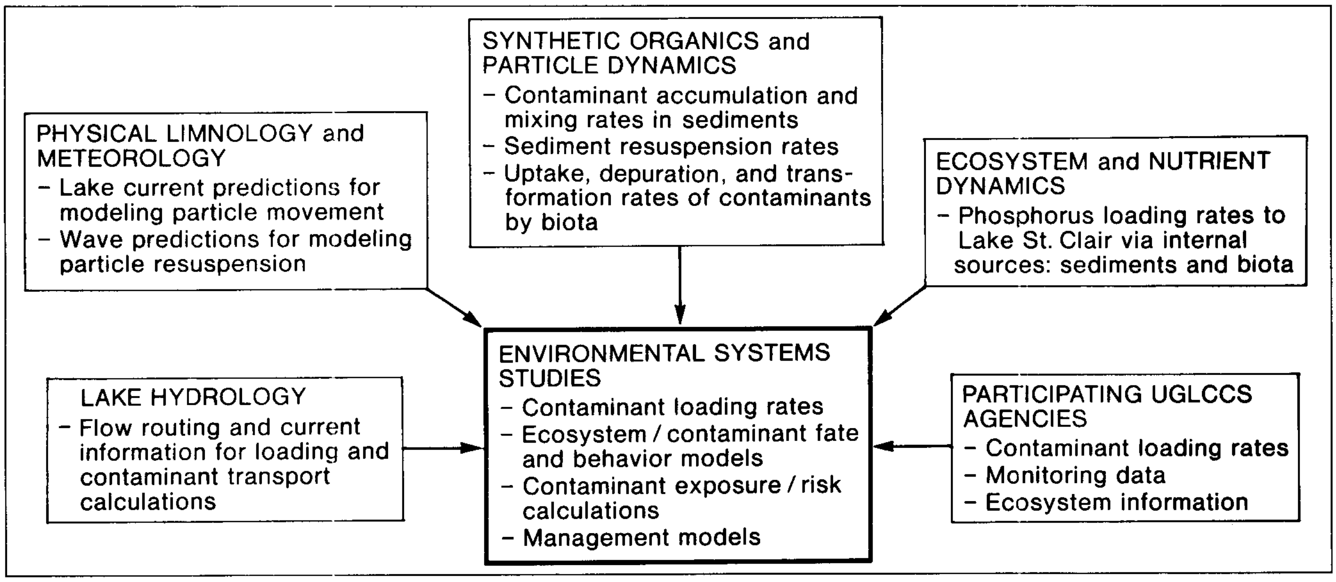


Figure 34. Interrelationships among GLERL projects in the Upper Great Lakes Connecting Channels Study. Lines connecting boxes denote two-way flows of information.

ment plans; to build such a multi-objective optimization framework is one goal of the Environmental Systems Studies Group.

UGLCCS: Cooperating for the Greater Good

The Environmental Systems Studies Group coordinates (Fig. 34) and actively participates in GLERL's efforts in the Upper Great Lakes Connecting Channels Study (UGLCCS). A generic model that can be used to predict contaminant fate and behavior, as well as exposure probabilities, is being developed using physical, chemical, and biological information provided by other UGLCCS participants. This model should assist in the development of contaminant management strategies. A phosphorus mass balance model for Lake St. Clair was developed (Fig. 35) during FY 1985 and will be used during FY 1986 to examine the relative importance of various pathways (external versus internal loading, resuspension, etc.) in controlling the seasonal variation of phosphorus levels.

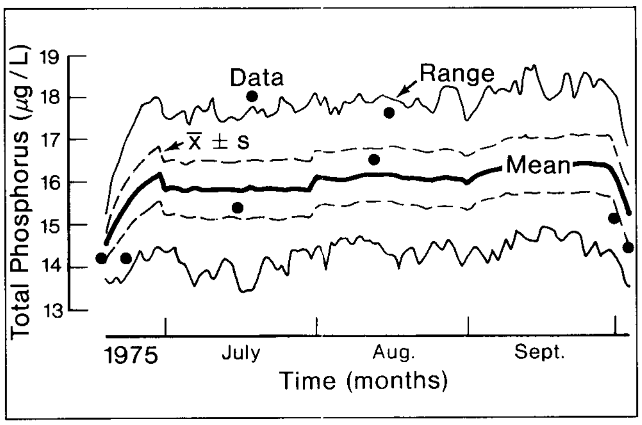


Figure 35. Comparison of the output from the phosphorus mass balance model with measured (dots) total phosphorus concentrations in Lake St. Clair during 1975. The mean (heavy solid line), ± one standard deviation (dashed line), and ± the range (light solid line) of model behavior are shown and result from consideration of the variability expected in loading and apparent settling rates. Model output and data represent lake wide averages.

Information Services

The GLERL mission includes the development of environmental information for the Great Lakes region to improve understanding and to provide improved environmental service tools, data, information, and consulting services in support of user needs in government and private organizations. Identification of the environmental information required in association with Great Lakes and estuarine use and development is vital to the GLERL mission and is one of the goals of Information Services efforts at GLERL. GLERL staff participation on boards, commissions, task forces, and committees is an essential part of this effort.

The value of GLERL products to the many government and private users is a function not only of the scientific content, but also of the timeliness and form of the output. Information must be packaged and interpreted to satisfy specific needs and applications. GLERL Information Services includes a Publications Unit that ensures that GLERL's research products reach the user-communities in a timely manner and readable form.

International and Interagency Participation

Staff participation on boards, commissions, task forces, and committees provides a mechanism for defining user needs and guiding the development of usable products. It helps to maintain staff involvement in programs concerned with Great Lakes environmental problems, and keeps staff familiar with water- and land-oriented resource development and management issues.

During FY 1985 GLERL staff participated as members (unless noted otherwise) of the following International Joint Commission boards, committees, and task forces:

- International Great Lakes Technical Information Network Board
  - Systems Evaluation Committee
  - Hydrology Committee
- International Great Lakes Levels and Flows Advisory Board (U.S. Co-Chairman)
- Great Lakes Water Quality Board, Surveillance Work Group
  - Upper Connecting Channels Task Force
  - Lake Michigan Task Force
  - Lake Erie Task Force
  - Task Force on In-Place Sediment Contaminants, Workshop on Monitoring in Areas of Concern
- Great Lakes Science Advisory Board
  - Great Lakes Levels Task Force (Chairman)
  - Great Lakes Research Strategy and Toxic Contaminants Committee
  - Health and Aquatic Communities Workgroup (Advisor)
  - Task Force on Great Lakes Modeling

GLERL staff also participated as members (unless noted otherwise) of other interagency and international activities:

- Upper Great Lakes Connecting Channels Study (UGLCCS)
  - Management Committee
  - Activities Integration Committee
  - Modeling Task Force (Chairman)
- Coordinating Committee for Great Lakes Hydraulic and Hydrologic Data
  - Riverflow Subcommittee
- U.S.-Canada Ice Information Working Group (U.S. Co-Chairman)
- *Journal of Great Lakes Research* (Associate Editors)
- International Association for Hydrologic Research
  - Section on Water Resources Systems (U.S. Representative)

GLERL staff took part in an interagency planning activity with NOAA/NMPPO and Great Lakes representatives of EPA, FWS-Great Lakes Fisheries Laboratory, and COE to develop an "Action plan for federal research and monitoring related to Great Lakes water quality and water quantity."

Other activities involving participation with other NOAA units included the NOAA Marine Environmental Quality Task Force (OAR Technical Representative), the Synthetic Organics Research Subcommittee (Chairman), the Habitat Modification Research Subcommittee (Member), the Nutrient Overenrichment Research Subcommittee (Member), and the NOAA Technical Subcommittee, New Bedford Superfund Action (Member).

Several GLERL scientists were members of the Executive Board of the International Association for Great Lakes Research (IAGLR), including functions as Past-President and Secretary. IAGLR is the primary Great Lakes research professional society and is involved with coordinating programs and disseminating results.

One GLERL scientist was a member of the National Research Council Conference on Review of the Great Lakes Water Quality Agreement, and another presented a 2-day short course on Toxic Substances in the Great Lakes in conjunction with Michigan Sea Grant at Michigan State University. A GLERL scientist participated in numerous public information meetings and special briefings concerning record Great Lakes lake levels and their causes, including several meetings for the Great Lakes public, the U.S. Congress, and state legislators, sponsored by the International Joint Commission.

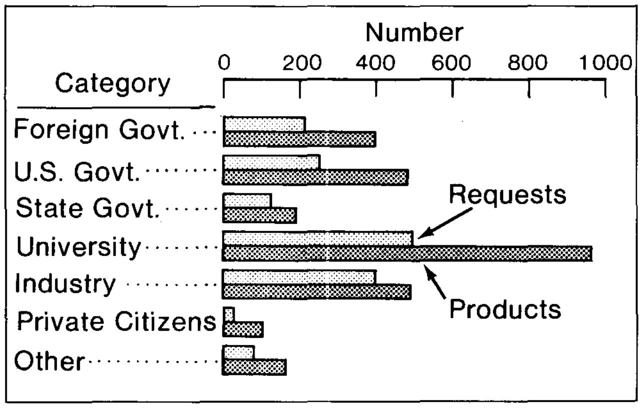


Figure 36. Summary, by user category, of information requests received and products provided by GLERL during FY 1985.

Publications Unit

The Publications Unit staff is responsible for providing editorial and publications support to the scientific staff, distributing GLERL publications, and responding to requests for publications and information. The unit also maintains and updates, as necessary, eight mailing lists covering GLERL products. New NOAA-series publications are automatically distributed according to these mailing lists; all new publications, including journal articles and books, are added to our six-month update listing of new publications, which keeps our users informed of GLERL's latest product releases.

In FY 1985, GLERL research products included 69 scientific articles, reports, and books, 85 talks presented at scientific and public meetings by GLERL staff, and responses to approximately 1,600 requests for information, providing almost 2,800 items to service those requests. In addition, a new comprehensive summary of GLERL publications to date was published (GLERL Publications, June 1985), and a brochure was produced for informal distribution. Figure 36 shows the number of documented FY 1985 information requests received and products distributed by user category. State and Federal government (both U.S. and foreign) requests were 37%, university requests were 31%, industrial requests were 25%, and private citizen requests were 2% of the total documented requests received during FY 1985.

Technology Transfers

Among the products that GLERL produces and distributes, many involve, to some degree, a transfer of technology as well as data. During FY 1985, there were eight major technology transfers of GLERL products to outside users:

- Method of Amino Acid Analysis of Natural Waters
  User: Michigan State University.
- Track Autoradiography Procedure
  Users: University of Southern California; Michigan State University.
- Methods of Measuring Primary Production in Lakes and Rivers
  User: Georgia Environmental Protection Agency.
- PATHFINDER Trajectory (spill) Model
  Users: National Weather Service—National Meteorology Center and Weather Service Forecast Offices in Chicago, Ann Arbor, Cleveland, and Buffalo; U.S. Coast Guard; Atmospheric Environment Service of Canada.
- Lake Champlain Water Supply Model
  User: National Weather Service–Northeast River Forecast Center in Hartford, Connecticut.
- GLERL Interactive Wave Prediction Model
  Users: National Weather Service—Weather Service Forecast Offices in Cleveland, Ann Arbor, Buffalo, and Chicago
- Lake Superior Water Supply Model
  User: U.S. Army Corps of Engineers (Detroit District)
- Procedure to Estimate Snow Water Equivalent from Gamma Radiation Measurements
  User: U.S. Army Corps of Engineers (Detroit District)

Facilities

The present GLERL facilities are a combination of office and laboratory spaces, the latter consisting of both biology and chemistry laboratories. A Marine Instrumentation Laboratory is maintained at another location in Ann Arbor, while bulk storage and warehousing have been located some 60 miles away in Monroe, Michigan. These facilities were meant to be only temporary quarters when GLERL moved to Ann Arbor in 1974. While GLERL continued to occupy them during FY 1985, at the close of FY 1985 negotiations were being finalized for a new leased facility to be located in Ann Arbor, with occupancy slated for early FY 1987. GLERL's base for field operations, including the R/V *Shenehon*, is in Grand Haven, Michigan.

Biology, Chemistry, and Ice Laboratories

The chemistry program at GLERL is primarily focused on organic compounds and nutrients in the ecosystem and the use of radionuclides to study sediment dynamics. Major instrumentation includes glass capillary gas chromatographs, high pressure liquid chromatography (HPLC) units, a total carbon analyzer, a multichannel autoanalyzer system, and a suite of low-level gamma and alpha radiation detectors. Two liquid scintillation counters are shared by the Synthetic Organics and Ecosystem Dynamics Groups, and are used to study the uptake of radio-labeled organic compounds, nutrients, growth rates, competition for nutrients by algae, and cycling rates of selected algal nutrients. Within the chemistry section, the particle dynamics radionuclide laboratory is a specialized facility equipped to detect and measure very low levels of many of the radioactive substances present in water, sediment, and biota. The laboratory was established as part of the cooperative program with the University of Michigan's Great Lakes and Marine Waters Center, and is housed on the University of Michigan North Campus.

The biology laboratories include a multichannel Coulter Counter to study particle-size selection and zooplankton grazing on natural lake algae and seston, a full complement of growth chambers and incubators, stereo, inverted, and epifluorescent microscopes, and equipment for culturing phytoplankton and zooplankton, the latter particularly useful for laboratory studies of ecosystem models. Shipboard and shoreside incubators have been constructed to simulate ambient light and temperature conditions for as many as two dozen 20-liter growth chambers and have been used for zooplankton grazing experiments. A mobile trailer fitted to support field investigations of the physiology and feeding rates of planktonic and benthic organisms is located at the docking facility for the R/V *Shenehon* (see below). A recent addition to GLERL's specialized laboratories is the High Speed Microcinematography Laboratory. The design of this lab is based on the microcinematography facility at Skidaway Institute of Oceanography. A critical difference is that the GLERL facility is housed in a separate temperature controlled environmental chamber. The combination of high speed (500 frames per second) and precise temperature control over the temperature range from 1 to 30°C allows advanced studies of the feeding behavior of zooplankton over the broad range of temperatures found in the natural Great Lakes environment.

GLERL's Ice Laboratory provides scientists with an extended opportunity to make winter measurements by allowing them to characterize and perform experiments on ice samples collected and stored during the previous field season. The facility consists of a work room maintained at −7°C, and an ice storage room. The work room can be used to conduct experiments on natural ice, as well as to calibrate instrumentation for the ice research program in an environment similar to that encountered in the field.

Marine Instrumentation Laboratory

The Marine Instrumentation Laboratory staff selects, calibrates, repairs, and, when necessary, adapts or designs instruments to collect data in the lakes and their environs. The facility includes wood and machine shops, and electronics design, fabrication, and repair shops, and houses both the Ice and Microcinematography Laboratories. Engineers and technicians in this unit work closely with GLERL researchers to ensure that instruments are compatible with their needs. MIL staff also participate in field experiments, providing support for the deployment and retrieval of field equipment, assistance with sample and data collections, and in-field maintenance or repair of equipment.

New instrumentation acquired and tested for use in the 1985 field season included an acoustical Doppler current profiler, four Neil Brown Instrument Systems acoustical current meters, three sets of Hewlett Packard 3421A analog data acquisition system controls and HP75 calculators, and two EPSON Geneva PX-8 portable computers for lab and field data handling. Some of the instrumentation fabricated by the Marine Instrumentation Laboratory in support of GLERL programs in 1985 include a 20-sample water sampler, a bottom sediment flume, tripods for bottom sediment studies, and support structures for acoustic current meter deployment.

Computer Facility

The GLERL Computer Facility consists of an on-site VAX 11/780 system and includes the capability of

Figure 37. R/V *Shenehon*, GLERL's primary field platform.

accessing either a mainframe computer (Cyber 180/855) or a supercomputer (Cyber 205), both located at the National Bureau of Standards in Gaithersburg, MD. GLERL is one of five remote nodes to that facility, which is known as the Department of Commerce Consolidated Scientific Computing Service.

The GLERL computer supports over 80 authorized accounts for a variety of applications, including realtime data acquisition, data reduction, graphics, large scale modeling, statistical/mathematical analysis, telecommunications, and word processing. On-site access is supported via 20 graphics terminals, 32 non-graphics interactive terminals, and 30 dumb terminals. Overall system access was upgraded during FY 1985 by installation of a Micom Instanet 6600 communications switch which allows most GLERL terminals to be hardwired and to select interactive sessions on either the VAX or the Cyber 180/855 in Gaithersburg.

Research Vessel *Shenehon*

The R/V *Shenehon* is the primary platform used in support of open lake field investigations (Fig. 37). The vessel is 65.6 feet long, with a 6.5-foot mean draft, a 600-nautical mile cruising range, and a 10-knot cruising speed. A hydraulic articulated crane is used for deployment and retrieval of heavy instrument moorings. Winches handle hydrographic wire and multiconductor cable for sample casts and *in situ* measurements of water variables. The *Shenehon* is based at the U.S. Army Corps of Engineers' boat yard at Grand Haven, Michigan, which includes warehouse facilities and space for a mobile shore-based laboratory.

During FY 1985 an on-board laboratory was redesigned, modernized, and expanded to facilitate physical, chemical, and biological experiments. Other shipboard improvements during the past year include opening of a large access through the stern laboratory bulkhead, relocating the freezer and incubator, and installing a new system for housing the data acquisition instruments. These improvements resulted in easier access, and more deck and storage space. An HP75 calculator-based data acquisition system with a cassette recorder is used to record depth, temperature, transparency, meteorological and other data in digital format. Data from the cassette can be rapidly entered into the VAX 11/780 computer and are then readily available to all users. A Loran C navigation system provides the capability and precision for the boat to return to an exact site in the lakes for equipment retrieval.

Library Facility

The GLERL library staff support laboratory activities by maintaining a tailored research collection and offering special retrieval services when the existing collection cannot meet the needs of the researchers. Library services include reference, interlibrary loan, photocopying, acquisition, circulation, and online information retrieval for laboratory-affiliated personnel. Collection holdings include 3,100 books, 3,700 unbound periodical volumes, and 2,900 technical reports in the areas of climatology, hydraulics, hydrology, ice, limnology, mathematical modeling, meteorology, oceanography, sedimentation, and wave motion, with emphasis on the Great Lakes basin. Recently, contaminant organics and nutrients were included as major subject areas. The GLERL library is a member of the Michigan Library Consortium, Washtenaw-Livingston Library Network, Federal Library and Information Network, NOAA Library and Information Network, and the Online Computer Library Center, Inc.

During FY 1985 the library received 239 current periodical titles and retrieved 387 interlibrary loan requests. The library's online information retrieval capabilities were expanded through the addition of the QL/Search database collection, which provides access to Canadian data bases.

Permanent Staff as of 30 September 1985

	Full Time	Part Time
Office of the Director	11	3
Ecosystem and Nutrient Dynamics Group	8	5
Environmental Systems Studies Group	1	0
Lake Hydrology Group	10	1
Physical Limnology and Meteorology Group	11	4
Synthetic Organics and Particle Dynamics Group	9	3
TOTAL	50	16

Office of the Director

Aubert, E.J. — Director
Noble, P.E. — Secretary
Reid, D.F. — Ass't to the Director

Administration

Mark, S.V. — Head
Dunivan, E.M.
Hubbard, B.D.
James, O.L.
Lee, J.P.

Computer Facility

Spalding, G.E. — Head
Del Proposto, D.J.
Fenton, J.F.
Herche, L.R.
Lefevre, J.T.
Shrum, A.F.

Information Services

Reid, D.F. — Head

Environmental Systems Studies Group

Fontaine, T.D. — Head

Physical Limnology and Meteorology Group

Schwab, D.J. — Acting Head
Townsend, G.H. — Secretary
Campbell, J.E.
Clites, A.H.
Liu, P.C.
Lynn, E.W.
McCormick, M.J.
Miller, G.S.
Saylor, J.H.

Marine Instrumentation Laboratory

Soo, H.K. — Head
Booker, H.L.
Dungan, J.E.
Kistler, R.D.
Miller, T.C.
Muzzi, R.W.

Ecosystem and Nutrient Dynamics Group

Gardner, W.S. — Head
Lojewski, N.L. — Secretary
Cichocki, E.A.
Fahnenstiel, G.L.
Laird, G.A.
Lang, G.L.
Liebig, J.R.
Malczyk, J.M.
Nalepa, T.F.
Quigley, M.A.
Scavia, D.
Tarapchak, S.J.
Vanderploeg, H.A.

Lake Hydrology Group

Quinn, F.H. — Head
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Assel, R.A.
Bolsenga, S.J.
Croley, T.E., II
Derecki, J.A.
Hartmann, H.C.
Kelley, R.N.
Leshkevich, G.A.
Norton, D.C.

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Carrick, B.J. — Librarian

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Hawley, N.
Landrum, P.F.
Morehead, N.R.
Robbins, J.A.

R/V *Shenehon*

Morse, D.V. — Master Mate
Burns, W.R.
Grimes, J.E.

Publications

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NOAA/GLERL
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Ann Arbor, MI 48104
313-668-2262

Staff Publications

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*No longer affiliated with this laboratory.

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Contracts and Grants During FY 1985

Principal Investigator	Institution	Title
A.M. Beeton	University of Michigan	Great Lakes Research Planning
J.A. Bowers	University of Michigan	Phosphorus Release by Zooplankton
J.E. Breck	Oak Ridge National Laboratory	Models for Behavior and Fate of Long-Lived Contaminants
S.J. Eisenreich	University of Minnesota	Toxic Organic-Sediment Dynamics in the Great Lakes
M.S. Evans	University of Michigan	Characterization of Particulate Flows
J.P. Giesy	Michigan State University	Changes in the Free Amino Acid Pool of Lake Michigan Invertebrates
B.M. Lesht	Argonne National Laboratory	Benthic Nepheloid Layer in Southern Lake Michigan
B.M. Lesht	Argonne National Laboratory	Bottom Sediment Resuspension in Lake St. Clair
G.A. Meadows	University of Michigan	Airborne Radar Synoptic Wave Observations
C.H. Mortimer	University of Wisconsin (Milwaukee)	Inertial Motion and Related Internal Waves
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