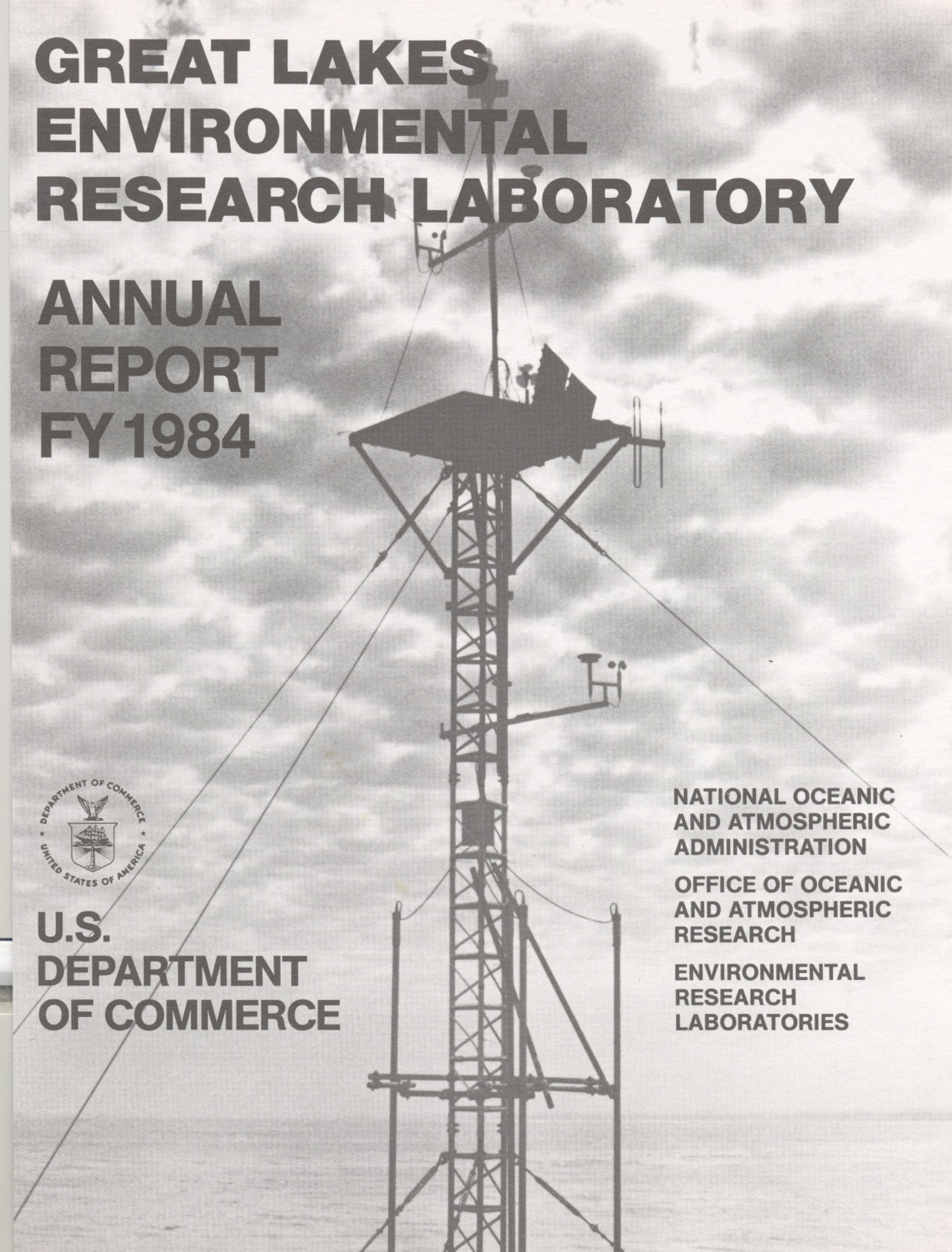
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

ANNUAL REPORT FY 1984



U.S. DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH

ENVIRONMENTAL RESEARCH LABORATORIES

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ANNUAL REPORT FY 1984

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Eugene J. Aubert, Director

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
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PREFACE

The Great Lakes Environmental Research Laboratory (GLERL) has completed its tenth year of operation in Ann Arbor. 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 special emphasis on the Great Lakes. The environmental information developed is made available to NOAA, other government agencies, universities, industries, and individual citizens to aid them in their environmental services, plans, and operations.

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 on field, laboratory, and analytic investigations of the limnological, hydrological, and meteorological properties of the lakes, their basins, and the overlying atmosphere. The ultimate goal of the GLERL program is to understand the lake-land-atmosphere-sediment system to the extent that environmental simulation and prediction models can be built that will provide sufficiently precise information on Great Lakes and coastal and estuarine processes and phenomena to support enlightened use of the regions' resources.

This annual report is intended to inform the scientific community, decision-makers, and other interested individuals of GLERL's capabilities, program, significant results, and plans for the future. It is also intended to encourage an exchange of information between those in need of environmental information for operational, planning, or management activities.

GLERL's multidisciplinary program reflects the need for improved understanding, prediction, and specific information about the Great Lakes. Biogeochemical studies of the cycling and dynamics of nutrients and toxic contaminants are needed to improve understanding and prediction of processes occurring in the Great Lakes ecosystem and to provide more precise scientific information relevant to the management of wastes, water supplies, and fisheries. Models to simulate and predict the transport and fate of contaminants as a function of human input to the lakes are needed to support management decisions on wastewater and regulation policies. More precise scientific information on lake water levels, connecting channel flows, and ice distribution is useful to those concerned with erosion control, transportation, recreation, and power generation. Studies of the lakes' physics improve understanding and prediction of the circulation, the thermal structure, and the transport and dispersion of chemical and biological variables in the ecosystem; numerical forecast tools result in products applicable to pollution transport and dispersion. Research on physical phenomena like surface waves, seiches, and surges provides improved understanding and numerical prediction methods that are applicable to shipping activities, recreation, shoreline flooding, and erosion.

GLERL staff continue to work with Great Lakes regulatory and management agencies, in both Canada and the United States, to provide them with the research products, data, and expertise they need. They also serve as officers, board members, or committee members of such organizations as the International Joint Commission, the Great Lakes Commission, and the International Association for Great Lakes Research. These activities provide an outlet for GLERL products and a means of identifying environmental problems requiring further study.

Other outlets for GLERL products include requests from private organizations and individual citizens. The scientific community is informed of the products through journal articles, NOAA technical reports and memoranda and data reports, and presentations at society meetings. The location of GLERL in Ann Arbor near the University of Michigan provides the opportunity for cooperative research programs and for graduate student participation in GLERL projects. Visiting scientists participate in GLERL research studies on a continuing basis.

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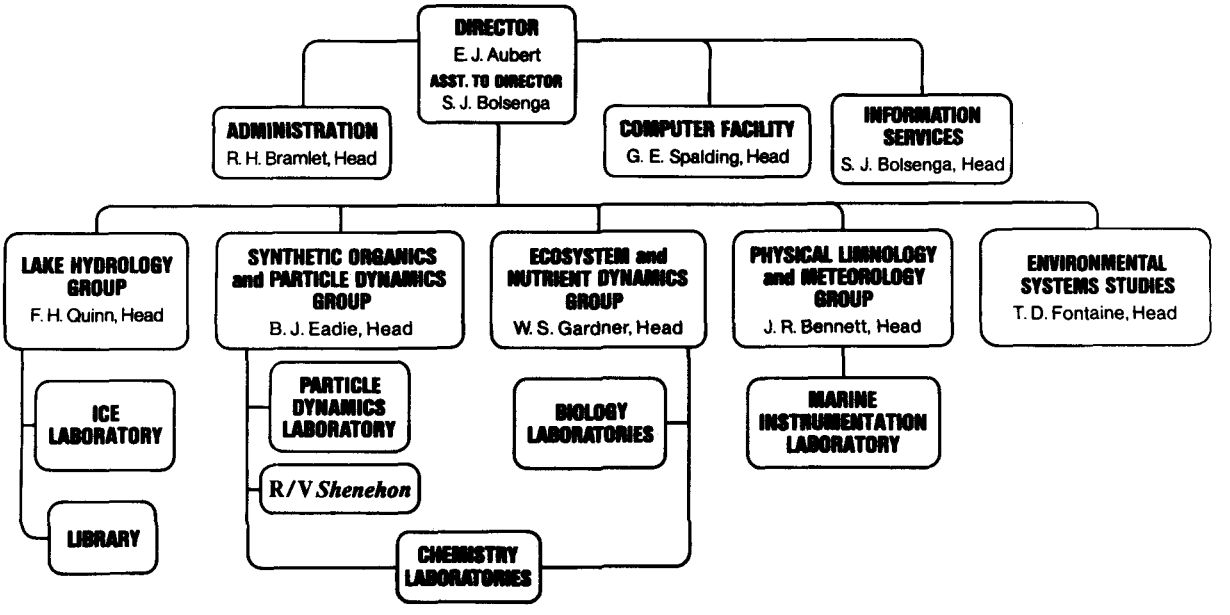
GLERL Organization Chart



HIGHLIGHTS

For 10 years the Great Lakes Environmental Research Laboratory (GLERL) has been conducting research on significant processes and problems in the Great Lakes Region and other coastal and estuarine waters. GLERL research is diversified in form. Process research is aligned along four primary disciplines. But problem-oriented multidisciplinary research, using staff from more than one group, is also conducted. The in-house research program is supplemented by grants and contracts with private institutions. In turn, GLERL supports the efforts of other government agencies. GLERL research products are disseminated by publications or presentations and discussions at scientific and user meetings. During FY 1984, 51 papers authored by GLERL staff and 15 papers by contractors were published, and 49 papers prepared by GLERL staff were presented at meetings.

Research

The GLERL research program continues to evolve. Some major research accomplishments during the past fiscal year are indicated below.

- Ammonium excretion rates by several life stages (nauplii to adult) of the marine copepod *Eucalanus pileatus* were measured in two controlled food environments to assess the importance of life stage and food abundance to nutrient regeneration by zooplankton. When food was abundant, animals of all stages released ammonium at similar rates per unit ash-free dry weight, but at low food levels, late-stage juveniles and adult females released ammonium significantly more slowly than did nauplii or early stage juveniles.
- A Temperature-Diffusion Model was calibrated for a 20-year data set from Lake Washington, and estimates of vertical turbulent diffusion coefficients were completed. These diffusivities were used to model a nearly conservative substance—total alkalinity.
- A final report documenting the results of the major, year-long (1979-80) Lake Erie experiment using current-meter moorings was published. Analyses of thermistor chain profile data define the seasonal development and decay of stratification in the central basin and its response to storms.
- Studies have been conducted with current drifters in Lake Michigan to determine whether they can be used confidently as indicators of particle trajectories. A cluster of three drifters was deployed in a patch of rhodamine B dye. Separation of the centroid of the drifters and the dye center of mass was compared with wind data and used to calculate the slippage velocity.
- Recent laboratory experiments of the sorption process have determined the equilibrium partition coefficient (Kp) for a series of radiolabeled organic compounds ranging over four orders of magnitude in solubility onto the settling particulate matter collected monthly in offshore Lake Michigan sediment traps. Initial results indicate there is less than an order of magnitude change in Kp on the settling material over a single season.
- The survival and viability of the meroplanktonic diatoms *Melosira granulata* are being investigated in cooperation with University of Michigan scientists. This diatom remains viable for periods of at least 100 years while buried in the sediments and is capable of photosynthesis immediately upon exposure to light.
- The effects of nutrient patchiness on the composition of natural assemblages of algae were examined in laboratory experiments. Patchy supply resulted in dominance of a single blue-green algal species, whereas homogeneous supply resulted in co-dominance among the blue-greens, flagellated greens, and a diatom. These results demonstrate that the mechanism of nutrient supply can affect algal composition in the Great Lakes.
- A series of articles to synthesize knowledge and recent Lake Erie research accomplishments is being prepared jointly by GLERL and the Canada National Water Research Institute for publication in a special issue of the *Journal of Great Lakes Research*. A key paper will be a synopsis of the Lake Erie current-meter studies described above. A second paper will discuss analyses of the current-meter measurements done with a new objective analysis method and compare analyses with the results of a time-dependent numerical circulation model.
- A two-dimensional, vertically integrated circulation model has been used to study the importance of Ekman layer physics to the sedimentation patterns of southern Lake Michigan. One experiment used a circularly symmetric idealization of Lake Michigan's southern basin, a "typical" Great Lakes storm system, and a sediment source assumed uniform over the surface of the idealized lake. The results of a comparison of sediment deposition and erosion for models with and without Ekman physics confirm the theory that deposition tends to occur preferentially in cyclonic gyres.
- Correlation of benthic invertebrate abundance with measurements of nutrient release from intact sediment cores indicated that *Pontoporeia hoyi* may suppress silica release from sediments by burying the silica-rich surficial floc layer. This increased understanding will lead to more accurate models of the dynamics of nutrient release from Great Lakes sediments.
- Approximately 100 sediment traps were deployed and retrieved throughout Lake Michigan over the past year to determine the rates of settling of particulate matter and the fluxes of various contaminants. Initial results indicate that during stratification traps deployed offshore above or immediately below the thermocline are useful in estimating the new load (predominantly atmospheric) of material entering the lakes, and that during the unstratified period (November-June) resuspension is very great and provides a

mechanism for intimate coupling between the water column and recent sediments.

- Since most synthetic organic contaminants of concern adhere to particles and rapidly settle out into the sediments, the process of direct uptake by benthic invertebrates and transfer up the food chain to higher trophic levels is of major concern. Field results indicate that the common benthic amphipod *Pontoporeia hoyi* and oligochaete worms have significantly higher concentrations of polycyclic aromatic hydrocarbons (PAH) than do the surrounding sediments.
- The field portion of the Hi-Sed program has been completed for all five Great Lakes with the collection of cores from the regions of high, recent sediment accumulation in Lake Superior. Results have supported previous reports of a near-surface layer of mixed sediments. A major advance is the development of a nonsteady-state model and an associated computer program to simulate the effects of zoobenthos feeding and mixing on sediment tracer and contaminant profiles.
- A qualitative study of the temporal impacts of St. Clair River dredging on the flows in the St. Clair, Detroit, and Niagara Rivers and on the levels of Lakes Michigan-Huron, St. Clair, and Erie has been completed. The impact was greatest near the end of the dredging project for the St. Clair and Detroit Rivers and Lake St. Clair; this time of maximum impact lagged by about a year maximum impacts on Lake Erie and the Niagara River.
- A series of software packages, from data acquisition through model application, has been developed for ultimate use in generating deterministic runoff outlooks in near real-time. Development of the near real-time data acquisition system is continuing. Procedures have been initiated for including substantial amounts of Canadian meteorological data on the National Weather Service (NWS) weather wire and for the rapid receipt of data from second-order stations.
- Equivalent channel sections based on measured hydrography have been used to revise the Upper Detroit River Unsteady Flow Model. The model is currently being modified to include the various islands and channels. A new dynamic calibration procedure has been developed; it will significantly improve model results over those obtained from the static calibration procedure that has been used by all agencies in the past.
- A computer forecast package for Lake Superior basin runoff was developed that uses near real-time meteorological data to produce operational outlooks of value to lake level regulation. The package is composed of (1) data acquisition and reduction by a computer system that monitors interagency data links and updates provisional meteorological station networks, (2) the automatic computation of weighted sub-basin meteorological data files from the provisional station data, and (3) the semiautomatic distributed-parameter application of GLERL's Large Basin Runoff Model with suitable graphic interpretations.
- Data analysis and evaluation from the 1983 Lake Michigan Ecosystem Experiment was completed for water column nutrients, sediment trap chemistry, community level phytoplankton growth, and zooplankton grazing. This data set is unique because all the processes known to contribute to growth and loss of phytoplankton were measured simultaneously from the same water mass. Transparency of the water column has increased dramatically over the last year and suggests that the quality of water in the lake has improved a great deal. One hypothesized reason for this change is an increase in large cladocerans and a reduction in algae due to increased salmonid predation on, and rapid decline of, the alewife population.
- Studies of primary production in Lake Superior demonstrated that abundant small cyanobacteria (bacteria-sized phytoplankton) account for about one-half of the total primary production and exhibit growth rates of two to four divisions per day. Microzooplankton, such as protozoa, appear to be consuming this production. These very small organisms constitute an important, but previously unrecognized, part of the Lake Superior food chain.
- Phosphate uptake kinetics and computer simulations suggest that mixed microbial assemblages have half-saturation constants from two to three orders of magnitude lower than those shown previously in laboratory cultures. Phosphorus stress apparently induces micro-organisms to produce high-affinity uptake systems, thus allowing relatively rapid growth rates at low ambient phosphate concentrations. This helps explain the controversial paradox of high phytoplankton growth rates when phosphate concentrations are very low in lake and ocean waters.
- The relation between zooplankton feeding rate and food concentration for laboratory cultures of algae and for lake seston was determined in a study to test the Effective Food Concentration Model. Results validated the model and demonstrated that feeding rates determined with algal cultures cannot be applied directly to lake seston.
- Frame-by-frame analysis of 140 films of copepod feeding showed that the copepod *Diaptomus sicilis* is not an optimal forager (i.e., it does not necessarily select the most abundant available food), and supported the accuracy of the Effective Food Concentration Model. This information is needed for a quantitative understanding of how zooplankton obtain food and affect the composition of phytoplankton seston in the Great Lakes.
- Film analysis also showed that both the current field produced and the feeding behavior of *Diaptomus sicilis* differ from those of marine copepods. These results explain why *D. sicilis* can specialize on small particles for food and also why, for it, there is an invariant relation between particle selection and particle size. Based in part on these results, a model is being developed to describe the feeding rate of this copepod in mixtures of various particles such as are found in lake water.
- Calcite particles at the same concentration and size found during calcite whiting in Lake Michigan were found to depress

zooplankton grazing significantly. This depression was greater than that observed for clay particles at the same concentration. Whitings in fecal pellets accelerate the downward flux of the pellets up to tenfold.

- Nutrient transformation studies on silty Lake Michigan sediments indicate that nitrogen released by macroinvertebrates as ammonium is rapidly converted to nitrate (nitrification) and then converted to nitrogen gas (denitrification) by microbes. These processes must be quantified to determine the importance of sediment mineralization as a nutrient supply mechanism in the Great Lakes.
- Microcosm experiments indicate that invertebrate mixing enhances phosphorus release from sediments, but that mixing beyond a threshold level has no effect on the rate of phosphorus release; i.e., phosphorus release is not related to animal density. This enhanced phosphorus release may explain why disproportionately high levels of primary production have been observed for nearshore regions. These studies are part of an effort to quantify the importance of aerobic sediments as a source of phosphorus in Lake Michigan.
- Microbial transformation rates of labile organic materials dissolved in lake waters were examined by measuring concentration decreases of low levels of amino acids added to Lake Michigan water. Amino acid turnover was slow during summer in offshore Lake Michigan.
- First-order estimates of bacterial growth in the Lake Michigan Ecosystem Experiment also indicate that turnover of organic carbon by bacteria is slower than previously expected. These results suggest that bacteria may play a less important role in nutrient and energy cycling in the nutrient-poor lakes than in nutrient-rich systems.
- A wind-generated-wave prediction model has been developed theoretically and tested numerically against a 2-month data set from a GLERL tower and a NOAA Data Buoy Center (NDBC) NOMAD buoy in Lake Erie with remarkable agreement between observed and computed wave height. Validation and comparison with NWS operational forecast procedures are under way. Interactive wave prediction software, implemented on the GLERL VAX 11/780 computer, has been made available to five Great Lakes NWS Forecast Offices to facilitate model validation as a local marine weather forecast tool.
- The 1981 Lake Erie Coastal Boundary Layer Experiment data have been used to examine the probability distributions for both deep and shallow water waves. Results show that both the Rayleigh distribution for wave heights and the Longuet-Higgins distribution for wave period overpredicted the highest waves in a record and underpredicted the intermediate waves. By applying a two-parameter Weibull distribution to both height and period data and using parameters determined from the data, the accuracy of the fit was improved significantly.
- The representation of shallow water wave spectra is a basic tool for linking theoretical analysis with measurements. The GLERL generalized spectrum representation yields excellent agreement between model results and measurements for both deep and shallow water waves.
- Four satellite-tracked buoys deployed in ice in the central and eastern basins of Lake Erie during January 1984 revealed continuous ice movement, often at surprisingly high speeds. Flights were made every 2 weeks to observe ice conditions and make ice measurements in the vicinity of each buoy.
- The GLERL Hydrologic Response Model was used to predict the impacts of the record St. Clair River ice jam on lake levels and flows. The analysis and results received nationwide attention.
- The recently published *Great Lakes Environmental Research Laboratory Ice Atlas,* an official NOAA atlas, will be the standard reference on Great Lakes ice cover for some years to come. It documents improved understanding of the Great Lakes ice cycle.

Information Services

- During the past year, more than 4,200 research products were provided in response to almost 2,000 documented requests. Of these, 27% came from institutions of higher learning, 12% from private citizens, 31% from foreign government agencies, 7% from industry and private organizations, 16% from U.S. Federal Government agencies, and 7% from State Governments. This was in addition to regular mailings to those interested in receiving semiannual lists of publications and any of the five types of GLERL publications.

International and Interagency Activities

- GLERL staff were active on several IJC boards and committees including the Levels and Flows Advisory Board; the Technical Information Network Board; the Health of Aquatic Communities Work Group; the Task Force for Lake Michigan Surveillance; the Task Force for In-Place Sedimentary Contaminants; the St. Marys, St. Clair, and Detroit Rivers and Lake St. Clair Task Force of the Surveillance Work Group; the Aquatic Ecosystem Objective Committee Work Group; the Modeling Task Force of the Science Advisory Board; and the Lake Erie Task Force of the Surveillance Work Group.
- A GLERL staff member serves on the Natural Resources Management Committee (Subcommittee on Land and Air, Subcommittee on Water) of the Great Lakes Commission.
- GLERL staff participated in the activities of the International Association of Sediment Water Science, the International Coordinating Committee on Great Lakes Hydraulic and Hydrologic Data, the Regional Response Team for Spills of Oil and Hazardous Substances, the Joint United States-Canadian Ice Information Working Group, the International Association for Great Lakes Research (President, Secretary), the Science Education Administration of the United States Department of Agriculture, NOAA-United States Geological Survey Coordinating Committee for Hydrologic Research, the International Association for Hydrologic Research, the Inter-

agency Great Lakes Hydromet Steering Committee, and the National Research Council Panel on Niagara River Ice Boom Investigations.

- The laboratory is participating in the planning phase of an international (United States-Canada) and interagency, multiyear study on water quality and marine pollution problems in the upper Great Lakes connecting channels. The United States agencies are the Environmental Protection Agency (EPA), NOAA, the Corps of Engineers, the Fish and Wildlife Service, and the Michigan Department of Natural Resources. The Canadian agencies are the Environmental Protection Service, Department of the Environment; the National Water Research Institute, Inland Waters Directorate; the Department of Fisheries and Oceans; and the Ontario Ministry of the Environment.
- Activities involving participation with other NOAA units included the Marine Environmental Quality Task Force, the Quality Assurance Working Group, the Manned Undersea Research and Technology Program—National Marine Fisheries Service, the New Bedford Harbor PCB Contamination Assessment Team, the Marine Environmental Quality Review, and the Estuarine Review. GLERL staff participated in several Sea Grant activities including the University of Wisconsin Site and Subprogram (Microcontaminants) Reviews and the Ohio State University Site Review. In a joint program with the Ohio State Sea Grant, GLERL is developing a recreational atlas for Lakes Erie and St. Clair. GLERL has also worked extensively with the NWS in the United States and the Atmospheric Environment Service in Canada on an operational, interactive wave model.
- GLERL scientists were also active in providing information to several local agencies, such as the Kalamazoo River Preservation Agency and the Technical Advisory Committee of the Huron River Watershed Council.

Facilities

- Two major types of compounds are analyzed by GLERL's chemistry laboratories: trace synthetic organics and nutrients. The synthetic organics, primarily PAH, are extracted from various ecological matrices, cleaned, and analyzed on glass capillary gas chromatographs. These chromatographs are currently being interfaced with GLERL's VAX 11/780 to upgrade data analysis capability.
- The uptake and release rates of selected PAH by benthic organisms are being followed through use of carbon-14- and tritium-labeled compounds. Compounds are extracted, cleaned, and counted by liquid scintillation. Numerous water samples from Lake Michigan were analyzed for various forms of phosphorus and silica and other water quality indicators as part of the Lake Michigan Ecosystem Experiment. The purpose was to define processes contributing to phytoplankton dynamics, bacterial growth, and ecosystem carbon flow in Lake Michigan.
- The biology laboratories are now in the process of acquiring and installing microcinematography apparatus similar to that used at the Skidaway Institute of Oceanography to make the first observations of the feeding processes for a freshwater copepod. This will be used to study and quantify the feeding mechanisms of other Great Lakes zooplankton. The process of zooplankton feeding and other zooplankton-algal interactions occupies a central role in models of eutrophication and toxic organic cycling.
- The GLERL computer facility supports data acquisition, data reduction, graphics, and modeling applications for scientists and technicians in the research groups. A VAX 11/780 superminicomputer supports general purpose applications (e.g., graphics, data reduction and analysis, modeling, word processing) and a Hewlett-Packard 9603 minicomputer supports data acquisition tasks. Within a year, a link to the National Bureau of Standards (NBS)-ERL Scientific Computing Facility Cyber 205 in Gaithersburg, MD, is planned.
- The RV *Shenehon* is the primary platform used in support of open lake field investigations. 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. An onboard laboratory facilitates onsite physical, chemical, and biological experiments. 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.
- The marine instrumentation laboratory staff selects, calibrates, repairs, and, when necessary, adapts or designs instruments to collect data in the lakes and their environs. This past year, a Wave Rider Information Processing Station (WRIPS) buoy was acquired to process wave statistics and spectra and transmit data to a GOES satellite. In addition, several data acquistion systems using a Hewlett-Packard 75 calculator were acquired for use in the field.
- GLERL library staff support laboratory activities by maintaining a tailored research collection and offering special retrieval services when the collection cannot meet the documentation or information needs of the researchers. The GLERL library made its collection more readily available to scientists with the recent improvements in the GLERL Library Automated Retrieval System (GLARES) and its implementation on the VAX 11/780 minicomputer. The system now permits browsing, boolean logic, cross references, and multiple access points.

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. The work is organized into the areas of toxic organic cycling, the role of benthic invertebrates in the fate of pollutants, synthetic organic partitioning, lake particle flux dynamics, and studies of early diagenesis in Great Lakes sediments.

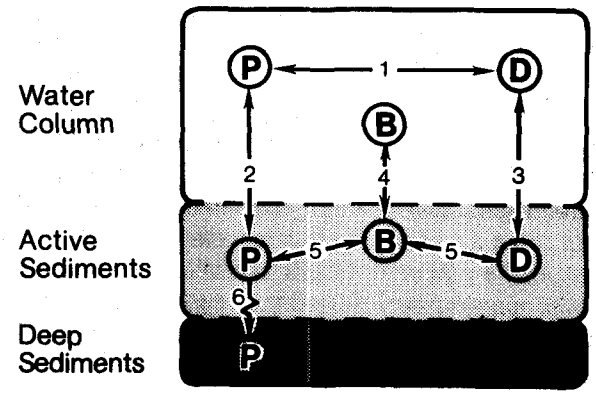
With the increase in population and industrial activities over the last half century, more human-induced pollution has been added to the Great Lakes. Since many of these contaminants are resistant to decomposition and are foreign and/or toxic to the biota, precise information on their behavior, fate, and effects is necessary to develop and implement cost-effective management strategies. The goal of this program is the development of the necessary tools (models, information bases, networks of experts, etc.) to enable us to predict accurately the consequences to the Great Lakes ecosystem of alternative toxic management decisions. This requires a systematic understanding of the major ecosystem processes that affect or are affected by the substance(s) under consideration.

Since its creation in 1974, GLERL has specialized in the design and development of ecosystem models that simulate or predict the physical, chemical, and biological responses of the Great Lakes to imposed stresses. In this program, efforts to date have focused on the development of system models, supported by the specific process research required to improve, calibrate, and/or validate models that simulate the behavior and fate of persistent contaminants. Modeling-experimental interactions enables us to make stepwise improvements in our understanding of the ecosystem's response to contaminants. Such information is necessary to identify which contaminants pose the greatest threat to the environment, which organisms or regions within the lakes are most affected, what can be expected in the years ahead, and what can be done to reduce the level of ecosystem stress.

In August 1979, GLERL began a research program in cooperation with the Office of Marine Pollution Assessment, NOAA, recently renamed the Ocean Assessment Division (OAD) of the National Ocean Service, NOAA. The purpose of this program is to develop the ability to predict the environmental consequences of persistent synthetic organic contaminants in the Great Lakes ecosystem. The assurance of a long-term cooperative program with the OAD has allowed GLERL to develop cooperative agreements with several research institutions and to pursue a comprehensive research program focused on a few questions regarding the flow of selected organics within the Great Lakes. The results will be transferable to coastal marine systems.

A predictive capability requires models. Therefore, an in-house modeling team, consisting of chemical, toxicological, ecological, and physical scientists, has been established. This modeling group is supported by researchers working on primary ecosystem processes.

Sediment-Water Process Model



Simplified conceptual model of processes associated with the behavior of toxic organic contaminants. P represents particle phase, D represents dissolved phase, and B is an abbreviated food chain. The six process arrows are (1) sorption, (2) settling and resuspension, (3) transport and dispersion, (4) benthic food chain dynamics, (5) benthos-sediment interactions, and 6) bioturbation and burial. The fate of toxic materials entering the Great Lakes has important implications for human health.

Early GLERL modeling results indicated that the contaminant concentrations in biota appear to come into relatively rapid equilibrium with the water column and that water column concentrations are mediated by sorption, settling, and resuspension. Benthic organisms appear to be somewhat different—they seem to acquire a substantial portion of their contaminant body burden from sediments. Thus they can be an important vector in transferring sediment-associated contaminants up the food chain.

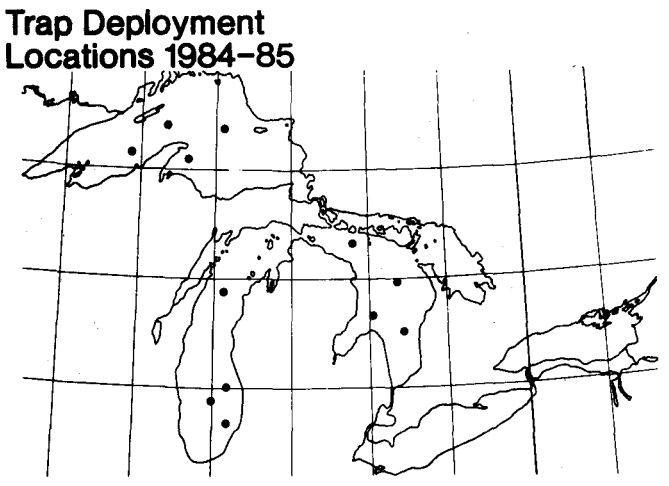
Settling and Resuspension Studies

Most polluting and enriching substances in the aqueous environment have a strong affinity for fine suspended particles; thus their transport and fate are dictated by the fine particle dispersal system. Total suspended matter (TSM) plays a vital role in the solution chemistry of the Great Lakes. TSM sorbs pollutants from the water, 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 into overlying water and exposing the ecosystem to "trapped" contaminants. It is necessary at this time not only to know the concentrations of TSM and associated contaminants and nutrients, but to determine the net flux of these substances into the lakes and sediments and the rates of reentrainment.

Some previous GLERL studies with sediment traps have shown open Lake Michigan metalimnetic TSM flux to be about 0.7 grams per square meter per day during the stratified period. This agrees well with lead-210 and cesium-137 sediment accumulation rates from the same region, indicating that, during the period of stratification, GLERL near-surface traps measure something approaching net downward flux of suspended material and its associated contaminants. For storm and nonstratified periods, measurements show a TSM flux of about 4.6 grams per square meter per day.

During the past year, GLERL scientists deployed and retrieved approximately 100 sediment traps throughout Lake Michigan. From measurements of the material in these traps, it is possible to estimate the rates of settling of particulate matter and, after chemical analysis, the fluxes of various contaminants. Sample analysis for several contaminants is currently underway. There have been two major results of initial analyses of the data. First, it appears that traps deployed offshore above or immediately below the thermocline during the period of stratification are useful in estimating the new load (predominantly atmospheric) of material entering the lakes. This extremely important measurement is a notoriously difficult estimate to make by other techniques. Second, these trap studies have shown that resuspension during the unstratified period (November-June) is very large and provides a mechanism of intimate coupling between the water column and recent sediments.

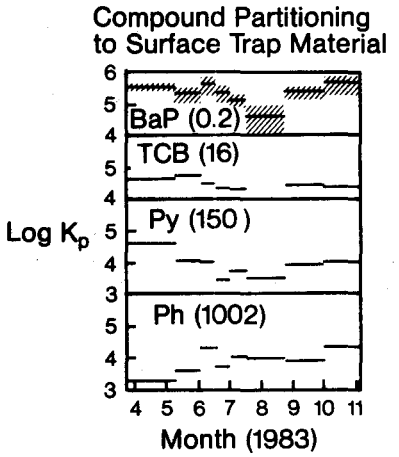
In an ongoing extension of this work, profiles of sediment traps were deployed (July) in offshore Lakes Superior, Huron, and Michigan. These traps were retrieved in September and have now been redeployed for winter collection.



GLERL sediment trap deployment locations for 1984-85. Traps collect material settling out of the water column, which can be analyzed for various compounds. Sediments can serve as sources and sinks for contaminants and nutrients.

Sorption Studies

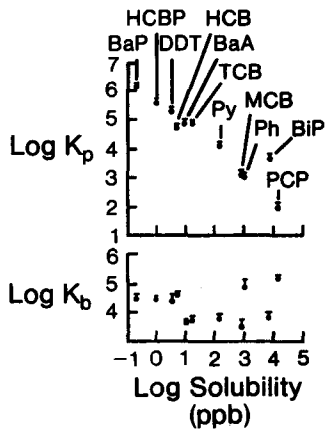
In GLERL sorption modeling efforts, it is assumed that adsorption (probably) and desorption (possibly) occur at fast enough rates that an equilibrium approach is acceptable. In that case, an equilibrium partition coefficient (Kp) is defined as the ratio of the particle-associated contaminant concentration (ppm) to the dissolved contaminant concentration (ppm). Kp has been shown to be inversely proportional to compound solubility and concentration of substrate and proportional to the organic carbon content of the substrate. Recent work has concentrated on making laboratory measurements of Kp of the settling particulate matter collected monthly in our offshore Lake Michigan sediment traps. There were 11 such collections in the past year, and studies of them have provided much insight into the vertical flux of particulate matter in the lake. Unpoisoned samples of these trap materials were used as substrates for laboratory measurements of Kp with a spectrum of organic compounds. The seasonal variation appears to be about one order of magnitude. Further analysis of these data is currently under way.



The seasonal partitioning coefficient (Kp) for benzo(a)pyrene, tetrachlorobiphenyl, pyrene, and phenanthrene on near-surface collected trap material from Lake Michigan. Kp is the ratio of concentration on particles to dissolved compound. Numbers in parentheses are compound solubilities in parts per billion. The hatched areas indicate 1 standard deviation.

In addition to these measurements, it has been shown that a substantial fraction of the operationally defined "dissolved" contaminant is weakly bound to natural dissolved organic matter (DOM), and it appears that this bound material is not bioavailable, at least to the common benthic amphipod *Pontoporeia hoyi*. The bioavailability of contaminants has important implications for their transfer through the food chain. Studies indicate that the partitioning of contaminant organics onto DOM is not related to compound solubility. The Kp and Kb (defined as the ratio of

the DOM-associated contaminant concentration to the dissolved contaminant concentration) for a wide spectrum of organics illustrate the strong differences in the solubility relationships. GLERL studies indicate that Kb is much more closely related to differences in the characteristics of the DOM; molecular weight appears to be an important factor. Laboratory and field experiments are currently being conducted in this area of research.



Partitioning (Kp) and binding (Kb) coefficients of a spectrum of radiolabeled contaminant organic compounds to Lake Michigan sediments. Kp is the likelihood that the compound will sorb onto particles and Kb is the likelihood that the compound will sorb onto organic matter. The compounds (in order of increasing solubility) are benzo(a)pyrene, hexachlorobiphenyl, DDT, hexachlorobenzene, benzo(a)anthracene, tetrachlorobiphenyl, pyrene, monochlorobiphenyl, phenanthrene, biphenyl, and pentachlorophenol. It is important that there be additional research on the relationship between Kp and Kb because it has important long- and short-term impacts on bioavailability.

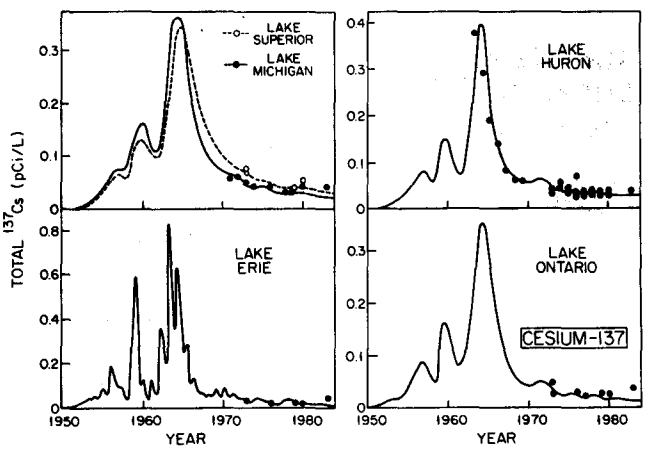
Transport and Dispersion

Transport and dispersion studies are being conducted jointly with the Physical Limnology and Meteorology Group and are partially described in that section. Satellite-tracked drifter buoys have been employed to refine the Pathfinder spill model. However, before any buoy configuration can confidently be used in Lagrangian studies, its effectiveness in tracking water parcels must be known. At this time, there is no buoy that is 100% effective. The combination of wind, wave, current shear, and buoy hydrodynamics influences drifter tracks, hampering identification of water particle trajectories.

The appropriate value for wind slippage as a percentage of the wind vector for the drifters was determined from theory to be 0.5%. Experiments designed to test this hypothesis were conducted during summer 1983 and 1984 on Lake Michigan. Preliminary results indicate that the behavior of the mini-TOD (Polar Research Laboratory, Inc.) drifters is complex and that current theory is of little use in explaining the divergence of dye and buoy trajectories except under light wind conditions. The experiments consisted of monitoring the spatial separation of the centroid of a drifter cluster and the center of mass of a patch of fluorescent dye.

Another accomplishment in this area is the development and calibration of the Coupled Lakes Contaminant Behavior and Fate Model (CLM). This model uses monthly rates of atmospheric deposition to the surface and drainage basin of each lake to compute concentrations in the well-mixed water column and resuspended sediments. The special properties of the fallout radionuclides and excellent quality of the records of their loadings to the Great Lakes make them attractive for calibration of long-term response models such as the CLM. Records of the monthly deposition of strontium-90 at some sites in the Great Lakes Region are nearly continuous over a 30-year period. The rate of deposition of cesium-137 may be reliably inferred from the strontium-90 data. Tributaries add very little strontium-90 (and considerably less cesium-137) to the total inventory in the water. Some data agree poorly with the model, especially for Lake Huron, but it should be noted that not all reported data are of comparable quality or accuracy. Some of the early strontium-90 data were obtained from water subjected to treatment and filtration processes and thus underestimate actual amounts present. Strontium-90 is only weakly associated with the particulate phase and is essentially conservative in each of the lakes.

In contrast to strontium-90, the other nuclide of interest (cesium-137) is strongly particle associated. At present, only a small fraction of the activity in each is in the water. What



Response of the five Great Lakes to loadings of the fallout radionuclide, cesium-137. Measured concentrations are indicated as closed circles (open for Superior). The curves are based on the Coupled Lakes Contaminant Behavior and Fate Model as calibrated by strontium-90. The persistence of cesium-137 in lake water into the 1970's and 1980's is due to resuspension of the radionuclide from bottom sediments.

little is left in the water appears to be largely the result of resuspension. Hence, the particle-associated radionuclides serve, in principle, to determine the magnitude of resuspension and the size of the pool of resuspendable sediments. These values can be determined with minimum ambiguity because, for the radionuclides, there are no degradation terms except for radioactive decay, which is precisely known. For lakes other than Lake Huron, the only data are from the 1970's, when there was relatively little change in concentrations. The Lake Huron data, covering a 34-year period, provide the best confirmation of the suitability of the CLM. The model can eventually be used for the simulation and prediction of contaminant organics.

Role of Benthic Invertebrates in the Fate of Pollutants

It is known that most contaminants of concern adhere to particles and rapidly settle out into the sediments. Their reintroduction into the water column via resuspension has been mentioned above. 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.

A model being developed under contract uses the concept of bioenergetics to propagate caloric energy (and contaminants) up the food chain. Results from model calibration runs for alewife, a midtrophic level planktivore, indicate that a substantial fraction of the fish's PCB body burden is derived from feeding on benthos. Major source pathways are direct uptake from water and consumption of the benthic amphipod *Pontoporeia hoyi;* fish mortality and elimination to the water are major loss pathways for PCB's.

PERCENTAGES OF TOTAL INFLUX AND OUTFLUX OF PCB IN THE LAKE MICHIGAN ALEWIFE POPULATION (133 kg PCB's)

Influx	Percentage	Outflux	Percentage
water	49%	elimination	49%
P. hoyi	24%	mortality	48%
other food	27%	spawning	3%
	100%		100%

The relative importance of these pathways is different when one examines the total flux through an individual alewife averaged across 8 years of life.

TOTAL FLUX OF PCB THROUGH AN INDIVIDUAL ALEWIFE WHEN AVERAGED ACROSS 8 YEARS OF LIFE

Influx	Percentage	Outflux	Percentage
water	43%	elimination	87%
P. hoyi	39%	(8-yr old survivors)	
other food	18%	spawning	13%
	100%		100%

Juvenile alewives do not spawn, and a smaller fraction of their diet is *Pontoporeia hoyi* than in older, adult alewives. The relatively large biomass of younger alewives in the population thus reduces the population's average spawning losses and benthic food chain uptake of PCB's.

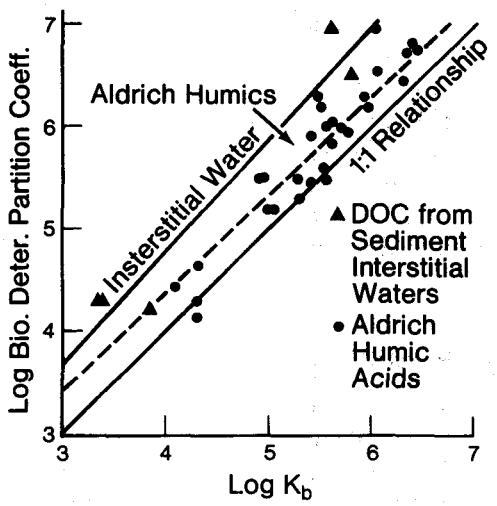
It is important to consider such population averages when assessing the contaminant flux through an aquatic ecosystem. Extrapolation from an "average" individual can result in biased estimates of the relative importance of different pathways of contaminant flux through an entire population. This contaminant model for alewives is currently being linked to a similar model for coho salmon. Also currently underway is an uncertainty analysis of the bioenergetics-based model of contaminant uptake.

Benthos-Sediment Interactions

Benthos-sediment interaction studies are designed to determine the uptake, depuration, and biotransformation rate constants for various toxic organics in Great Lakes invertebrates and to determine the empirical relationships between the rate constants and environmental parameters such as temperature, pollutant concentration, and sorption to dissolved and particulate organic matter. The past year's work has focused on alteration of bioavailability in the presence of dissolved organic matter. Bioavailability of organic xenobiotics from water is reduced in the presence of dissolved organic carbon (DOC) as measured by short-term static uptake experiments with the dominant Great Lakes benthic organism, the amphipod *Pontoporeia hoyi.*

The bioavailable fraction is the "freely dissolved" compound, while the material associated with DOC is apparently not bioavailable. The total body burden in the *Pontoporeia hoyi* can be accounted for from the uptake rate determined in the absence of DOC and the "freely dissolved" concentration based on the partition coefficient determined by the reverse-phase technique. The partitioning of organic xenobiotics to the DOC, determined biologically, correlated with the partitioning determined by reverse phase to yield a slope of the regression line of one. The intercept for the regression line indicated that there was a constant bias between the two methods of a factor of approximately three,

with the biologically determined partitioning greater than that determined from the reverse-phase methodology. Therefore, the reverse-phase-determined partition coefficient can be used to predict the bioavailable concentration of organics in the presence of DOC under the conditions that have been currently explored. Further work with other organisms, different natural DOC, more compounds, and greater lengths of exposure will be necessary to describe fully the usefulness of the reverse-phase-determined partition coefficient to predict the bioavailability of organic xenobiotics. Also, the binding to particulate organic carbon can be expected to influence the bioavailability of organic xenobiotics as much as DOC, and additional work is required to determine the influence of particulate sorption on bioavailability.



Log of Kb (the partition coefficient determined by reverse phase) versus the log of the partition coefficient determined from the uptake kinetics for binding or sorption of organic xenobiotics (material foreign to the ecosystem) to both Aldrich humic acids and natural dissolved organic matter, both measured as dissolved organic carbon (DOC). The two methods of determining Kb agree very well; thus if Kb determined by reverse phase is known, the log of the biologically determined partition coefficient can be predicted accurately.

The seasonal toxicokinetics of PAH to *Pontoporeia hoyi* are currently being studied with measurements of sorption to DOC, lipid content of the animals, and organism size. The thermal dependence of the kinetics is also under study. Preliminary results indicate that the major factor affecting the seasonal variation in the uptake rate constant is binding to DOC. This binding results in underestimates of the uptake rate constant for benzo(a)pyrene (BaP) by as much as 61%. Correction for sorption to DOC yields a seasonal variability profile for BaP that is similar to that for phenanthrene. The phenanthrene uptake rate constant is not subject to the influence of binding to DOC by more than 1-2% because of its lower octanol to water partition coefficient and the relatively low concentration of DOC in Lake Michigan water.

In conjunction with the studies of laboratory kinetics, the concentrations of PAH in *Pontoporeia hoyi*, water, and sediments from a field study site off Grand Haven, MI, are being determined over the course of the season in an attempt to validate the seasonal change in the animal concentration predicted from the Toxicokinetics Model. The water and sediment data will be used to determine the parameters for the GLERL Current Model to permit predictions of the animal concentrations. The Current Model will have to be modified to take into account the fraction of the compound found in the water that is bioavailable. Therefore, three-phase sorption studies are being performed over the course of the season to determine the bioavailable concentration of a suite of xenobiotics. It is hoped that this field validation will point out the areas necessary for further study and provide a better understanding of toxicokinetics as they apply to *P. hoyi*.

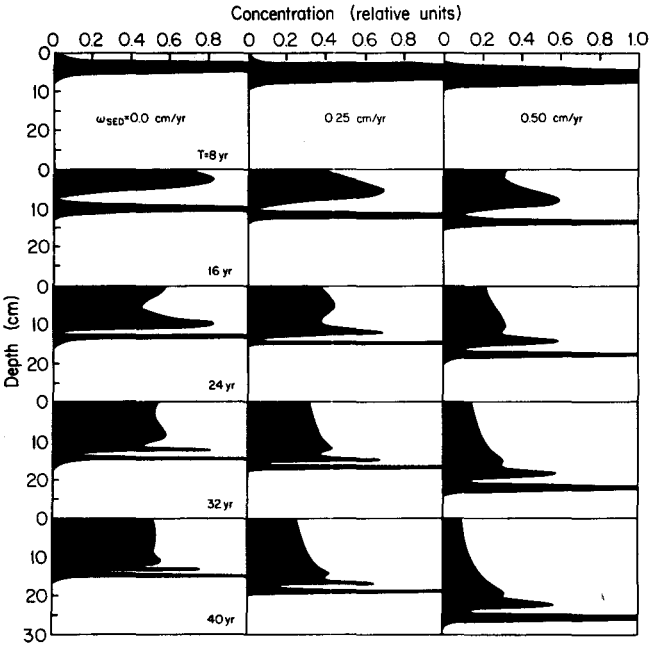
In addition to these studies, GLERL supports two contract projects on the development of techniques to measure chronic effects of PCB's and PAH on benthic invertebrates. The first of these involves the analysis of the distribution of free amino acids in the organism and changes when exposed to chemical stresses. The second procedure is designed to measure changes in the rate of activity (sediment mixing for the oligochaetes being tested) when exposed to chemical stress. In this procedure, a thin layer of cesium-137-labeled sediment is placed on top of a laboratory microcosm and the movement of the cesium is nondestructively monitored. Techniques have been refined and field work is currently underway.

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 have collected and partially analyzed sets of sediment cores from the areas of maximum accumulation in each of the five Great Lakes. This could only have been accomplished with the help of the Canada Centre for Inland Waters, which provided ship and technical support. The collection phase was recently completed with work in Lake Superior.

These cores have been carefully subdivided and distributed to 23 researchers for analysis. At this time, radionuclide measurements (for "dating" purposes) are nearly complete, and analysis of trace organics (PCB's, PAH, dioxin, other chlorinated hydrocarbons) and one selected metal (lead) on a few of the cores is complete. Results have supported previous reports of a near-surface layer of mixed sediments. A major advance is the development of a nonsteady-state sediment mixing model (currently being calibrated and tested), which 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 at once unique and 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, 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.



Time-lapse graphs of distributions resulting from introduction of a tracer pulse into a nondispersive system with localized conveyor-belt feeding by oligochaetes. In the left-hand panel, the sedimentation rate is zero. After 8 years, the pulse is buried, but has not encountered significant redistribution through feeding. By 16 years, the peak is in the feeding zone, and a surface peak has appeared and moved downward slightly. By 24 years, the secondary peak itself has encountered the feeding zone and produced a tertiary peak. Compression of the peaks occurs on burial as the particle velocity approaches zero at the base of the feeding zone. After 40 years, the tracer is almost uniformly mixed within the feeding zone except for remnant peaks at its terminus. In the middle and right-hand panels are distributions in systems with nonzero sedimentation rates (0.25 centimeters per year and 0.5 centimeters per year). While such reflections can, in principle, be produced by conveyor-belt feeding, they are not expected to occur much in practice since they are transient features obliterated by prolonged mixing and by both distributed feeding and dispersive processes. The model has also been applied to predict the effect of particle-selective feeding on radionuclide and pollen distributions used for sediment dating and to examine time resolution in nondispersive systems.

ECOSYSTEM AND NUTRIENT DYNAMICS

The "health" of the Great Lakes is evidenced by the quantity and composition of biota in them. Benthic organisms can indicate long-term trends in water quality, whereas pelagic biota reflect water quality more immediately. Planktonic plants and animals are of particular interest because they are at the base of the aquatic food chain. The ability to predict quantitatively types and amounts of these organisms in the lakes is important to assessing potential effects resulting from human activities or natural changes in lakes or marine coastal ecosystems. Basic research is needed 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 of physical (e.g., light, temperature, ice cover, water movements), chemical (e.g., nutrient supply and availability, toxic substances), and biological (e.g., food chain dynamics, predation, nutrient uptake, and regeneration) factors.

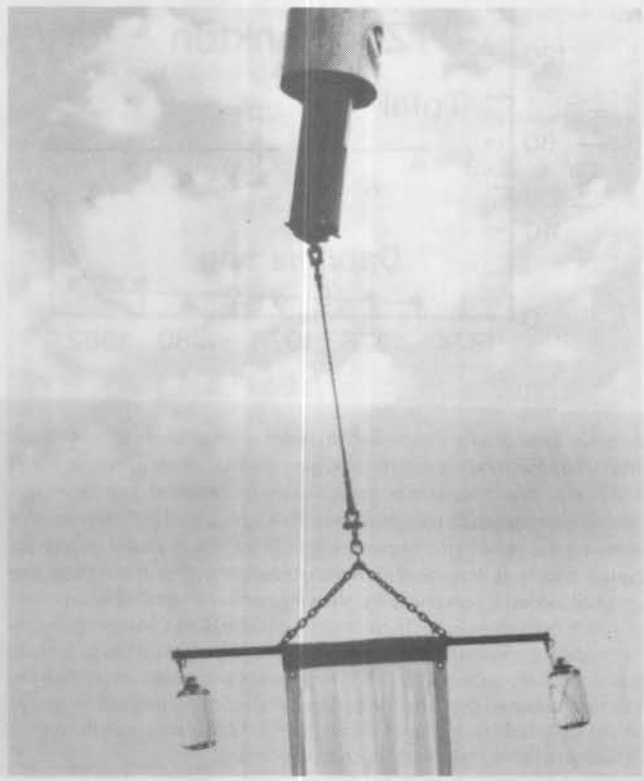
To predict accurately the effects of human activities on the Great Lakes or marine coastal ecosystems, critical factors affecting the biota must be recognized and quantified as parts of mathematical models of the system. Conceptual and mathematical models developed at GLERL and elsewhere have demonstrated that nutrient limitation is a major force 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 so that critical processes can be quantified and integrated into simulative and predictive models. The Ecosystem and Nutrient Dynamics Group is investigating factors controlling nutrient and energy cycling and ecological succession in the Great Lakes and is integrating experimental results into ecosystem models applicable to the Great Lakes, as well as to other freshwater and coastal marine ecosystems.

Pelagic Ecosystem Dynamics

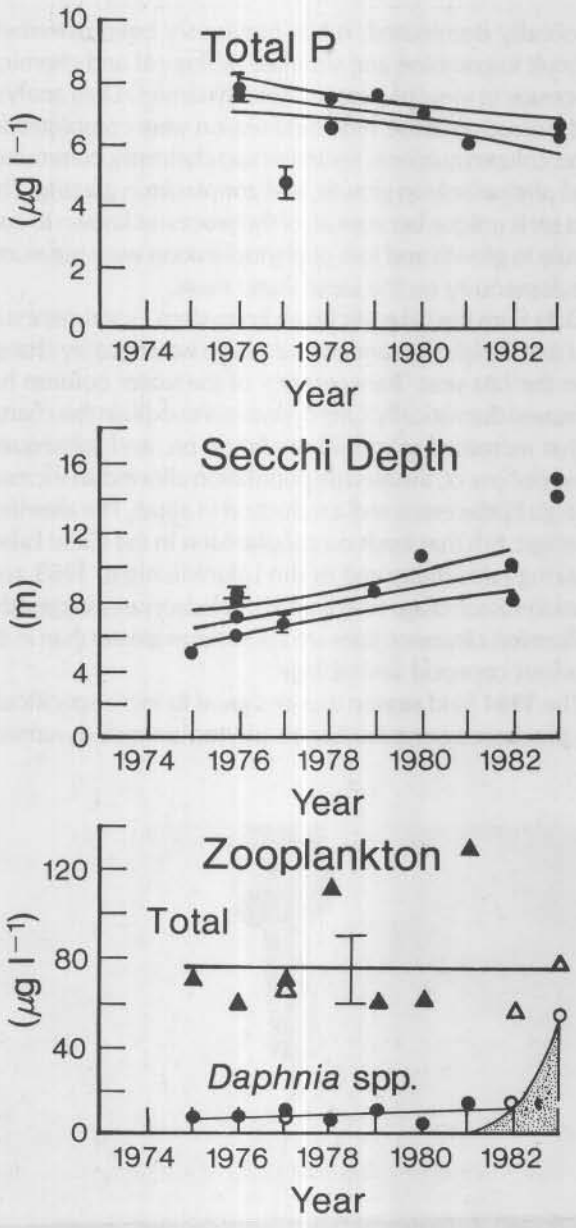
A comprehensive study on Lake Michigan (the Lake Michigan Ecosystem Experiment) was conducted in 1983-84 to define and quantify biological and chemical processes causing dynamic short-term and seasonal ecological changes in Lake Michigan phytoplankton. A free-drifting, satellite-tracked drogue was used for this Lagrangian study to minimize the complicating influence of physical transport of water on the interpretation of biological and chemical measurements. Because large aquatic systems such as the Great Lakes are physically dominated, it has previously been extremely difficult to combine and simulate biological and chemical processes in view of state-variable dynamics. Data analysis and evaluation of the 1983 field season were completed for water column nutrients, sediment trap chemistry, community level phytoplankton growth, and zooplankton grazing. This data set is unique because all of the processes known to contribute to growth and loss of phytoplankton were measured simultaneously on the same water mass.

Data from the Lake Michigan Ecosystem Experiment suggest that the lake has undergone a large water quality change over the last year. Transparency of the water column has increased dramatically. One hypothesis to explain this change is that increased salmonid predation on, and subsequent rapid decline of, the alewife population allowed an increase in large cladacerans and a reduction in algae. The alewife is a pelagic fish that feeds on zooplankton in the Great Lakes. Grazing rates measured in the Lake Michigan 1983 zooplankton assemblage (dominated by cladacerans) suggest that epilimnion clearance rates are 20-30 times greater than in the previous copepod assemblage.

The 1984 field season was designed to focus specifically on processes contributing to phytoplankton dynamics,



Satellite-tracked drifter buoy with attached window-shade drogue and bottles containing phytoplankton and lake water samples. This instrumentation was used to gather data for the phytoplankton growth part of the Lake Michigan Ecosystem Experiment.



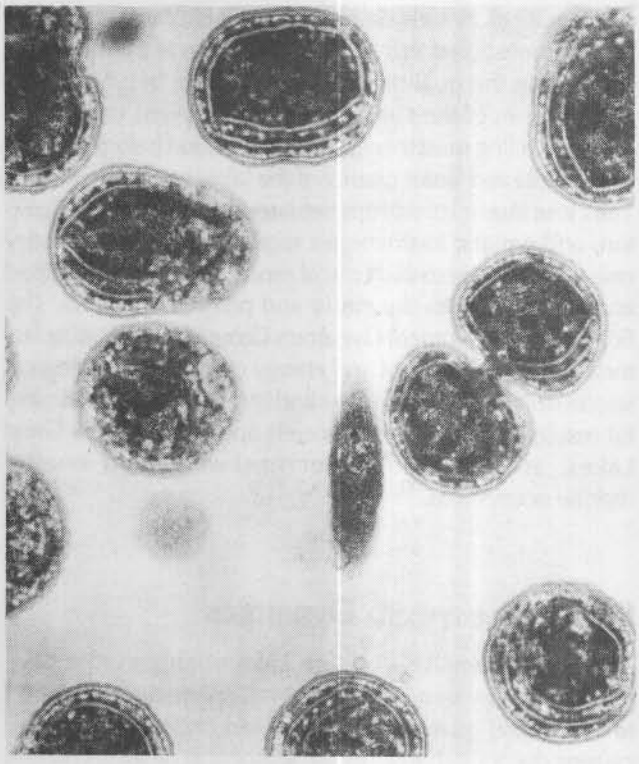
Total phosphorus (top), Secchi depth (middle), and zooplankton (bottom) data collected in Lake Michigan offshore of Grand Haven, MI, over the past decade. Total phosphorus has decreased gradually. Secchi depth (a measure of water clarity) also changed gradually until 1983, when in July and August it increased by over 4 meters from previous years. This increase may be attributed to increased grazing of phytoplankton by zooplankton and linked to a shift in the zooplankton community toward large-bodied *Daphnia pulicaria* (shaded portion of the bottom graph). One explanation for this shift is the final decline of the alewife, a planktivorous fish that prefers large zooplankton.

bacterial growth, and ecosystem carbon flow. As an outgrowth of the 1983 field season, aspects of the above dynamics were measured to provide a composite ecosystem perspective on the factors controlling phytoplankton, bacteria, and carbon (energy) flow. Methodology to determine extracellular release of organic matter by phytoplankton, its uptake by bacteria, and bacterial grazing by zooplankton was explored and applied to studies of these processes in Lake Michigan during the 1984 summer field season. Preliminary results suggest that phytoplankton release less than 10% of the carbon fixed by photosynthesis as dissolved organic products.

Microbial transformation rates of labile organic materials dissolved in lake water were also examined by measuring concentration decreases of low-level additions of amino acids in Lake Michigan water. Amino acid turnover was slow (less than 1 nanomole per liter per hour) during summer in offshore Lake Michigan, but cycling was more rapid in subsurface waters than in the nutrient-poor epilimnion.

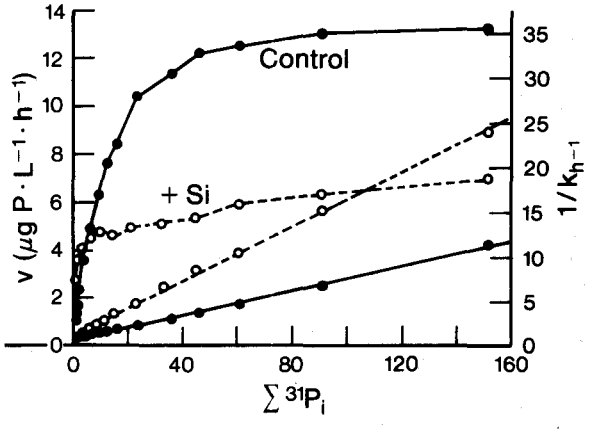
The abundance and importance of small cyanobacteria in Lake Superior were demonstrated. Bacteria-sized phytoplankton accounted for about one-half of the total primary production and exhibited growth rates of 1-2 doublings per day. Microzooplankton, such as protozoa, appear to be consuming this production. These very small organisms constitute an important, but previously unrecognized, part of the Lake Superior food chain.

Experimental data on the relative importance of phosphate and silicate limitation in Lake Michigan reveal that diatoms



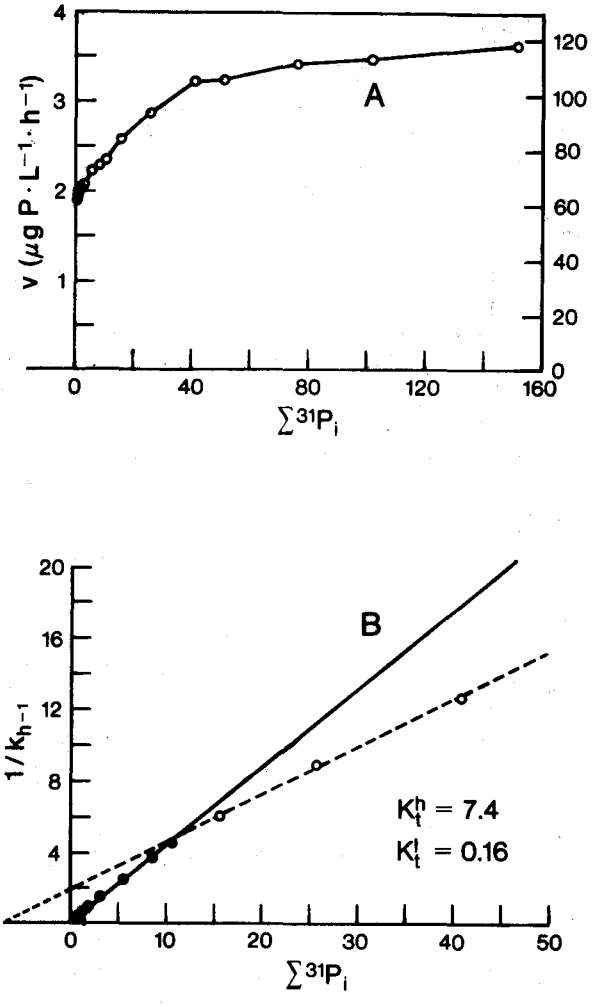
Phycoerythrin-containing cyanobacteria. These phytoplankton are very small (0.4-0.9 microns) and are responsible for about 20% of the total primary production in Lake Superior. They exhibit abundances of 30,000-50,000 cells per milliliter and growth rates of 1-2 doublings per day.

outcompete blue-green and green algae because they have transport systems for phosphate uptake that operate more effectively on low substrate concentrations. This could account for diatom supremacy during all periods except when silica limits diatom growth. Studies on nutrient uptake kinetics, coupled with data on phytoplankton and zooplankton abundance in Lake Michigan, also suggest major causes of seasonal succession patterns in the lake. Blue-green and green algae cannot compete with diatoms for bulk ambient phosphate and apparently coexist with diatoms during the late summer and early fall transition period because of high-phosphate plumes excreted by zooplankton.



Results of a perturbation experiment on Lake Michigan phytoplankton showing the effects of silicon (Si) limitation on phosphate (P) uptake rate. The two hyperbolas show the velocity (v) of phosphorus uptake as a function of phosphorus concentration in the control (closed circles) and a silicon-spiked sample (open circles). The open uptake data are by the Woolf transformation, where turnover time [the inverse of phosphorus turnover rate (1/k), right-hand ordinate] is plotted against phosphorus concentration; v is more rapid in the silicon-spiked sample at low phosphorus concentrations than in the control. The higher v observed by adding silicon also shows that diatoms have higher affinity uptake systems for phosphorus than blue-green and green algae, since only diatoms are limited by silicon.

Phosphate uptake kinetics and computer simulations suggest that mixed microbial assemblages have half-saturation constants from two to three orders of magnitude lower than previously shown in laboratory cultures. Phosphorus stress apparently induces micro-organisms to produce high-affinity uptake systems, thus allowing relatively rapid growth rates at low ambient phosphate concentrations. This helps explain the controversial paradox of high phytoplankton growth rates when phosphate concentrations are very low in lake and ocean waters. Studies on phosphate uptake in control and organically enriched samples of Lake Michigan water show that phytoplankton, rather than bacteria, have high-affinity transport systems for phosphate uptake. Bacteria, therefore, must be using dissolved organic phosphorus to support their growth. This information will be useful in defining and modeling the relative role of bacteria versus phytoplankton in nutrient and energy cycling.



Results of a perturbation experiment on phosphate (P) uptake by Lake Michigan phytoplankton showing that micro-organisms take up phosphate at much higher rates than calculated by traditional analysis methods that depend on adding high phosphate concentrations. (A) A typical Michaelis-Menten plot showing the velocity (v) of phosphate uptake versus added phosphate concentration. (B) Analysis of phosphate uptake (Woolf plot) using both low and high added P concentrations showing nonlinear uptake (solid points) at low P concentrations. The correct half-saturation constant (K_t^l) (0.16 micrograms phosphate per liter), obtained from the region of low phosphate additions (solid circles), is nearly two orders of magnitude lower than the estimate obtained by using the traditionally accepted method, where K_t^h values (7.4 micrograms phosphate per liter) are calculated from the region of high-level phosphorus additions (open circles).

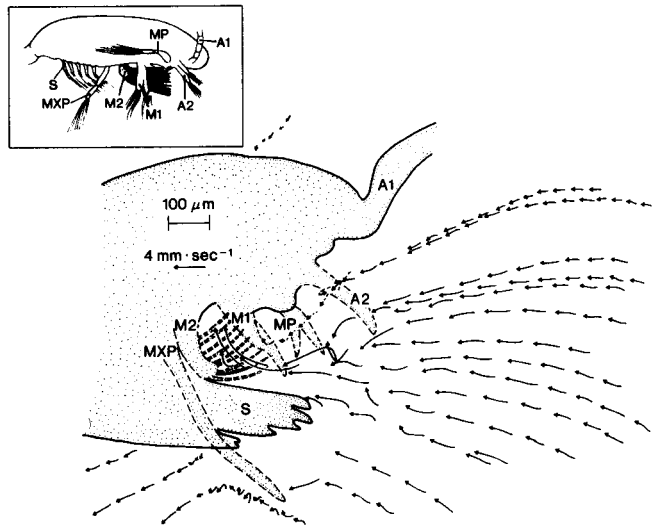
Zooplankton Feeding and Particle Transport

It is necessary to understand zooplankton feeding processes and rates to predict the role of these invertebrates in cycling nutrients and controlling phytoplankton successional patterns in the lakes. The relation between zooplankton feeding rate and food concentration for laboratory cultures of algae and for lake seston was determined to test the Effective Food Concentration Model published previously by GLERL scien-

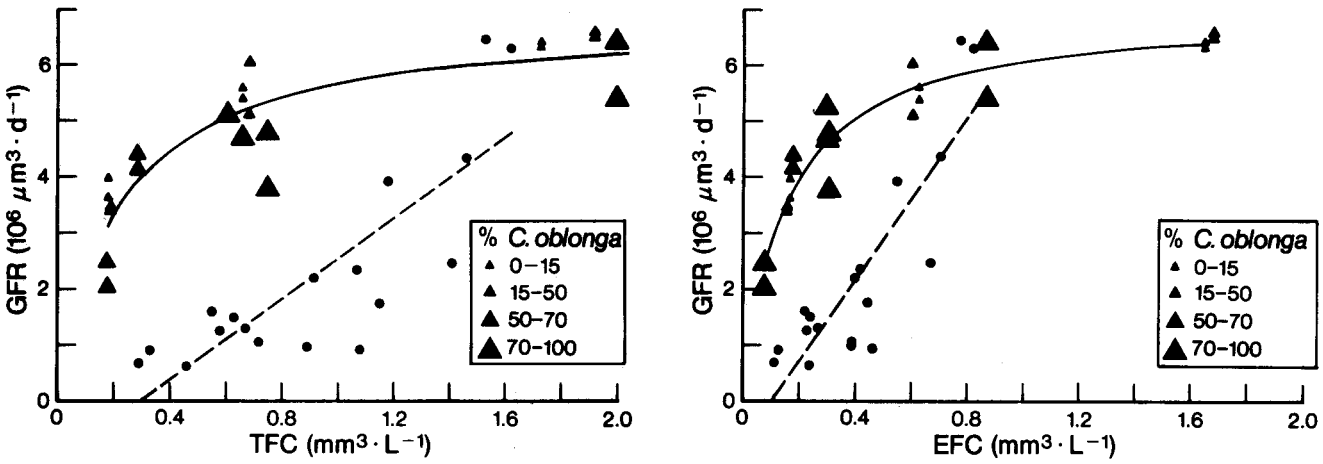
tists. Results supported the model and demonstrated that feeding rates determined with algal cultures cannot be applied directly to lake seston. Zooplankton grazing rates on Lake Michigan algae and seston were examined microscopically to provide information on how copepod grazing affects the removal of particular algal species. Results indicate that algal morphology affects grazing and that algae are grazed more rapidly than total seston in the lakes. Calcite particles at the same concentration and size found during calcite whitings in Lake Michigan significantly depressed zooplankton grazing. This depression was greater than that observed for clay particles at the same concentration. Whitings in fecal pellets accelerate the downward flux of the pellets by up to tenfold.

Microcinematography, a high-speed (500 frames per second) filming technique, was used to visually determine mechanisms of feeding by *Diaptomus sicilis,* an important Great Lakes copepod. This information is needed to understand how zooplankton obtain food and affect the composition of phytoplankton and seston in the lakes. Frame-by-frame analysis of 140 cinematography films showed that *D. sicilis* is not an optimal forager (i.e., does not necessarily select the most abundant available food) and supported the accuracy of the Effective Food Concentration Model. Film analysis also showed that both the "current field" produced and the feeding behavior of *D. sicilis* differ from those of marine copepods. These results explain why *D. sicilis* can specialize on small particles for food and also why it exhibits an invariant relation between particle selection and particle size. Based in part on these results, a model is being developed to describe the feeding rate of this copepod in mixtures of various particles such as would be found in lake water.

Microvideographic observations of *Daphnia magna* feeding in suspensions of algae led to the conclusion that many algal cells are drawn very close to the animal (in fact through the carapace) and subsequently flushed uneaten and

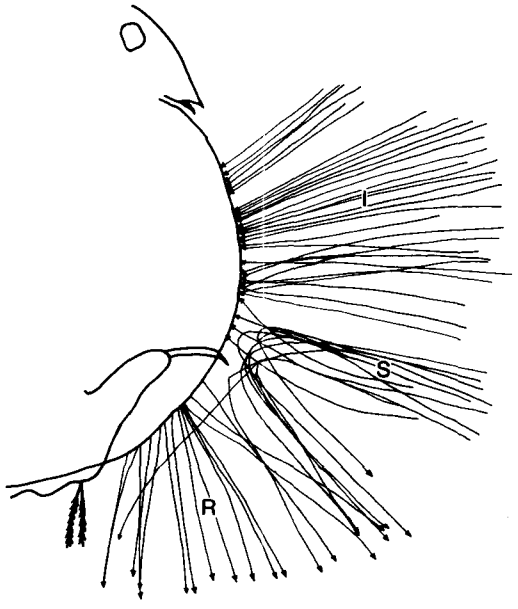


The current field around a tethered freshwater copepod, *Diaptomus sicilis,* determined by high-speed (500 frames per second) microcinematography. The large forwardly located swimming feet (S) focus water flow close to the body and into the mouthparts. This focusing enhances capture of small particles by the filtering apparatus formed by the mouthparts. In contrast, the swimming feet of the marine copepod *Eucalanus pileatus* (shown in the inset) are posteriorly located. This results in water flow around the body and less efficient capture of small particles. Labels on figure are: first antenna (A1), second antenna (A2), mandibular palps (MP), first maxilla (M1) second maxilla (M2), swimming feet (S), and maxilliped (MXP).



Gross feeding rate (GFR) of *Diaptomus sicilis* on mixtures of two different sized species of *Chlamydomonas* (triangles) and on lake seston (circles). The size of the triangle is an indication of the percentage of *C. oblonga* (the smaller algae). Food concentration is expressed as total food concentration (TFC) (left-hand graph) or effective food concentration (EFC) (right-hand graph). Effective food concentration is the weighted sum of the food concentrations in different size categories, where the weighting factors are the selectivity coefficients of the size categories. Expression of food concentration as EFC allowed direct comparison between the feeding rate response for seston and that for *Chlamydomonas* mixtures since it corrects for effects of differences in particle size of the lake seston and algae. The faster saturation of the algae-EFC curve is due to the lower food quality of the seston, that is, its lower digestibility and sensory quality for zooplankton capture.

presumedly unharmed. The amount of cells flushed this way as a percentage of cells entering the carapace increased from 3% to 70% as food concentrations increased. Two implications of this work are that much of the saturation in ingestion rate as a function of food concentration may be due to this flushing mechanism rather than bolus rejection and that algal cells experiencing this nondestructive encounter may benefit from increased nutrient stores.



Current field near *Daphnia magna* as shown by 10-second trajectories of *Chlamydomonas* cells brought through carapace gape (I), released through carapace gape (R), and swept close by (S). Outline and trajectories, traced from video tapes displayed on a television screen, illustrate the close, nondestructive encounters of algae with this zooplankter.

Ecological Modeling

A major problem in testing the predictive effectiveness of ecosystem models is the limited amount of comprehensive long-term field data available for aquatic ecosystems. Physical, chemical, and biological data collected from Lake Washington over the last 20 years are being used to test a generalized ecosystem model for natural waters, including the Great Lakes. The long-term goal of this work is to develop and test a "next-generation" ecological model of lakes.

The Temperature-Diffusion Model was calibrated for the 20-year data set, and estimates of vertical, turbulent diffusion coefficients were completed. These diffusivities were used to model a nearly conservative substance—total alkalinity. The results indicate the existence of previously undocumented sources of alkalinity in Lake Washington.

Lake Washington "finescale" temperature simulations were performed using 1972 hourly meteorological data. Temperature and vertical diffusion profiles were generated at 20-minute intervals and nocturnal convection for periods of 5-10 days to analyze daily heating and mixing cycles and their effects on such processes as mixed-layer depth, epilimnetic stability, and primary production. Thus, the Temperature-Diffusion Model can use hourly data to simulate small-scale processes (such as nocturnal convection) and use daily averaged data to simulate large-scale processes (such as the annual heat budget) without sacrificing accuracy.

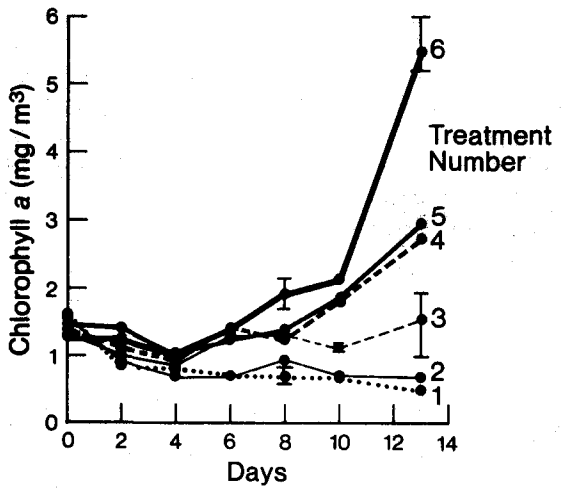
The extinction coefficient for the penetration of solar radiation has been related to observed Secchi depths. This relationship is important because Secchi depths increased in Lake Washington from 1-2 meters in the early 1960's to greater than 10 meters in 1980, thus increasing the depth of penetration of direct solar radiation. The results indicate that the Lake Washington extinction coefficient has decreased from 0.5 per meter to 0.15 per meter over the 20-year period. Light penetration is also being related to mixing depths as estimated by models driven by daily and hourly data.

Nutrient and Energy Cycling

Information on the sources and quantities of nutrients entering the photic zones from natural and anthropogenic sources is required for proper evaluation of the potential impact of changing inputs into the lakes. Chemical analysis of sediment trap material, combined with mass flux measurements, demonstrated that sediment resuspension may be the biggest source of "new phosphorus" in the epilimnion of Lake Michigan on an annual basis. Atmospheric input is another important, but little studied, source of phosphorus to Great Lakes surface waters. A joint study by GLERL and the U.S. Fish and Wildlife Service (Great Lakes Fisheries Laboratory, Ann Arbor) was conducted to evaluate the bioavailability of phosphorus in rain to Lake Michigan phytoplankton. Addition of untreated and acidified rain to low-phosphorus epilimnetic Lake Michigan water, followed by laboratory incubations, indicated that phytoplankton growth can be enhanced by phosphorus in rain. Phosphorus from acidified rain was more available than that from untreated rain.

Nutrient regeneration in the epilimnion by zooplankton is an important process supplying phosphorus to phytoplankton in the Great Lakes. Phosphorus regeneration rates of the predatory copepod *Cyclops biscuspidatus thomasi* were examined as functions of temperature and prey density (under a grant to the University of Michigan). Temperature, prey density, and hunger level significantly and predictably altered the phosphorus release rates of this predatory copepod.

Chemical and biological processes within the sediments and just above the sediment-water interface are important to nutrient cycling and energy transformations in the Great Lakes. Many substances are incorporated into the sediments as part of particles settling to the bottom, but some are returned to the water column as a result of biochemical



Chlorophyll a concentration versus time in low-phosphorus epilimnetic Lake Michigan water collected September 19, 1983, in response to additions of reagent-grade water (RGW; treatment 1), acidified RGW (treatment 2), RGW containing phosphate (treatment 3), unmodified rain of pH 3.2 (treatments 4 and 5), and filtered, unmodified rain of pH 3.2 (treatment 6). Each point is the mean of the indicated range of replicate chlorophyll a measurements. Ranges not indicated were less than 10% of the mean. These data indicate that phosphorus from acid rain can stimulate the growth of Lake Michigan phytoplankton in late summer when they are phosphorus limited.

degradation, chemical reactions, and/or sediment resuspension. Experiments at GLERL are quantifying the importance of aerobic sediments as a source of phosphorus to Lake Michigan. A study of phosphorus release from intact sediment cores indicated that this source of phosphorus may explain disproportionally high levels of primary production observed for nearshore regions of Lake Michigan.

Because oxygen is present in most Great Lakes sediments, benthic invertebrates, as well as microbes, must be considered in examining nutrient and energy cycling processes in the lakes. Microcosm experiments indicate that invertebrate-mixing activities enhance phosphorus release from sediments, but that mixing beyond a threshold level has no effect on the rate of phosphorus release; i.e., phosphorus release is not related to animal density. Calculations based on sediment trap estimates of detrital input rates and measurements of *Pontoporeia hoyi* biomass and ammonium excretion rates indicate that about 40% of incoming detritus is mineralized by *P. hoyi* in the hypolimnion of offshore Lake Michigan. Nutrient transformation studies in silty Lake Michigan sediments indicated that nitrogen released by macroinvertebrates as ammonium can be rapidly converted to nitrate (nitrification) and then converted to nitrogen gas (denitrification) by microbes. These processes must be quantified to determine the importance of sediment mineralization as a nutrient supply mechanism in the Great Lakes.

A new study was initiated to measure the lipid content of benthic invertebrates in Lake Michigan. This information is needed to assess the caloric content of these animals and to determine their role in transforming "potential energy" in sediment detritus and microbial biomass into "usable energy" available to fish and other predators in the lakes. Lipids are also storage sites of many toxic organic chemicals and may affect the partitioning of these compounds in the lakes. A micromethod was developed to measure lipids in individual benthic invertebrates and a seasonal study of the lipid and caloric content of these animals in Lake Michigan was begun. Species known to be important prey for Great Lakes fish, *Pontoporeia hoyi* and *Mysis relicta*, had higher levels of lipids relative to dry weight than did oligochaetes (*Limnodrilus sp.* and *Stylodrilus heringianus*) or insect larvae (Chironomids) occurring in the Great Lakes.

Lake Assessment

Perhaps no other biological group of organisms is a better indicator of water quality than benthic fauna. Benthic communities respond to and reflect environmental changes over long periods of time. GLERL scientists are continuing to evaluate present-day distributions of benthic invertebrates in southern Lake Michigan. By comparing the number and kinds of organisms now in the lake to those found 17-50 years ago, they are gaining insight into the lake's changing trophic status.

Thirteen hundred samples were collected from forty stations in southern Lake Michigan in 1980-81. The number, type, and biomass of the benthic invertebrates in these samples were determined. The data were incorporated in a computer file and will be statistically analyzed to determine the nature and extent of changes in community structure. Preliminary analysis of biomass data indicated that the amphipod *Pontoporeia hoyi* is clearly the dominant form in southern Lake Michigan. The dominance of *P. hoyi* (70% of total biomass) illustrates the importance of this species when considering nutrient and energy transformations in Lake Michigan sediments.

New studies of the feeding habits of *Pontoporeia hoyi* indicate that this amphipod feeds irregularly, but that feeding may be an important mechanism affecting particle composition and nutrient distribution in lake sediments.

The distribution of epibenthic microcrustaceans in nearshore Lake Michigan was investigated to determine the relative occurrence of these forms in both the sediments and the water column. Many taxa were more abundant in the sediments, indicating that to quantify these forms in the nearshore environment the sediments as well as the water column must be considered. This study provides the first record of a resting stage for *Diacyclops thomasi* in the Great Lakes.

The survival and viability of the meroplanktonic diatom *Melosira granulata* is being investigated in cooperation with University of Michigan scientists. This diatom remains viable for periods of at least 100 years while buried in the sediments and is capable of photosynthesis immediately upon exposure to light.

LAKE HYDROLOGY

The Great Lakes System contains 95% of the nation's fresh surface water supplies. Variations in these supplies result from fluctuations in the hydrologic cycle and anthropogenic changes to the system. The hydrologic research program is directed at improving our knowledge of the hydrologic and hydraulic processes, at improving methods of forecasting and simulating water supplies and lake levels, and at improving large river dynamic flow models.

Prediction and simulation information on water supplies, lake levels, and flows are required for water resource planning and management and for the solution of problems with water supply, water quality, shore erosion, flooding, hydropower, navigation, and recreation. Primary users of the hydrologic research results are the IJC, the U.S. Army Corps of Engineers, the EPA, the Great Lakes States, power utilities, navigation interests, and the general public.

Ice research is conducted to improve understanding of the processes governing the formation, growth, and decay of the Great Lakes ice cover. This research will lead to improvements in the prediction of freeze-up, breakup, areal extent, and thickness of ice in the Great Lakes and their bays, harbors, and connecting channels. It will also improve our understanding of the natural variability of the Great Lakes ice cover.

Great lakes ice processes and related data are of interest to all who use the lakes during winter. Ice forecasts and information are of value for water supply management, shoreline engineering, hydropower generation, and water quality and fisheries management. Primary users of ice information include the NWS, the U.S. Coast Guard, the St. Lawrence Seaway Development Corporation, the U.S. Army Corps of Engineers, the Great Lakes shipping industry, and the general public, including riparian property owners.

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

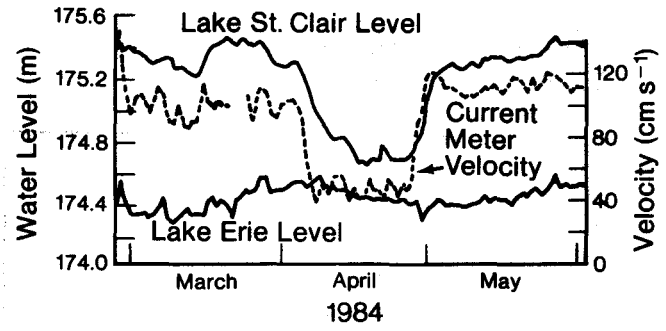
Winter Flows in the St. Clair and Detroit Rivers

Ice buildup and jamming in the St. Clair River is one of the primary processes governing the seasonal cycle of the Great Lakes water levels. Ice reduces the channel capacity of the river, resulting in water storage in Lakes Michigan and Huron and lower flows in the St. Clair River during winter and early spring. This water is released later in the year, accentuating the seasonal cycle of winter minimums and summer maximums. Accurate determination of the St. Clair River flows is therefore required for lake level and water balance studies and water quality assessments of the Great Lakes.

The river flows are currently computed with dynamic flow models, which are considerably less accurate for winter conditions than for open water conditions. An experiment was begun in 1981 to assess winter flows accurately by measuring variations in the flow velocity attributable to dynamic ice conditions. This past winter was the third and most successful field season in the program. Severe cold spells during December and January produced frequent episodes of frazil ice in the river and contributed to a heavy ice concentration in Lake Huron. The breakup of the Lake Huron ice cover in April produced the largest ice jam, in both magnitude and duration, in at least the past 50 years. During the peak of the jam, the river was completely ice covered, and the flow reduced by approximately 75%. This resulted in a 0.6-meter drop in Lake St. Clair water levels. There was relatively little impact on the other lakes because of their large storage capacities. During the latter part of the jam, it was estimated that economic losses were on the order of $6 million a day for navigation interests alone. Current-meter measurements and real-time lake levels provided by the National Ocean Service were used with the Great Lakes Hydrologic Response Model to forecast the impact on downstream levels and flows when the jam broke. The forecast predicted that Lake St. Clair would recover about 80% of the drop in levels during the first 3 days. This forecast proved accurate. The model also indicated that the jams would result in higher Lake Erie and Lake St. Clair levels by the end of the year because of the additional water stored in Lakes Michigan and Huron.

Freighters trapped in the St. Clair River ice jam. At the height of the jam, the cost to navigation interests alone was over $6 million a day.

The experimental study was expanded to the Detroit River in August 1984 with the deployment of two additional electromagnetic current meters. These will provide simultaneous flow velocity measurements in both the St. Clair and Detroit Rivers during the 1984-85 field season. The St. Clair River instrumentation will be augmented with an acoustical current profiler, which will permit continuous measurements of the velocity profile at the meter location. The experiment will provide a better understanding of the role of ice in the natural regulation of the Great Lakes and lead to improved flow models of the connecting channels for use in both water quality and quantity research on the Great Lakes.



Lake St. Clair and Lake Erie water levels (in meters) and current-meter velocities (in centimeters per second) for March through May 1984. Note the low water levels in Lake St. Clair in April 1984 due to the ice jam in the St. Clair River.

Forecasts of Net Basin Supply

Deterministic forecasts (outlooks) of accumulated net basin supply (basin runoff plus lake precipitation minus lake evaporation) to a large lake are required in near real-time for use in regulating lake levels. Runoff simulations from GLERL's Large Basin Runoff Model (LBRM) are produced by dividing the lake basin into subbasins draining into the lake. The historical meteorological data from all available stations about and in the subbasins are combined to produce areally averaged daily values for each subbasin. Then the model is used in a distributed-parameter application by combining the subbasins' runoff in a simulation of total net basin supply. Outlooks are possible in near real-time by using the LBRM with forecast meteorology. The model is first calibrated with historical data for all subbasins about a lake and then is run from the end of the historical data sets to the present by using recent provisional data. This allows basin moisture storages corresponding to the present to be established and used as initial conditions in the forecast. Boundary conditions from field measurements are incorporated into these model runs as they become available. Forecast meteorological scenarios for each subbasin are then selected from the historical records that most closely match available weather forecasts and are used with the runoff model and the simulated initial conditions to forecast subbasin runoff. These are combined with corresponding historical lake evaporation and precipitation to forecast net basin supply for the lake. There are three parts to the outlook package: data acquisition, data reduction, and outlook generation.

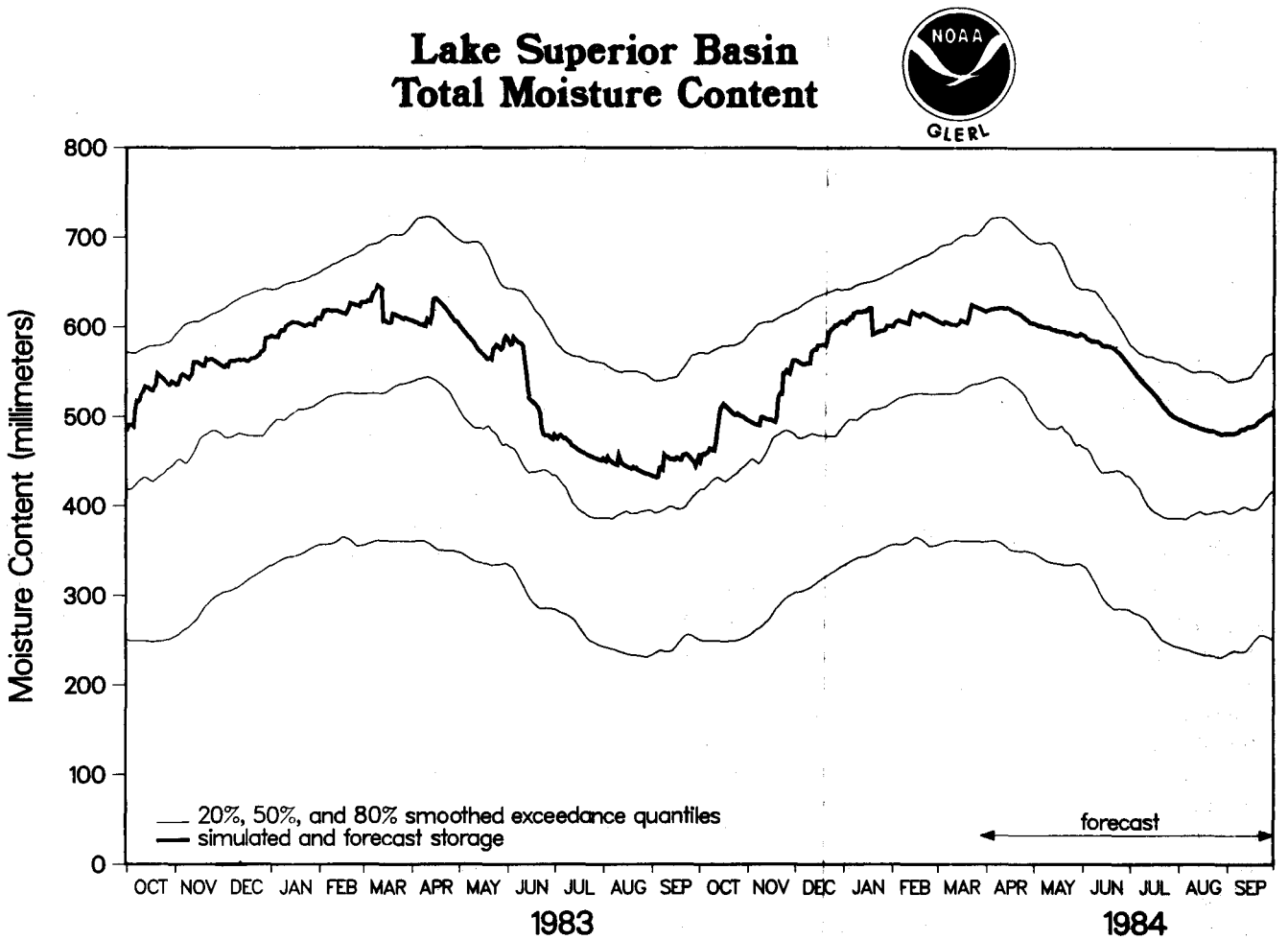
Data acquisition has been semiautomated at GLERL this past year. Currently, GLERL receives daily historical data from about 2,000 stations in the Great Lakes and Lake Champlain Basins. However, there can be a 2-year lag between when the data are collected and when they are available in computerized form. GLERL has established contacts and telecommunication links to receive provisional data from several participating agencies in the United States and Canada within 1 week of measurement. Data from these linkages are received automatically and added to the provisional data base weekly.

Data reduction has also been automated this year. Historical data are processed with self-contained procedures to produce daily areally averaged climatic subbasin data files for use with the model. While this is only required once every 2 years (as historical updates are received) for each large lake basin, it is now possible to consider any new large lake with a minimum of processing time. The process also includes the modeling of basin storages; the extraction of storage, net basin supply, and meteorology quantiles for use in subsequent outlook perspectives; and the estimation of historical climatic quantiles for use in selecting a meteorological scenario compatible with the forecast meteorology to use in the outlook determination.

Production of outlooks is completely automated. The computer program selects appropriate meteorological scenarios for the forecast; creates temporary data files that run from the end of the climatic data sets through 6 months into the future; extracts appropriate storage and meteorological quantiles to provide the outlook perspective; runs the model on all subbasins; accumulates subbasin storages, runoff, and meteorology over the lake basin; adds forecast lake precipitation and evaporation to the accumulated basin runoff; and plots the summary outlooks in terms of each of the total basin storages.

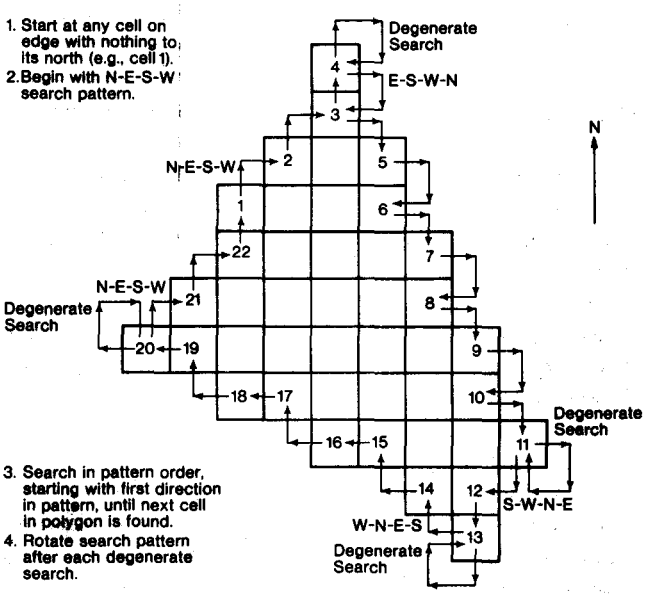
Determining Areas of Influence

GLERL's automated computer forecast package uses near real-time provisional meteorological data from a data collection network that changes frequently as stations are added, dropped, moved, or fail to report from time to time. As the network changes in near real-time, the data reduction package must quickly adapt to consider the relative importance of each station in the new network to each subbasin, as determined by the areas of influence in each subbasin for each station. The area of influence for a station is taken here as the Thiessen area enclosed by a polygon whose sides are halfway between the station and its closest neighbor. The Thiessen areas are intersected with subbasin areas to find the station's area of influence in each subbasin. Existing methods of computing Thiessen areas on the computer either provide unacceptable approximations or have large computational overheads. A method combining the accuracy of a fine-resolution digital map and the evaluation of a small number of points is ideal. A new algorithm was derived for quickly computing Thiessen areas for all stations in a network for each of several subbasins of interest. The algorithm determines areas by finding only the edges of the Thiessen polygons rather than every point within the polygon. These edges are used as "windows" into the map of subbasins to find the intersections of the polygons with subbasin areas. Although comparisons of methods depend on particular network configurations, an example application to 18 stations cover-



Simulated and forecast Lake Superior Basin moisture storage (surface plus upper and lower soil zone plus ground water plus snow). The simulation and forecast were done with the GLERL Large Basin Runoff Model. They can be used to forecast Lake Superior water levels. The heavy line is the simulation/forecast; the thin lines are historical exceedances, meaning that historically 20%, 50%, and 80% of the time the moisture storage will exceed that indicated for the time of the year indicated.

ing 22 watersheds, represented on a 760-kilometer-by-516-kilometer map at 1-square-kilometer resolution (392,160 cells), requires only 10.0 cpu-seconds on a VAX 11/780 minicomputer (2 cpu-seconds on a CDC 750). This represents a 93% savings in computational time with no loss of accuracy when compared to conventional computer methods. The algorithm has several applications, including areal averages of meteorological variables, lake-level estimations, ground water-level estimations, near real-time accounting of network changes, computer map generation



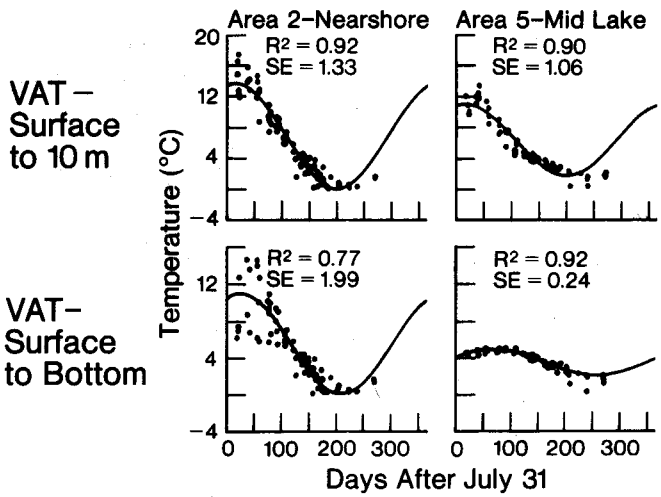
Algorithm for determining the area-of-influence polygon about a meteorological station on a map. Typically, a 20:1 reduction in computation time is achieved by finding Thiessen polygons by their edge cells instead of by finding every cell within the polygon. This enables scientists to compute areal average hydrometeorology more accurately on a daily basis over large areas with many stations.

and real-time graphics, and even industrial engineering applications in computer-aided descriptions of convex shapes.

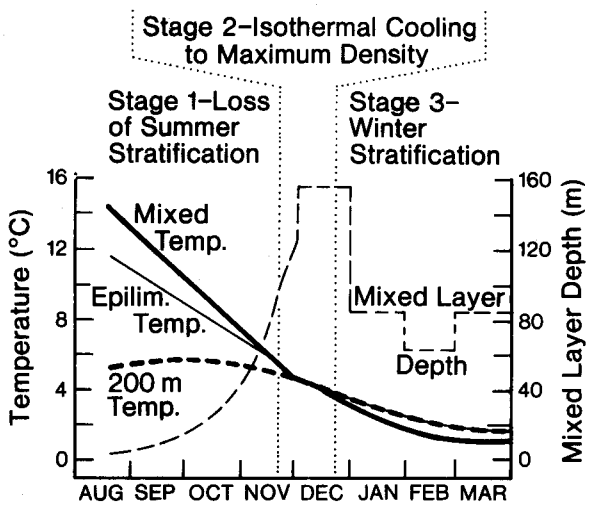
Lake Superior Thermal Structure

Fall and winter thermal structures for Lake Superior, defined from 46 bathythermograph surveys across the lake from 1973 to 1979, were analyzed this past year. Three stages in the cooling period were identified. The first stage is when summer stratification is broken down by convective cooling and wind mixing. During this stage, the mixed-layer depth increases at an approximately exponential rate. This stage starts in mid-September and is nearly complete by mid-November. The second stage begins when the isothermal water column starts to cool to the temperature of maximum density. This stage is called the pressure-sensitive stage because the depth at which maximum density occurs varies according to small changes in temperature. Thus, the effectiveness of wind mixing near the end of fall overturn is dependent upon the depth of maximum density because of buoyancy. The third stage is winter restratification. As the surface water cools and the water column stratifies, the mixed layer recedes toward the lake's surface. This stage can start as early as December or as late as February, depending primarily upon wind conditions. During this period, the water surface cools sufficently for ice to form. Once ice forms, the areal extent of the ice cover dampens the effects of wind stress so that winter stratification is maintained. In winters when wind speeds are low following the end of fall overturn (such as January 1977 and January 1979), extensive ice covers form early. In winters when winds speeds are high following the end of fall overturn (such as January 1975), extensive ice covers usually do not form until February or March, if at all.

Spatial divisions in the lake's thermal structure reflect an east lake basin and a west lake basin, both divided into nearshore and offshore areas. Separate thermal regimes are attributable to variations in lake bathymetry and the prevailing counterclockwise shore circulation. Temperature ranges for both surface and column temperatures are smaller and lag time between the occurrence of extreme temperatures in the surface layer and in the entire column are longer for midlake areas relative to shore areas. This is a direct result of the greater depth and greater thermal reserve in midlake areas. During summer stratification, the general counterclockwise shore circulation pattern produces lower epilimnion temperatures in shore areas along the northwestern shore and in the western end of the lake owing to advection of upwelling waters from the deep trough along the northwestern shore. The epilimnion temperatures in areas adjacent to the western shore of the Keweenaw Peninsula and the southeastern shore are lower than those in adjacent areas west of them because of upwelling as water from these areas moves toward shore. Results of this study are useful for the development and verification of temperature structure simulation and forecast models, including the time of initial ice formation for various locations in Lake Superior.



Vertically averaged temperature (VAT) for the 10-meter surface layer and for the entire water column at nearshore and midlake areas of Lake Superior. The least square trends (solid lines) illustrate the thermal regime dichotomy between nearshore and midlake regions. (R^2 is the coefficient of determination; SE is the standard error of estimate for least squares analysis.)



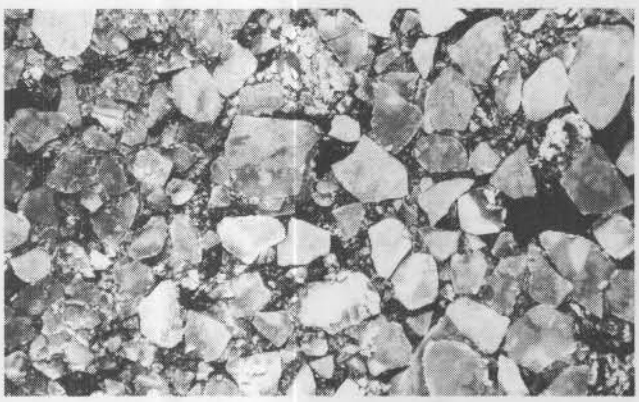
Mean thermal structure trends for Lake Superior during fall and winter cooling periods.

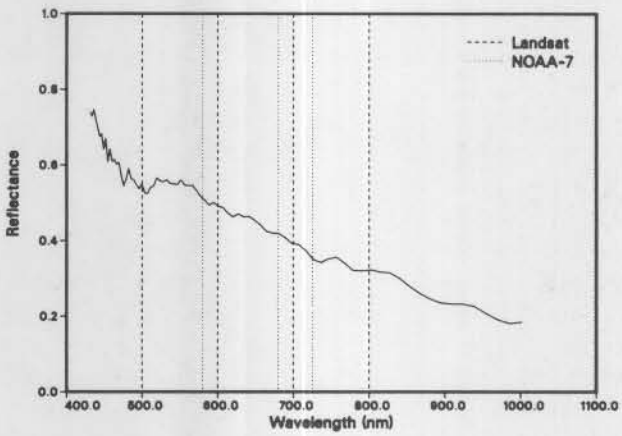
Optical Properties of Ice

Two different approaches were used to continue field work in support of characterizing the spectral reflectance of snow and freshwater ice types last winter. The first approach

employed an existing dual spectroradiometer system to make simultaneous measurements of incident and reflected global (sun plus sky) radiation in the visible and near-infrared region from a height of approximately 1.5 meters. Measurements of global radiation, as well as separate measurements of incident and reflected diffuse (sky) radiation, were made to test an algorithm that could be used to calculate reflectance values of various ice types for various sky conditions. Measurements of additional surface types under differing illumination angles are still needed. Such an algorithm could be used to rapidly expand a library of spectral signatures for major freshwater ice types.

The second approach employed a programmable band radiometer to make airborne reflectance measurements of homogeneous and heterogeneous ice types. Mounted in a Sikorsky built U.S. Coast Guard helicopter, the instrument was used to measure the spectral reflectance of open water and four major ice types located in the southern end of Lake Huron from an altitude of 300 meters under clear skies. The surface area measured was 80 meters in diameter and approximates a Landsat multispectral scanner pixel (56 meters by 79 meters) in area. Such data would be particularly valuable as ground truth for use in the interpretation of satellite imagery and as input into overlake energy balance models.





Large ice floes in a black ice matrix. These appear to be pieces of refrozen slush or snow ice frozen into black ice. Their spectral reflectance (430-1,000 nanometers) is plotted in the graph to the right. Because of its composition and large areal extent, this type can only be measured accurately from the ground by individually measuring the spectral reflectance of each ice type and then artificially integrating those values, but can easily be sensed from satellite and aircraft altitudes, where spatial integration is automatically obtained.

PHYSICAL LIMNOLOGY AND METEOROLOGY

The Physical Limnology and Meteorology Group studies the physical variables describing the lake environment and the way they change with external forces. The relevant variables are currents, temperatures, waves, water-level fluctuations, sediments, and suspended matter. The primary driving forces are the wind acting on the lake surface, the heat exchanged between the lakes and the atmosphere, and the river flows. Waves and water level oscillations are hazards that may result in loss of lives and in damage to shoreline property, shipping, and recreational activities. The purpose of this group is to develop and test models that improve prediction of these variables. In addition, these models will allow estimates of the chemical and biological properties of the lakes that are important in waste disposal, power generation, fisheries management, and water supply planning.

The scales of the variables that need to be modeled and predicted range from years to seconds and from the size of the lake down to a few meters. In view of this tremendous range in time and space, the various phenomena must be separated according to their scales 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, and upwelling; and surface waves, water-level fluctuations, and overwater winds, which deal with wind-generated waves, storm surges, and seiches. Both areas involve prediction on a real-time basis and climatological studies. The group also contributes to studies of particle dynamics conducted by the Synthetic Organics and Particle Dynamics Group and scientists at the University of Michigan. This program was initiated because many toxic organic substances and nutrients enter the lake attached to particles. Hence the pathways and ultimate fate of these pollutants in the lakes depend on the movement of various types of particles through 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.

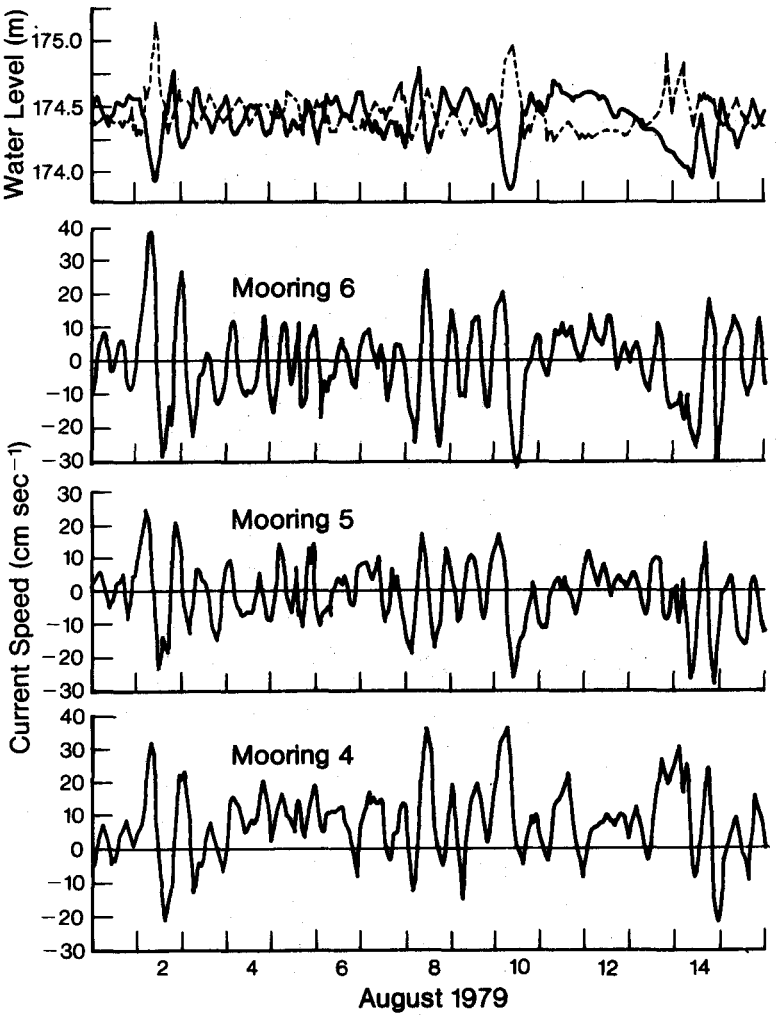
Water Movements and Temperature

A report describing the results of a joint United States-Canadian study of Lake Erie's currents was recently published. A shorter version of this work will appear in a special volume of the *Journal of Great Lakes Research*. This volume, which is jointly funded by GLERL and the National Water Research Institute 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. This research is expected to be useful in evaluating the massive investment in waste water treatment during the last decade.

In the Lake Erie study, thermistor chains measured the development and decay of central basin stratification. First, a fragile stability developed, which was very susceptible to high wind stress. For example, a strong wind impulse in late May 1979 completely mixed the central basin and postponed development of stable stratification for 3 weeks. Currents measured in the lower half of the central basin water column were mostly return flows (beneath the surface wind drift) driven by the surface pressure gradient. There was a complex system of circulation gyres, but occasionally one of them became dominant. This caused the entire basin to circulate either clockwise or counterclockwise. The currents were somewhat more vertically uniform than predicted by full Ekman layer current models. In the island passages between the western and central Lake Erie basins, tide-like currents are driven by the longitudinal seiches of Lake Erie.

A second GLERL paper to be published in the Lake Erie volume analyzes the network of current-meter measurements with a new objective analysis method and by comparison with the results of a time-dependent numerical circulation model. The objective analysis method provides automatic interpolation of low-pass filtered current-meter data to a regular grid covering the lake. It uses the observed currents as constraints on a vorticity minimization scheme to arrive at a two-dimensional stream function field. The numerical model is used to demonstrate the sensitivity of the circulation pattern in the flat central basin of Lake Erie to the horizontal variability of the wind. A difference of 3 meters per second in the eastward component of wind speed over a north-south distance of 100 kilometers is sufficient to generate a one-gyre circulation pattern in the central basin. Both objective analysis results and time-dependent model results will be compared to the observed currents. Early results of this comparison indicate that there are some situations for which the model results may be more representative of the lakewide circulation pattern than the objectively analyzed observed currents.

During summer and fall, research was completed on currents and water temperatures in the four main passages between Green Bay and Lake Michigan and at several sites within the bay. The usual southwesterly winds are associated with a counterclockwise circulation in the bay, while episodes of northeasterly wind bring a rapid reversal of this pattern. Oppositely directed two-layer flow through the mouth is a common feature during the stratified season. Cold water from Lake Michigan enters through the mouth and extends far



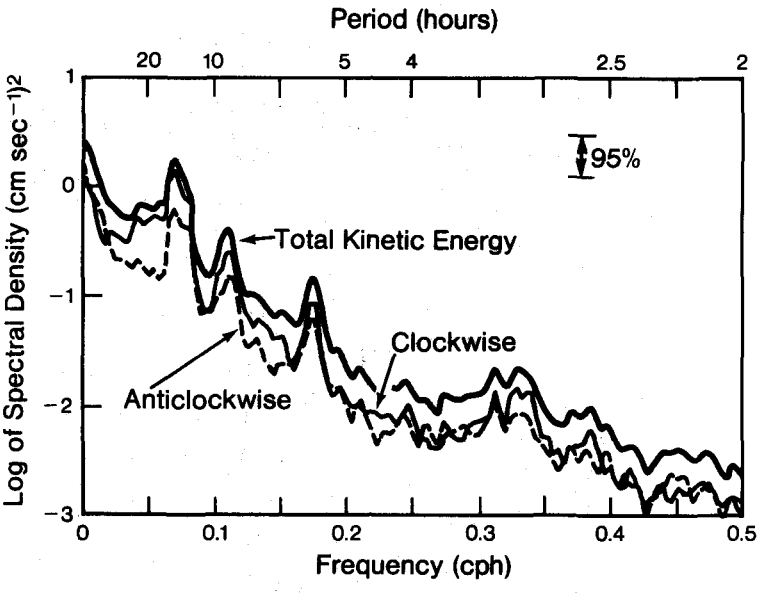
Hourly recorded water levels (in meters) at Toledo, OH, (solid line) and at Buffalo, NY, and current speeds (in centimeters per second) through island passages that connect the western basin of Lake Erie with the central basin. Positive current speeds are directed along the channel axis of each passage and toward Buffalo. Seiches drive currents that are similar in all of the passages and are the major current-producing force in that section of the lake.

into the bay; warmer Green Bay water flows outward. This process maintains stratification and promotes flushing. Oscillatory flows of a variety of periods were also observed in the currents at the mouth of the bay.

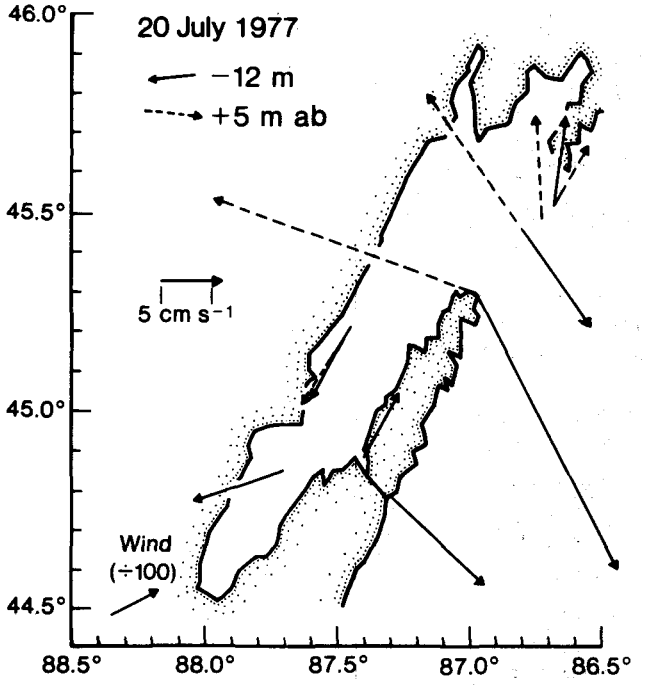
Current meters deployed in Lake Michigan in summer 1982 to study rotational waves were successfully recovered in July 1983. Magnetic tape cassettes on which the data are recorded were read and translated, and the data series was edited. All current meters were recovered and about 85% of the data were of acceptable quality.

Spectral and cross-spectral analyses of the long data time series will be performed first. Past experience suggests there will be high coherence in the period range of 3-8 days for some station pairs. To understand this, scientists plan to use rotary spectral analysis. The seasonally varying mean flow structure in the lake will also be studied by comparing this year's data with earlier data and with model simulated patterns.

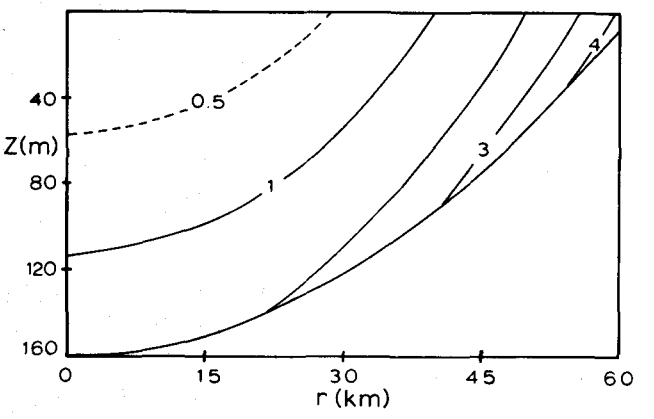
In addition to understanding water flow patterns, it is important to know the distribution and movement of suspended material to predict the fate of pollutants. Many long-lived pollutants become attached to solids and settle to the bottom. Eventually, they become incorporated into the sediments of the lake; but before that happens, they may become resuspended by currents many times. The physics of this process is being studied with models that include the effects of currents in moving and resuspending solids. Thus far during this research, it has also been found necessary to model the effect of the Earth's rotation on the vertical profiles of currents and suspended matter. The resulting model has been shown to reproduce the observed sediment patterns in Lake Michigan's southern basin with considerable accuracy.



Kinetic energy spectra of current flow through the island passages connecting the western basin of Lake Erie with the central basin. The three energetic peaks reveal that the first three longitudinal seiches of the lake are the main current driving forces. The clockwise and anticlockwise rotary spectral components show that the seiche-driven currents have two to three times as much energy in the clockwise component as theory predicts.



Daily Green Bay resultant currents 12 meters below the surface and 5 meters above bottom (ab) for July 20, 1977, with a southwesterly wind. Cold water from Lake Michigan enters through the mouth and extends far into the bay, while warmer Green Bay water flows outward. This process maintains stratification and promotes flushing.



Suspended matter concentration in water for a cross section of a circular model of Lake Michigan's southern basin. Depth (Z) is in meters and distance from the center (r) is in kilometers. The concentration is high near the shore because of resuspension by the strong shallow water currents; the concentration is high near the bottom because the particles tend to sink.

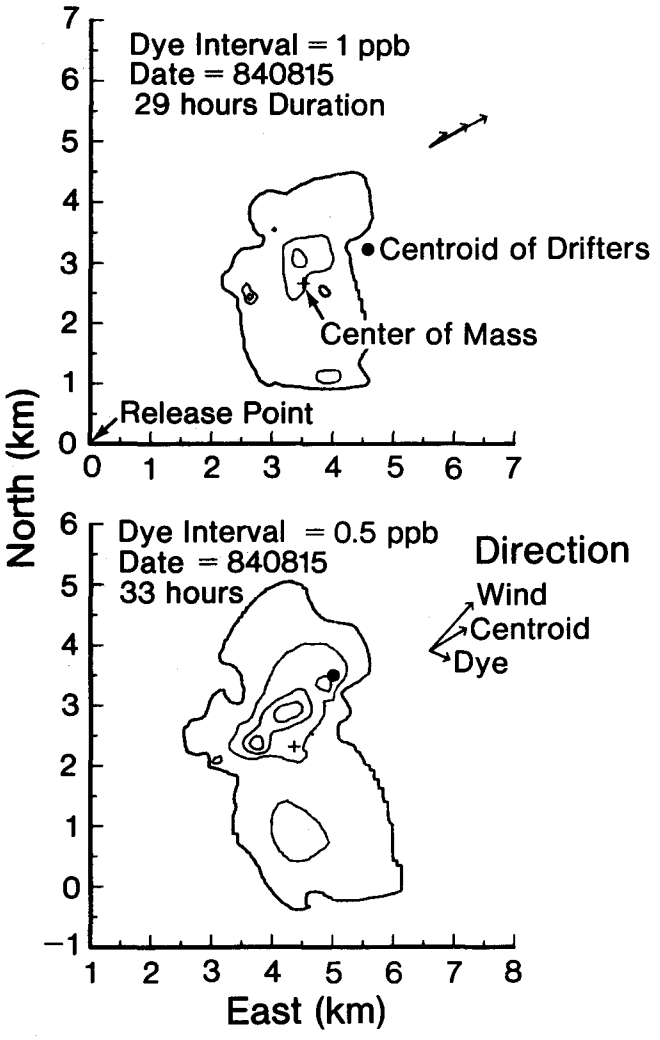
GLERL has completed an improved version of the Great Lakes Trajectory Model to replace the previous version, which has been in use for 4 years. The model is intended to be used as a tool in surface pollutant tracking, surface pollutant trajectory prediction, and search-and-rescue operations. Some of the improvements in the model are more accurate numerical methods for lake circulation prediction and particle trajectory prediction, multiple spill tracking capability, more versatile output display methods (including "zoom" capability), and two different restart options. The model is being used by the NWS, the U.S. Coast Guard, the NOAA Hazardous Materials Response Team, and some Canadian agencies.

Satellite-tracked drifter buoys were used in 1984 in several different projects. All of the data gathered will continue to be used to calibrate the Pathfinder Trajectory Prediction System. In addition, each of the drifter projects has separate goals. In winter 1984, drifters were used to study the movement of ice in Lake Erie. Four drifters were deployed in the ice of the central and eastern basins in January with the help of Coast Guard helicopters. Flights were made every 2 weeks to observe ice conditions and make ice measurements in the vicinity of each drifter that was successfully located. All four of these buoys were eventually retrieved. Two of the four are still operable. The longest continuous ice "track" was over 2 months long. The tracks reveal constant ice movement, often at surprisingly high speeds, correlated strongly with the overlake winds. Analysis of these results continues.

This previous summer, GLERL scientists used a tracer, rhodamine B fluorescing dye, to determine how accurately satellite-tracked drifter drifter buoys track water parcels in Lake Michigan. Releasing a cluster of drifters with the dye and following the movement of each over a period of days yielded important information about the Lagrangian effectiveness of these satellite-tracked drifters. Dye concentration was determined by fluorometry, and the center of mass calculated from continuous sampling profiles. Separation of the centroid of the drifters and the dye center of mass was compared with wind data and used to calculate the slippage velocity. The results are still being analyzed.

Drifter buoys are also quite useful in river plume studies. GLERL is again involved in a cooperative venture with the National Water Research Institute, Canada Centre for Inland Waters, to study the physics of the Niagara River plume in western Lake Ontario. In addition, drifters are being used to determine the path of the Detroit River plume in Lake Erie. These physical problems are of crucial significance because of the implications for toxics transport modeling.

Drifter Tracking Ability



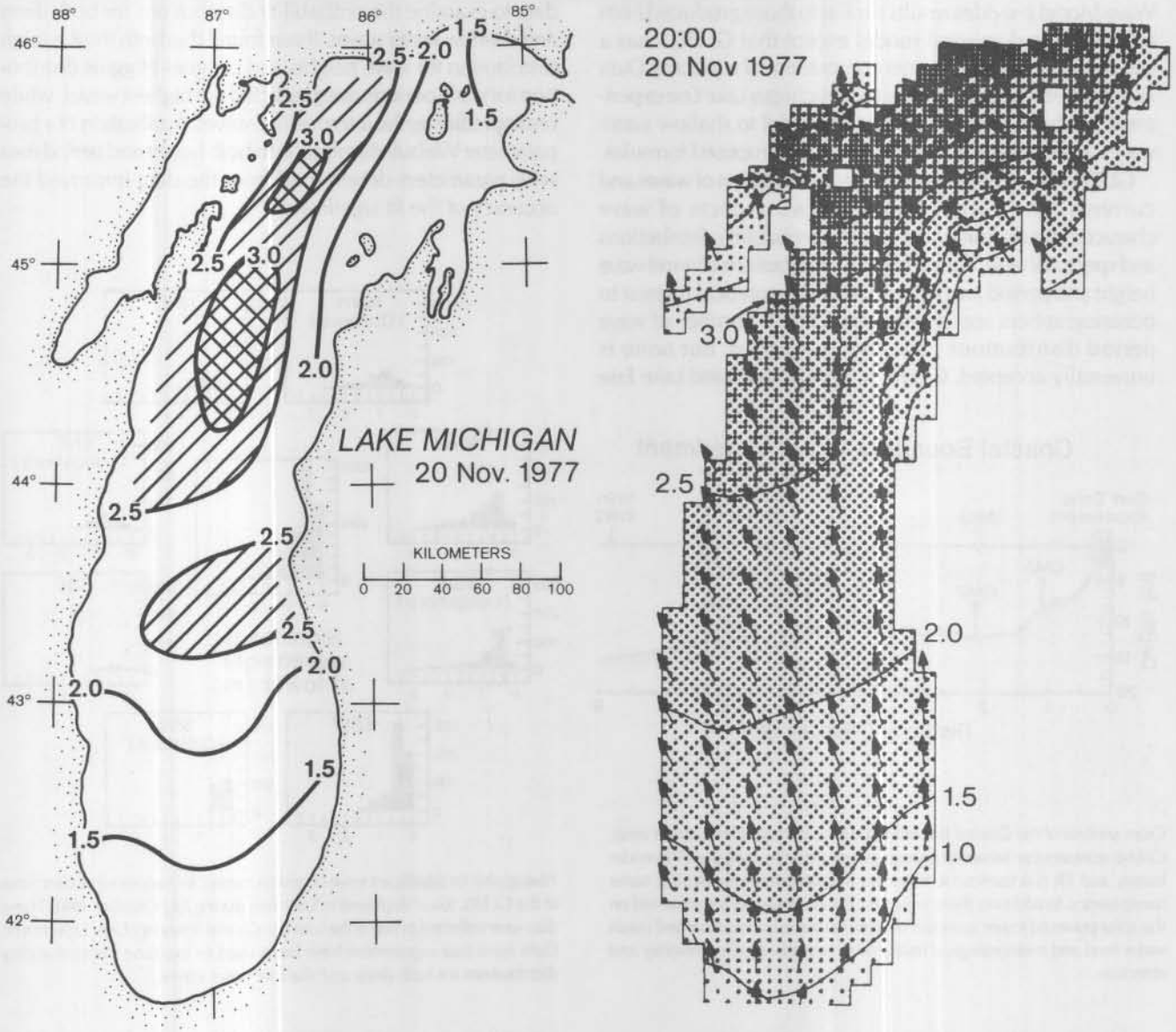
Comparison of the movement of six closely spaced satellite-tracked drifters (0,0 to centroid of drifters) with dye (0,0 to center of mass) released at the same time. The gross slippage of the buoys was calculated to be 0.5%; this agrees with the theoretical calculation, validating the theory for light wind conditions. A good understanding of the factors influencing movement of the drifters is important for their meaningful use in studies following the movement of spills, toxic contaminants, or water parcels.

Surface Waves, Water-Level Fluctuations, and Overwater Winds

An interactive version of the Wind Wave Model developed last year has been implemented on the GLERL VAX 11/780 computer. It can be accessed over telephone lines from remote computer terminals. The model is being used by NWS forecasters for operational wave forecasting. The system has been used over 150 times this year by United States and Canadian weather forecasters, scientists, and university staff and students. The response to the forecasts generated by the system has been very favorable.

The Wind Wave Model was tested against observed synoptic wave data from Lake Michigan. The observations, consisting of two sets of wave height measurements obtained from the NOAA C-130 aircraft during the passage of a cold front across the lake in November 1977, were assembled into wave height maps covering the lake and compared to similar maps produced by the model. The results showed that the model predicted almost all the synoptic features. Both the magnitude and the general pattern of the predicted wave height contours compared well with the measurements. The model also predicts the direction of wave propagation in conjunction with the wave height map, which is useful for practical ship routing and can be significantly different from the prevailing wind direction.

A satellite-reporting wave buoy was deployed in the western part of Lake Erie to provide further verification and calibration data for GLERL wave modeling efforts. The buoy extends



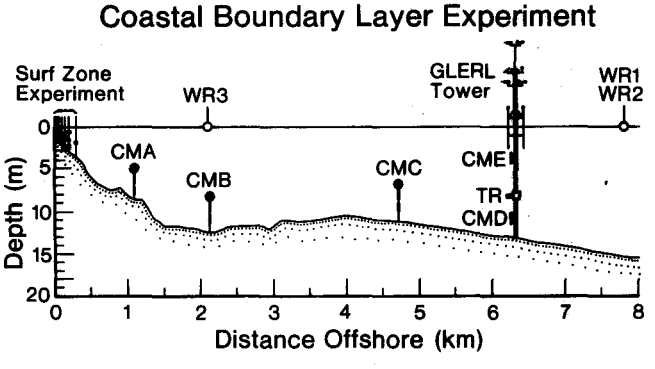
Observed synoptic (left-hand side) and simulated (right-hand side) significant wave height contours for Lake Michigan during a south wind, November 20, 1977. This indicates that the Wind Wave Model, used to simulate the wave height contours, is fairly accurate.

the range of GLERL wave measurement systems further offshore. Earlier systems required line-of-sight transmission to a shore recording station, but the new system couples onboard recording with GOES and ARGOS satellite reports to allow deployment in any part of the lakes.

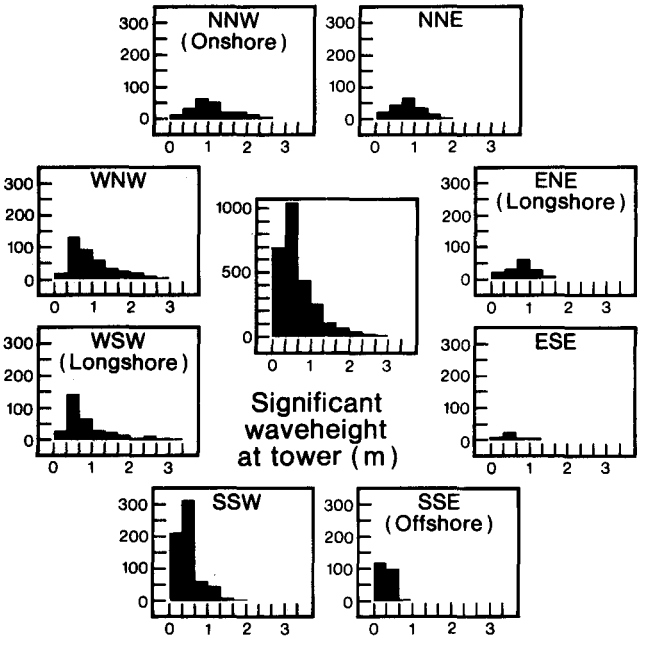
Continued analysis of wind and wave data recorded from the eight NDBC NOMAD buoys during 1981 led to two fruitful studies: the development of a generalized wave spectrum representation and a detailed testing of parametric correlations for wind waves in the Great Lakes. For over three decades, oceanographers have endeavored to develop a realistic model of wind wave spectra. A number of spectral forms have been proposed; they generally consist of empirical coefficients and exponents that differ among various authors. When applying one of these formulas in practice, it is seldom certain how close the representation is to the actual modeling or design conditions. GLERL scientists have developed a generalized form that avoids predetermining any coefficient and exponents in the spectrum representation. They can all be obtained from known parameters. The usefulness of this representation has been demonstrated with over 2,000 measured wave spectra recorded from a NOMAD buoy deployed in eastern Lake Superior during 1981. Combining this generalized spectrum representation with GLERL's Wind

Wave Model provides results similar to those produced from a conventional spectral model except that GLERL's has a simpler approach and greater computational economy. Data from the 1981 GLERL-University of Michigan Lake Erie experiment has been used to extend this model to shallow water waves. It is significantly better than other proposed formulas.

GLERL studies of the nearshore transformation of waves and currents have concentrated on two aspects of wave characteristics in finite water depth: probability distributions and spectral shape. The probability distributions of wind wave height and period are of practical and theoretical interest to oceanographers and ocean engineers. A number of wave period distributions have been proposed, but none is universally accepted. GLERL scientists have used Lake Erie data to examine the probability distributions for both deep and shallow water waves. It was found that both the Rayleigh distribution for wave heights and Longuet-Higgins distribution for wave periods overpredicted the highest waves, while underpredicting the intermediate waves. Application of a two-parameter Weibull distribution to both height and period data with parameters determined from the data improved the accuracy of the fit significantly.



Cross section of the Coastal Boundary Layer Experiment instrument array. CMA-E represent the five vector averaging current meters, WR1-3 are Waverider buoys, and TR is a transmissometer, an instrument for measuring water transparency. In addition, there were four Zwartz wave gauges mounted on the solar-powered tower to record directional wave information and mean water level and meteorological instruments to measure wind velocity and direction.



Histograms for significant wave height (in meters) for various wind directions at the GLERL tower deployed in Lake Erie during July-October 1981. These data were collected as part of the Lake Erie Coastal Boundary Layer Experiment. Data from that experiment have been used to examine the probability distributions for both deep and shallow water waves.

ENVIRONMENTAL SYSTEMS STUDIES

The focus of the Environmental Systems Studies Group is on synthesis and applied modeling. The objectives of the group are (1) to predict the effects of management alternatives and human-induced changes on Great Lakes ecosystems, (2) to develop and apply optimization, uncertainty, and risk analysis methods to the solution of water resource problems, (3) to develop strategies that will minimize the risks to human and ecosystem health resulting from pollutant inputs or other perturbations to the Great Lakes, and (4) to develop models that will facilitate the development of wise and cost-effective environmental management strategies.

Program Development

The Environmental Systems Studies Group, formerly known as the Special Projects Group, was reactivated at the end of FY 1984 and is currently undergoing program development. Research to be conducted by the Environmental Systems Studies Group will be holistic in scope and directed toward understanding and optimizing relationships between the human, economic, and ecological systems of the Great Lakes Region. By necessity, this group will draw heavily on the knowledge generated by other groups, both inside GLERL and from outside the laboratory. Research will cover a variety of temporal and spatial scales as dictated by the questions under investigation.

Central to the Environmental Systems Studies approach will be the premise that cost-effective management of the Great Lakes requires that the lakes be managed as an integrated system. Management actions applied to one lake or one use will affect the other lakes or other uses. For example, a fisheries management plan for Lake Michigan should not be developed without taking into account the influences it will have on Lake Erie fisheries. Nor should a toxics contaminant control program be implemented without weighing the economic implications of such a program. Just as modern medicine is beginning to develop an approach called holistic health care, whereby nutrition, stress management, biofeedback, and other approaches are all used to maintain and promote good health in humans (as opposed to the conventional approach of treating symptoms only), so too will a holistic management approach be needed to ensure the long-term health of the Great Lakes and the economy of the region.

Optimization, uncertainty, and risk analyses will be integral parts of work performed by the Environmental Systems Studies Group. Although used sparingly to date, these analyses should play a key role in environmental decision-making processes, just as they do in the decision-making processes that lead to the safe design of buildings and bridges. For example, building designers must determine a priori the risk (i.e., the probability) of structural failure and related human mortality that might result from a given distribution of earthquake tremors. Similarly, environmental managers must determine the risk of lowered water quality and related harm to economically important fish species that might result from a given distribution of pollutant inputs.

With increasingly uncertain estimates of model inputs (e.g., the magnitude and timing of pollutant loads) and structural attributes (i.e., how well the model corresponds to the real system), the focusing power of a model for predicting the future becomes more and more blurred; under highly uncertain conditions, the predicted statistical distribution of future ecosystem states will be wider than when inputs and model structure are known perfectly. The output from a model that has highly uncertain inputs (as is often the case with pollutants) might be normally distributed: some future states will be more likely to occur than others. The probability (risk) of an undesirable state occurring can be determined from such a distribution. If the risk is higher than is acceptable, then the environmental manager can recommend that the magnitude and timing of pollutant inputs be changed until an acceptable level of risk can be attained. Of course, creating an environment in which there are no risks from pollutants is not economically feasible. In reality, risks must be kept at acceptable levels while keeping within economic constraints. By combining risk analysis techniques with optimization techniques, minimal cost schemes can be devised that result in acceptable levels of risk.

Upper Great Lakes Connecting Channels Study

The Environmental Systems Studies Group will be the lead group in GLERL in this international (United States-Canada) and interagency (see the International and Interagency Activities Section for a list of agencies involved), multiyear study of water quality and ecosystem dynamics in the upper Great Lakes connecting channels. Areas to be studied include the St. Marys River, the St. Clair River, Lake St. Clair, and the Detroit River; all have been classified Class A areas of concern because they have previously received or now receive significant amounts of toxic industrial wastes and point and nonpoint inputs of pollutants from urban and rural areas. A detailed study plan that includes optimization, risk, and uncertainty analyses of ecosystem-economic models for the region is now under development. The plan will address such questions as (1) What combinations of inputs, outflows, ecosystem processes, and remedial actions will lead to acceptable (low risk) concentrations of toxic chemicals in the study area? (2) How cost effective are present nutrient and toxic substance control measures and how might cost effectiveness be improved? (3) What are the relative effects of toxic substances, nutrient loadings, and habitat modification on aquatic food chain dynamics? (4) To what extent do the channel's extensive submersed and emergent macrophyte wetlands influence circulation and sedimentation patterns,

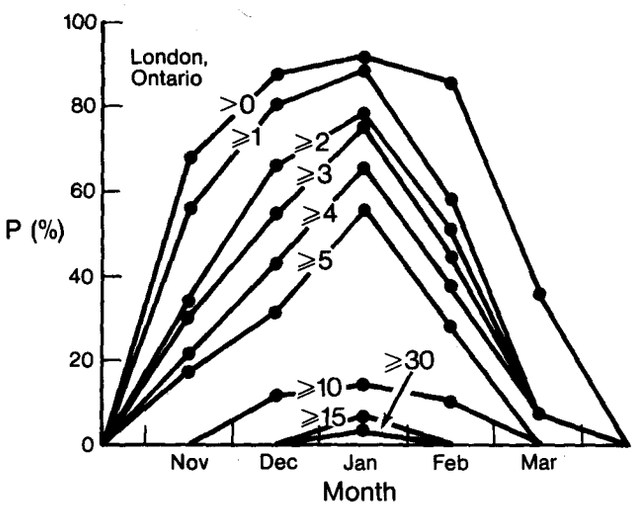
pollutant fate and transport, and the long-term survival of regional fisheries?

Lake Erie Area Environmental and Recreation Atlas

As part of a project started before formation of this group, the Ohio State Sea Grant and GLERL are collaborating to produce a *Lake Erie Area Environmental and Recreational Atlas.* This combined effort represents a new venture for GLERL and is based on the premise that much of the information developed and actively used by the Great Lakes scientific community can be used to great advantage by the general public if it is expressed in a slightly different format. The atlas, to be published in 1987, will show how data on natural atmospheric and hydrospheric phenomena can be used beneficially by recreational users. The main chapters will contain sections on (1) natural features and processes, (2) meteorological conditions, (3) lake and river conditions, (4) biotic character, (5) recreational facilities and points of interest, and (6) recreational planning. Coastal tours, shoreline vacations, and specific types of outings on both land and water will be highlighted.

Pollutant Loadings to the Great Lakes

Sound information on the timing and magnitude of pollutant inputs is necessary for understanding the behavior of the Great Lakes ecosystem. Understanding the relative importance of pollutant inputs is essential if the most cost-effective management strategy for the Great Lakes is to be found. Therefore, a portion of the Special Projects Group efforts was directed toward updating loading estimates of chloride, suspended solids, and various forms of nitrogen and phosphorus. Analyses were conducted for Water Years 1979-80 and complement previous analyses made by the Great Lakes Basin Commission for Water Years 1975-78. Because billions of dollars were spent on pollution control during the 1970's, a future comparison of these analyses can be used to evaluate the effectiveness of recommended pollution abatement measures.



Snow depth probability (P) as a function of the date (last day of the month) for a station in the area covered by the *Lake Erie Area Environmental and Recreational Atlas.* The curves are for various snow depths in inches.

INFORMATION SERVICES

The dissemination of scientific products in a form compatible with user needs is vital to fulfillment of the GLERL mission. Since research costs cannot be justified if the results are unused, a principal GLERL activity is maintenance of an advisory service as a means of providing scientific information in a form geared to user needs.

This past year, as part of that service, GLERL provided over 4,200 research products in response to almost 2,000 documented requests. Of these, 27% came from institutions of higher learning, 12% from private citizens, 31% from foreign government agencies, 7% from industry and private organizations, 16% from U.S. Federal Government agencies, and 7% from State Governments. This is in addition to regular mailings to those who have indicated interest in a semiannual listing of available publications and one or more of the five types of GLERL publications: chemistry and biology, environmental systems studies, ice, lake hydrology, and physical limnology and meteorology. But publications are but one form of environmental information. Also included are predictions and simulations produced from environmental models, forecasts and forecast techniques, descriptive or analytical information on the present or past status of one or more limnological characteristics of a lake or of the system, and data bases. Many of these involve what might be termed "technology transfers." A partial list of GLERL technology transfers effected this year and users is given below.

Technology Transfers

Sediment Trap Design, Deployment, and Recovery Techniques.
Users: Coastal Studies Institute, Louisiana State University; University of Michigan; Argonne National Laboratory; National Water Research Institute, Inland Waters Directorate; and Canada Centre for Inland Waters

Dynamic Mixing Model for Sediment Tracer Distribution.
Users: Case Western Reserve University and Pacific Marine Environmental Laboratory, NOAA

Sedimentation Estimation Methods.
Users: University of Michigan, University of Indiana, University of Minnesota, Electric Power Research Institute, and Canada Centre for Inland Waters

Water Column Sediment Monitoring Procedures.
User: IJC

Large Basin Runoff Models.
Users: IJC, U.S. Army Corps of Engineers, and consulting engineers

Climatic Water Balance Models.
User: Atmospheric Environment Service—Canada

Water Supply Forecasting Procedure.
Users: U.S. Army Corps of Engineers and IJC

Low-Level Radiometric Measurements for Sedimentation Studies.
Users: Pacific Marine Instrumentation Laboratory, NOAA, and Battelle-Northwest Laboratories

Autoradiographic Measurements.
User: University of Michigan

Lipid Analysis in Small Samples.
User: University of Michigan

Lake Ontario Phytoplankton Model.
User: University of Minnesota

Nutrient Measurements.
Users: University of Michigan, U.S. Fish and Wildlife Service, and U.S. EPA

Improved Wind Direction Measuring Instruments for Shipboard Applications.
User: R.M. Young Co.

Wave Forecast Model.
Users: NWS, Canada Centre for Inland Waters, U.S. Army Corps of Engineers, and University of Michigan

Improved Hazardous Spill Model.
Users: U.S. Coast Guard, NWS, and University of Michigan

Commercial Fishing Zone Area Calculations.
User: NOAA Sea Grant

GLERL reviews and critiques Draft Environmental Impact Statements in support of NOAA's Office of Ecology and Environmental Conservation. The Draft Environmental Impact Statements are required by law to be submitted by the company or agency planning the activity for review by all interested or affected entities. They are intended to ensure that proposed activities in and around the lakes have been designed to have little or no long-term adverse effects on the environment.

Other responsibilities carried out under this activity include identification of, and communication with, potential users; determination of user interests and needs; and liaison between the laboratory and users. Committee and board memberships and attendance at workshops, conferences, and other scientific gatherings are some means of informing people about GLERL; certain special publications, such as the technical plan and this annual report, are others. Advice was provided to such widely diverse users as the Council on Environmental Quality—Executive Office of the President; the White House Office of Science and Technology Policy; the NWS (an improved wave forecast model); several committees and boards of the IJC; numerous Great Lakes area radio stations, newspapers, and magazines; and an Egyptian scientist.

International treaties and agreements between the United States and Canada, such as the Water Quality Agreement of 1978 and the Boundary Waters Treaty of 1909, are considered and agreed to at the Federal level. Legislation pertaining to navigation, water quality, and water levels has been enacted by the Congress. GLERL has advised both the legislative and executive branches on these and other matters.

Publications Unit

Publications are a major GLERL product, and a critical part of the effort is to make research findings available to a broad spectrum of users for application to environmental problems and decisions. The publications unit has responsibility for the preparation of manuscripts, including editing, typing, proofreading, and procurement of graphics. Manuscripts are edited, typed, and proofread in house, while graphics and photographic services are procured under contract. Manuscripts are formatted according to the requirements of the publication form: articles and notes in professional journals, NOAA technical reports and memoranda and data reports, or in-house reports. During the last fiscal year, 44 manuscripts were processed.

This past year, the publications unit purchased spelling checker software to further upgrade their word processing equipment. Advances in software and hardware are constantly being evaluated to find more efficient ways to produce GLERL output.

Every 6 months, a listing of GLERL publications is sent to a mailing of individuals who have requested that list, and requests are filled until supplies are exhausted. Copies of publications are also available through the National Technical Information Service, Springfield, VA.

INTERNATIONAL AND INTERAGENCY ACTIVITIES

The GLERL program includes support activities for, and participation in, the work of many agencies in both the United States and Canada. This is one of the mechanisms whereby research products are used; in addition, GLERL obtains information on requirements for environmental information to support planning and management activities. This user need information is helpful in shaping future research programs.

International Joint Commission

GLERL staff members were active on several IJC boards and committees including the Levels and Flows Advisory Board; the Technical Information Network Board; the Health of Aquatic Communities Work Group; the Task Force for Lake Michigan Surveillance; the Task Force for In-Place Sedimentary Contaminants; the St. Marys, St. Clair, and Detroit Rivers and Lake St. Clair Task Force of the Surveillance Work Group; the Aquatic Ecosystem Objective Committee Work Group; the Modeling Task Force of the Science Advisory Board; and the Lake Erie Task Force of the Surveillance Work Group.

Great Lakes Commission

A GLERL staff member serves on two subcommittees of the Great Lakes Commission's Natural Resources Management Committee—the Subcommittee on Land and Air and the Subcommittee on Water. The Natural Resources Management Committee is responsible for initial commission consideration of all natural resource issues and legislation. The two subcommittees cover broad spectra of related resource management and environmental protection/pollution control programs administrated at both State and Federal Government levels.

International Association for Great Lakes Research

Scientists at GLERL actively participate in activities of the International Association for Great Lakes Research, a major mechanism of scientific communication. Senior GLERL scientists serve as President and Secretary of the Association.

Regional Response Team for Spills of Oil and Hazardous Substances

GLERL continues to play a role in spill response in the Great Lakes by providing the alternate Department of Commerce representative to the Regional Response Team (RRT) and supporting the NOAA National Ocean Service regional Scientific Support Coordinator (SSC). The RRT is a standing committee that evaluates and revises the regional contingency plan for response to spills of oil and hazardous materials. It may be called upon to provide specialized resources in response to a spill. A full-time SSC is assigned to work at GLERL. The SSC establishes and maintains contacts with all U.S. Coast Guard Marine Safety Officers in Coast Guard District 9, chemical manufacturers, and the regional scientific community; identifies vulnerable resources in conjunction with State, Federal, and Canadian agencies; and assists in the preparation of regional and local contingency plans. When a spill occurs, the SSC acts as liasion between the on-scene coordinator and the scientific community and supplies oil spill trajectory information, chemical and safety data, and immediate, localized resources-at-risk information.

As part of this work, a Great Lakes-wide environmental sensitivity mapping program has been initiated. Work is underway on the St. Lawrence River, Lake Erie, and the Detroit-St. Clair River System. GLERL scientists have provided assistance to the U.S. Coast Guard and the U.S. EPA in regional spills and have participated in drills conducted by the U.S. Coast Guard and NOAA's Office of Marine Pollution Assessment (now OAD).

Joint United States-Canadian Ice Information Working Group

A GLERL scientist is the U.S. Cochairman of this group, the primary mission of which is to coordinate the gathering and dissemination of ice information and data for the Great Lakes.

Interagency Great Lakes Hydromet Steering Committee

The Interagency Great Lakes Hydromet Steering Committee was established to coordinate the efforts of the participating U.S. Government agencies in planning and implementing a Great Lakes Hydrometeorological Forecast System. Participating agencies are NOAA, the U.S. Geological Survey, and the U.S. Army Corps of Engineers.

Interagency Upper Great Lakes Connecting Channels Study

The laboratory has recently become involved as a member of the Management Committee in an international (United States-Canada) and interagency, multiyear study on water quality-marine pollution problems in the upper Great Lakes connecting channels (the St. Clair River, Lake St. Clair, the Detroit River, and the St. Marys River). The United States agencies are the EPA, NOAA, the Army Corps of Engineers,

the Fish and Wildlife Service, and the Michigan Department of Natural Resources. The Canadian agencies are the Environmental Protection Service, Department of the Environment; the National Water Research Institute, Inland Waters Directorate; the Department of Fisheries and Oceans; and the Ontario Ministry of the Environment. The primary marine pollution problems to be studied are synthetic organic pollutants and nutrient overenrichment.

International Coordinating Committee on Hydraulic and Hydrologic Data

Because much of the Great Lakes data base is used internationally, Canadian and United States users of hydraulic and hydrologic data formed a coordinating committee in 1953. The objectives of this committee are to reach agreement on hydraulic, hydrologic, and related physical data concerning the Great Lakes; to assist agencies in pursuing studies requiring international data; to provide basic data to anyone with a recognized need; to reach agreement on methods and procedures for measuring, collecting, and storing pertinent data; and to publish coordinated data. GLERL participates on the River Flow Subcommittee, which is charged with coordinating data on tributary stream inflow to the Great Lakes System, coordinating studies of flow in the connecting channels and the St. Lawrence River, and establishing procedures for updating and disseminating river flow data.

NOAA Sea Grant

A joint project between GLERL and the Ohio State Sea Grant Program to develop an environmental and recreational atlas for Lakes Erie and St. Clair was continued. GLERL staff participated in the University of Wisconsin Site and Subprogram (Microcontaminants) Reviews, and the Ohio State University Site Review.

NOAA

Activities involving participation with other NOAA units included the Marine Environmental Quality Task Force, the Quality Assurance Working Group, the Manned Undersea Research and Technology Program-National Marine Fisheries Service, the New Bedford Harbor PCB Contamination Assessment Team, the Marine Environmental Quality Review, and the Estuarine Review. GLERL has also worked extensively with the NWS in the United States and with the Atmospheric Environment Service in Canada on an operational, interactive wave model.

Other Activities

GLERL scientists participated in a number of other international and interagency activities, including the activities of the International Association of Sediment Water Science, Science Education Administration of the U.S. Department of Agriculture, NOAA-U.S.Geological Survey Coordinating Committee for Hydrologic Research, and the International Association for Hydrologic Research. GLERL scientists were also active in providing information to several local agencies, such as the Kalamazoo River Preservation Agency and the Technical Advisory Committee of the Huron River Watershed Council.

FACILITIES

GLERL's laboratory and support facilities are an integral part of its research program. These are housed in four leased buildings in Ann Arbor containing offices and support facilities, at the University of Michigan North Campus, and in a warehouse and dock facility at Monroe, MI.

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. Engineers and technicians in this unit work closely with GLERL researchers to ensure that instruments are compatible with the purpose of the experiment.

This past year, marine instrumentation laboratory personnel deployed and retrieved four Marsh McBirney, Inc., model 585 electromagnetic vector averaging current meters (VACM's) in the St. Clair and Detroit Rivers. They also deployed 32 EG&G model 610 VACM's and 13 model 314 acoustical releases in Lake Michigan. They have now recycled the inventory of eight mini-TOD buoys numerous times. A "crush-proof" package for these units is under development. It will be valuable for ice tracking applications.

Various biological and chemical sampling and laboratory instruments were designed, fabricated, and maintained. Efforts to integrate these laboratory instruments with GLERL's computer facilities continue.

In addition to a normal inventory of 45 VACM's and 15 acoustical releases, some new instruments were acquired to advance GLERL capabilities. These include a WRIPS buoy that processes wave spectra and wave statistics on board and transmits data to a GOES satellite; an acoustical Doppler current profiler; four ACM-2 acoustical current meters; a Hewlett-Packard 75 calculator-based system installed on board the RV *Shenehon* for acquisition of meteorological data, as well as transparency, temperature, and depth casts and conversion of navigational coordinates; and a similar Hewlett-Packard 75 system used for recording and processing test data for current meters in GLERL's flow tank.

Chemistry Laboratories

There are two major types of compounds analyzed by GLERL's chemistry laboratories: trace synthetic organic materials and nutrients. The synthetic organics, primarily PAH, are extracted from various ecological matrices by Soxhlet extraction and cleaned on Sephadex and silica. Separation and analysis are done on glass capillary-equipped Hewlett-Packard gas chromatographs equipped with photo and flame ionization and electron capture detectors and on a Waters liquid chromatograph equipped with ultraviolet and fluorescent detectors.

Vector averaging current meter. The marine instrumentation laboratory deployed 36 current meters this past year, including 4 in the St. Clair and Detroit Rivers and this one in Lake Michigan. The work done by this group in maintaining and calibrating current meters and other instruments is vital to the success of field experiments.

The uptake and release rates of selected PAH by benthic organisms and the sorption of PAH onto Great Lakes particulate matter are being followed through carbon-14- and tritium-labeled compounds. Compounds are extracted, cleaned on thin layer or high-performance liquid chromatography, and counted by liquid scintillation.

A great many water samples from Lake Michigan were analyzed for various forms of phosphorus, silica, and other water quality indicators (e.g., transparency) as part of the Lake Michigan Ecosystem Experiment to define processes contributing to phytoplankton dynamics, bacterial growth, and ecosystem carbon flow in Lake Michigan.

Micromethods have been developed to measure the lipid content of individual benthic animals. The lipid contents of major species of benthic invertebrates are being examined to help estimate the importance of these animals in converting detrital energy into a form (invertebrate biomass) available to fish and other predators (e.g., *Mysis relicta*).

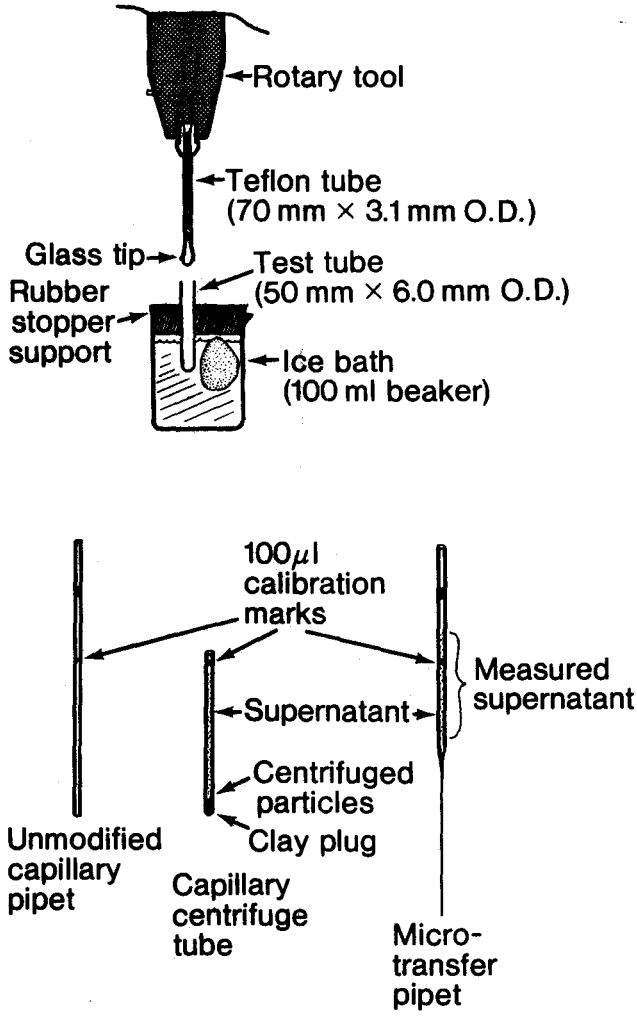
Studies are being done to demonstrate the quantitative importance of animals relative to microbes in converting organic nutrients in the sediments into inorganic forms.

Biology Laboratories

The biology laboratories' equipment and instrumentation include a multichannel Coulter Counter used to measure particle-size selection and zooplankton grazing on natural lake algae and seston. An array of instruments, including a liquid scintillation spectrometer, is used to investigate nutrient uptake, growth rates, competition for nutrients by algae, and cycling rates of selected algal nutrients. Facilities also include a full complement of sampling gear and instrumentation, growth chambers, stereo and inverted microscopes, and cultured populations of phytoplankton and zooplankton species for model studies. A mobile trailer has been fitted for lakeside investigations of the physiology and feeding rates of planktonic and benthic organisms.

Shipboard and shoreside incubators have been constructed to simulate ambient light and temperature climates for as many as two dozen 20-liter growth chambers and have been used for zooplankton grazing experiments. Submersible light meters with hemispherical and spherical sensors are used to record incident and underwater photosynthetically active radiation.

The process of zooplankton feeding and other zooplankton-algal interactions occupies a central role in models of eutrophication and toxic organic cycling. Progress in developing mechanistic models has been hindered by the inability to observe the feeding process directly because of the small size of both zooplankton and algae and the high frequency (50 Hertz) of zooplankton appendate movement. Using the recently developed tool of high-speed microcinematography, GLERL scientists, working with scientists at Skidaway Institute of Oceanography, made the first direct observations of these processes for a freshwater copepod. These observations and those of others on marine copepods suggest the occurrence of zooplankton-food interactions not previously suspected. To study the feeding mechanisms of Great Lakes zooplankton in detail, GLERL is now in the process of duplicating the microcinematography apparatus at Skidaway Institute. A special feature of this laboratory will be accurate temperature control. Because many Great Lakes zooplankton are boreal species, the apparatus will be placed in a cold room at controlled temperatures between 2° and 20°C.



Schematic diagram of microtissue grinder (top) and capillary centrifuge and transfer tubes (bottom) developed to analyze individual benthic invertebrates for lipids. Lipid measurements on these animals provide information needed to understand energy and contaminant dynamics in the Great Lakes.

Ice Laboratory

The ice laboratory makes it possible to extend the winter measurement season and to expand opportunities for measurements of ice characteristics. The facility consists of a work room and an ice storage room. The work room, held at -7.0°C, can be used to conduct experiments on natural ice harvested in previous field seasons, as well as to calibrate instrumentation for the ice research program in an environment similar to that encountered in the field. The interior walls are painted flat black to facilitate optical experiments.

Ancillary equipment includes a high-intensity light source, a mercury line source, and an optical bench. Adjacent to the work room is a smaller room held at -29.0°C. In addition to providing low temperature storage for ice samples and a limited number of field samples from the chemistry and biology programs, the facility serves as an additional calibration room.

Particle Dynamics Laboratory

Natural and artificially produced radionuclides introduced into the Great Lakes serve as excellent model contaminant and process indicators. The particle dynamics laboratory has equipment to measure very low levels of many such radioactive substances present in water, sediment, and biota. The

laboratory was established in 1981 as part of the cooperative program with the University of Michigan, Great Lakes and Marine Waters Center.

Facilities include several gas-flow proportional counters with automatic sample changers for total alpha and beta counting. These systems are used both for low-level counting of environmental samples and for laboratory radiotracer studies. The laboratory has one absolute geometry alpha spectroscopy system and has recently added four additional alpha spectroscopy modules. This addition is a significant improvement in capability for extremely low-level, high resolution measurement of alpha emitting radionuclides, such as the plutonium and thorium isotopes and polonium-210. There is now an extensive capability for gamma analysis. A well-shielded 3-by-5-inch sodium iodide detector is used for routine measurement of fallout cesium-137 in sediment and in trap samples. Several 2-by-2-inch sodium iodide detectors are presently used in gamma scan systems. In these systems, the detectors are housed in extremely well-collimated lead shields mounted on hydraulically operated platforms. The gamma-scan systems are used to determine the vertical distribution of gamma emitting tracers added to laboratory microcosms containing sediments, water, and zoobenthos. In addition, the laboratory includes a major gamma detection system—a high volume, high resolution, well-shielded lithium-drifted germanium detector coupled to a state-of-the-art multichannel analyzer. The system is interfaced with the GLERL VAX 11/780 computer, allowing online data processing. The system is designed for simultaneous determination of many radioisotopes, including beryllium-7, potassium-40, cesium-137, and other fallout radionuclides. The system may also be used for quantitative determination of stable element concentrations via neutron activation analysis. The alpha spectroscopy facility is used primarily to date sediment cores from the Great Lakes and other lakes, as well as coastal marine systems, by means of the lead-210 method. The gamma spectroscopy system is in constant use for analysis of tracers that characterize recent sediment mixing and deposition processes. Also analyzed by both methods are numerous trap samples, which allow comparison of in-lake radionuclide fluxes with atmospheric delivery rates. A new project on radionuclide transport and storage in the dynamic system of Lake St. Clair and its connecting channels will require an expanded gamma counting facility.

Computer Facility

The GLERL computer facility supports data acquisition, data reduction, graphics, and modeling applications for scientists and technicians in the research groups.

In December 1983, a superminicomputer was installed to support general purpose applications (e.g., graphics, data reduction and analysis, modeling, word processing). The new system is a VAX 11/780 with 14-megabyte memory, 1,700-megabyte disk storage, two 1,600/6,250-bytes-per-inch tape drives, five input-output channels, 48 asynchronous and one synchronous port, and three printers. Graphics peripherals supported by the system include a Calcomp plotter, Tektronix terminal with hardcopy, a Printronix printer/plotter, and 20 graphics terminals.

The GLERL VAX 11/780 communicates with the NOAA Cyber 750 mainframe in Boulder, CO, via a dedicated 9,600-baud circuit. Within a year, it is expected that the Boulder link will be replaced by a link to a Cyber 205 at the NBS-ERL Scientific Computing Facility in Gaithersburg. This facility will offer a very powerful computing capability and will support GLERL modeling applications.

A Hewlett-Packard 9603 minicomputer is used to support data acquisition tasks. It is used to collect data from NWS's weather and marine circuits; to process tapes from field instrumentation, such as tracking satellite-transmitting drifter buoys; and to obtain data from instrumented towers.

Research Vessel *Shenehon*

The *Shenehon* is the primary platform used in support of open lake field investigations. The vessel is a 65.6-foot-long converted T-boat, with a 6.5-foot mean draft, a 600-nautical-mile cruising range, and a 10-knot cruising speed. A hydraulic articulated crane with a 1,630-pound lifting capacity at 21-foot extension 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. An onboard laboratory facilitates onsite physical, chemical, and biological experiments. 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.

During FY 1984, the *Shenehon* was based at the U.S. Army Corps of Engineers' boat yard at Grand Haven, but made two extended cruises through the upper Great Lakes. The corps also provided warehouse facilities and space for a mobile shore-based laboratory at that location.

In a study to quantify the vertical mass and chemical flux during thermal stratified and nonstratified periods, sediment trap moorings were deployed at four locations in Lakes Michigan, Superior, and Huron during July and September 1984 for collections during the stratified period and winter. These traps will be retrieved in July 1985.

Sediment traps and an instrument tripod supporting a current meter, transparency meter, and temperature sensor were deployed west of South Haven, MI, to study bottom currents, resuspension of sediments, and the diffusion of soluble ions in the near-bottom water. The study was done in cooperation with Dr. Barry Lesht of Argonne National Laboratory and Dr. Thomas Tisue of Clemson University.

Biological work supported by the *Shenehon* during the past year included benthic, planktonic, and bacterial experiments

studying nutrient cycling in the aquatic environment and the long-term effects of toxic material inputs. As part of a toxics materials study, specimens of the organisms *Pontoporeia hoyi* and *Mysis relicta* were collected in Lakes Huron and Michigan to measure uptake of PAH. The *Shenehon* also supported a Lagrangian study that used a satellite-tracked surface drogue to follow and ensure sampling in the same water mass. Sediment traps were suspended below the drifter. Other operations included the deployment and retrieval of moorings, light and temperature studies, plankton net tows, and collection of water samples by hydrographic casts and pumping.

In continued cooperation with the University of Michigan, the *Shenehon* was used to collect water and bottom sediment samples and light and temperature data in the vicinity of Grand Haven and Muskegon, MI, and to train students in oceanographic techniques.

In support of the Physical Limnology and Meteorology program, the *Shenehon* crew took measurements at the NDBC NOMAD buoy in southern Lake Michigan for verification of output of meteorological and underwater sensors. These buoy data are used in GLERL investigations and are routinely used in NWS forecasts. As part of another cooperative program with NDBC, the vessel was used to deploy and retrieve satellite-tracked drogues that tracked water current trajectories in Lake Michigan.

In the data collection phase of an investigation of the rotational mode currents induced in Lake Michigan in May and June by suddenly imposed wind stresses, the vessel was used to deploy eight current-meter moorings located west of South Haven. Sediment traps were also deployed near the current-meter moorings to take advantage of the water current data to provide greater insight into the mass movement of settling of resuspended particles in Lake Michigan.

A "wire line" sweep technique designed by GLERL personnel was used successfully four times during FY 1984 to recover submerged sediment traps. These recoveries resulted in little or no loss of data and a considerable savings because divers were not used.

This past year, a Hewlett-Packard 75 calculator-based data acquisition system using a cassette recorder was installed on the *Shenehon* to record depth, temperature, transparency, and meteorological data in digital format. This has resulted in a significant time savings since the data from the cassette can be quickly entered into the VAX 11/780 computer and is then readily available to all users.

Deployment of a water sampler tripod for a near-bottom experiment. One important function of the RV *Shenehon* is the deployment and retrieval of the instruments used to collect basic data.

Library and Information Services

GLERL library staff provides library and information services necessary to laboratory research activities by maintaining a tailored research collection and offering special retrieval services when the collection cannot meet the documentation or information needs of the researchers. The current collection consists of research materials in the areas of climatology, hydrology, hydraulics, ice, limnology, mathematical modeling, meteorology, oceanography, sedimentation, and wave motion, with emphasis on the Great Lakes Basin. Contaminant organics and nutrients are now being included as major subject areas. Holdings include almost 3,000 books, over 3,500 unbound periodical volumes, and over 2,700 technical reports (excluding an estimated 200 books, 2,300 reports, and 1,200 unbound periodical volumes kept in a remote storage location). Space limitations have necessitated both local and distant storage facilities.

Library staff performs reference, interlibrary loan, photocopying, acquisition, circulation, and bibliographic services, including online information retrieval, for laboratory-affiliated personnel. In addition, the staff expedites on-demand document retrieval and increases reference capability on behalf of GLERL scientists though onsite access arrangements with the University of Michigan library system. Limited services to nonlaboratory-affiliated individuals are provided upon special request.

During FY 1984 the GLERL Library Automated Retrieval System (GLARES) was rewritten, over 230 current periodical titles received, over 400 interlibrary loans retrieved, and over 100 online bibliographic searches performed. GLARES, an in-house technical report catalog, was converted to the new GLERL VAX 11/780 superminicomputer and enhanced to

permit interactive searching by researchers using their desk terminals. The system now permits browsing, boolean logic, cross references, and multiple access points.

The Michigan Library Consortium (MLC) was added to the list of networks through which the library seeks to cooperate with other libraries and information centers to improve services and share resources.

In FY 1985 the library plans to further expand online bibliographic searching capabilities through the addition of another database collection—QL/Search. The Canadian data bases in QL/Search are expected to provide valuable access to additional environmental reports on the Great Lakes Basin. Staff will also continue refining formats in portions of the GLARES catalog and adding records. Further, the library hopes to upgrade its electronic communication by the addition of a specialized microcomputer. The new equipment will enhance communications for interlibrary loans, cataloging, and bibliographic searching.

STAFF AS OF SEPTEMBER 30, 1984

	Permanent Employees	
	Full Time	Part Time and Intermittent
Office of Director	11	3
Lake Hydrology Group	10	1
Ecosystems and Nutrient Dynamics Group	9	4
Synthetic Organics and Particle Dynamics Group	9	4
Environmental Systems Studies Group	1	
Physical Limnology and Meteorology Group	11	4
TOTAL	51	16

Assel, R.A.	LH	Kistler, R.D.	PLM
Aubert, E.J.	OD	Laird, G.A.	END
Bell, G.L.	SOPD	Landrum, P.F.	SOPD
Bennett, J.R.	PLM	Lang, G.A.	END
Berry, J.S.	OD	Lawton, B.J.	LH
Bolsenga, S.J.	OD	Lee, J.P.	OD
Booker, H.L.	PLM	Leshkevich, G.A.	LH
Bramlet, R.H.	OD	Liebig, J.R.	END
Burns, W.R.	SOPD	Liu, P.C.	PLM
Campbell, J.E.	PLM	Lojewski, N.L.	END
Carrick, B.J.	LH	Lynn, E.W.	PLM
Cichocki, E.A.	END	Malczyk, J.M.	END
Clites, A.H.	PLM	Mark, S.V.	OD
Croley, T.E., II	LH	McCormick, M.J.	SOPD
Del Proposto, D.J.	OD	Miller, G.S.	PLM
Derecki, J.A.	LH	Miller, T.C.	PLM
Dungan, J.E.	PLM	Moorhead, N.R.	SOPD
Dunivan, E.M.	OD	Morse, D.V.	SOPD
Eadie, B.J.	SOPD	Muzzi, R.W.	PLM
Fahnenstiel, G.L.	END	Nalepa, T.F.	END
Faust, W.R.	SOPD	Noble, P.E.	OD
Field, L.P.	PLM	Norton, D.C.	LH
Fontaine, T.D.	ESS	Quigley, M.A.	END
Frez, W.A.	SOPD	Quinn, F.H.	LH
Gardner, W.S.	END	Robbins, J.A.	SOPD
Gray, M.J.	SOPD	Saylor, J.H.	PLM
Grimes, J.E.	SOPD	Scavia, D.	END
Hartmann, H.C.	LH	Schwab, D.J.	PLM
Haskin, V.	OD	Soo, H.K.	PLM
Hawley, N.	SOPD	Spalding, G.E.	OD
Herche, L.R.	OD	Stubblefield, B.	LH
James, O.L.	OD	Tarapchak, S.J.	END
Kelley, J.M.	OD	Vanderploeg, H.A.	END
Kelley, R.N.	LH		

LH—Lake Hydrology Group
OD—Office of Director
SOPD—Synthetic Organics and Particle Dynamics Group
PLM—Physical Limnology and Meteorology Group
END—Ecosystem and Nutrient Dynamics Group
ESS—Environmental Systems Studies Group

PUBLICATIONS

A 6-month listing of available publications can be obtained from

Information Services
Great Lakes Environmental Research Laboratory
2300 Washtenaw Avenue
Ann Arbor, MI 48104

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CONTRACTS AND GRANTS DURING FY 1984

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
C.E. Herdendorf	Ohio State University	Lake Erie Environmental and Recreational Atlas
J.T. Lehman	University of Michigan	A Dynamic Lake Ecosystem Model
B.M. Lesht	Argonne National Laboratory	Benthic Nepheloid Layer in Southern Lake Michigan
G.A. Meadows	University of Michigan	Airborne Radar Synoptic Wave Observations
C.H. Mortimer	University of Wisconsin (Milwaukee)	Coupling of Physical and Biological Dynamics in Large Lakes
C.H.Mortimer	University of Wisconsin (Milwaukee)	Inertial Motion and Related Internal Waves
C.H. Mortimer	University of Wisconsin (Milwaukee)	Synthesis Report on Lake Erie Research
D. Nelson	Argonne National Laboratory	Removal of Radionuclides From Watersheds of the Great Lakes
C.P. Rice/P.A. Meyers	University of Michigan	Partitioning and Cycling of Toxic Organics
R. Rossman	University of Michigan	Records of Contaminant Fluxes
M.S. Simmons	University of Michigan	Photochemical Degradation
E.F. Stoermer	University of Michigan	Phytoplankton Population Analysis
D.S. White	University of Michigan	Redistribution of Sediment Bound Toxic Organics