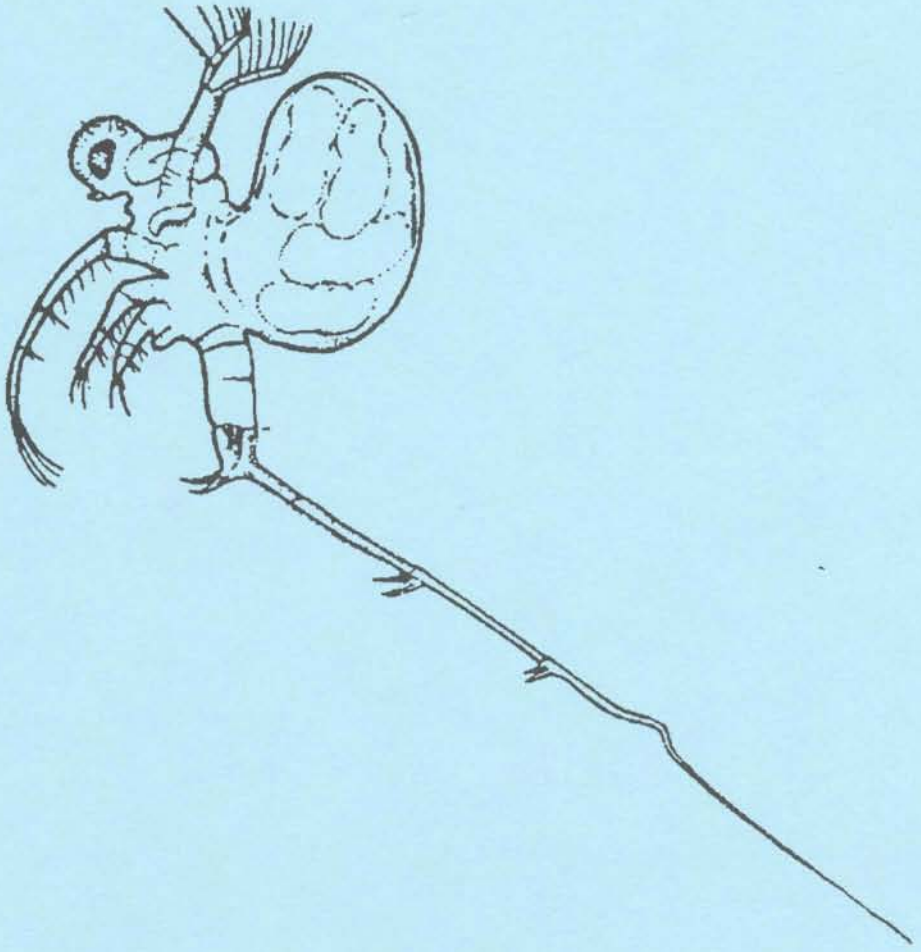
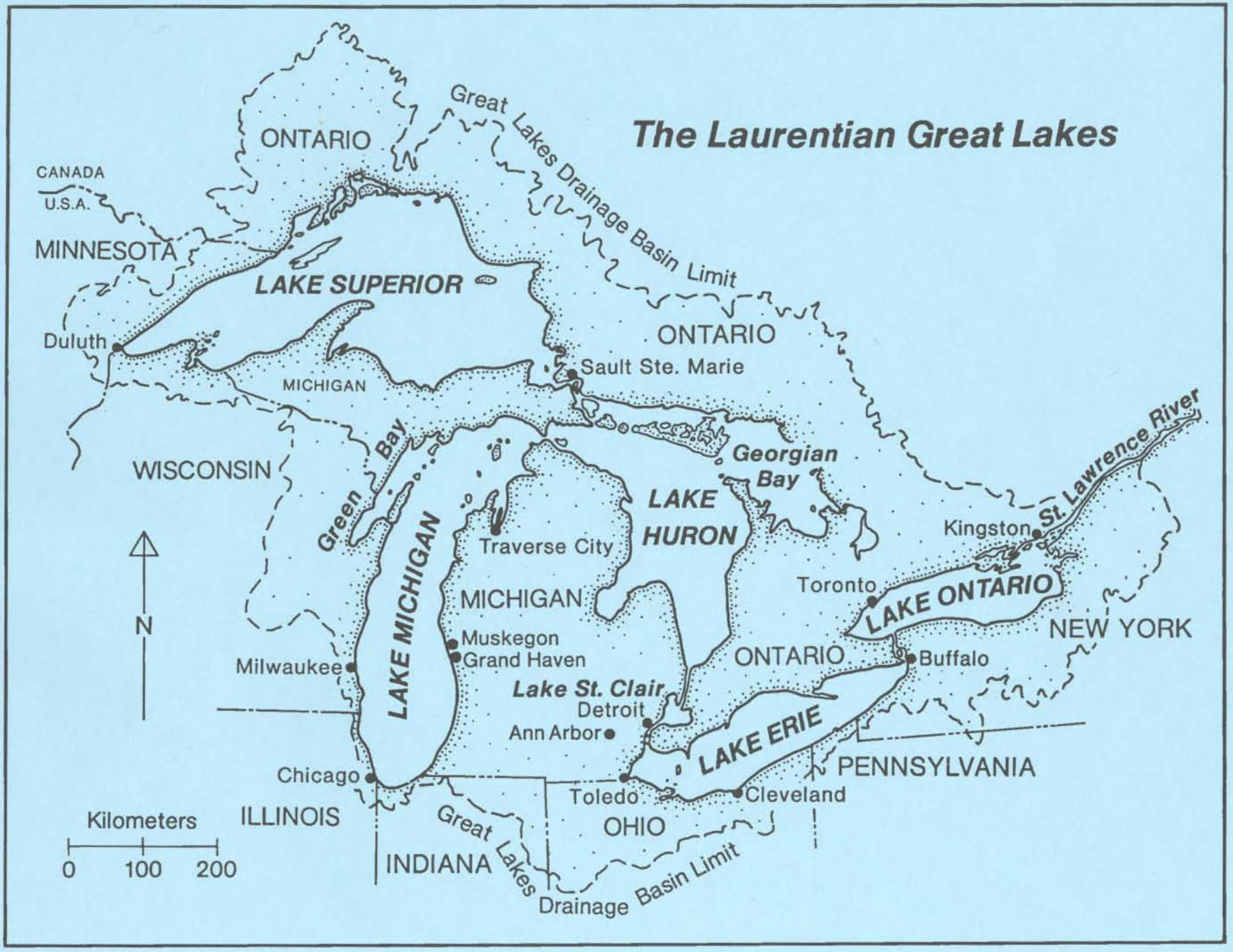
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY



ANNUAL REPORT FY 1989

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Environmental Research Laboratories



On the cover. Bythotrephes, *a Great Lakes invader. Redrawn from Berg, D.J., and D.W. Garton. Seasonal abundance of the exotic predatory cladoceran,* Bythotrephes cederstroemi, *in western Lake Erie.* Journal of Great Lakes Research *14:479-488 (1988).*

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY ANNUAL REPORT FY 89

DIRECTOR

Alfred M. Beeton

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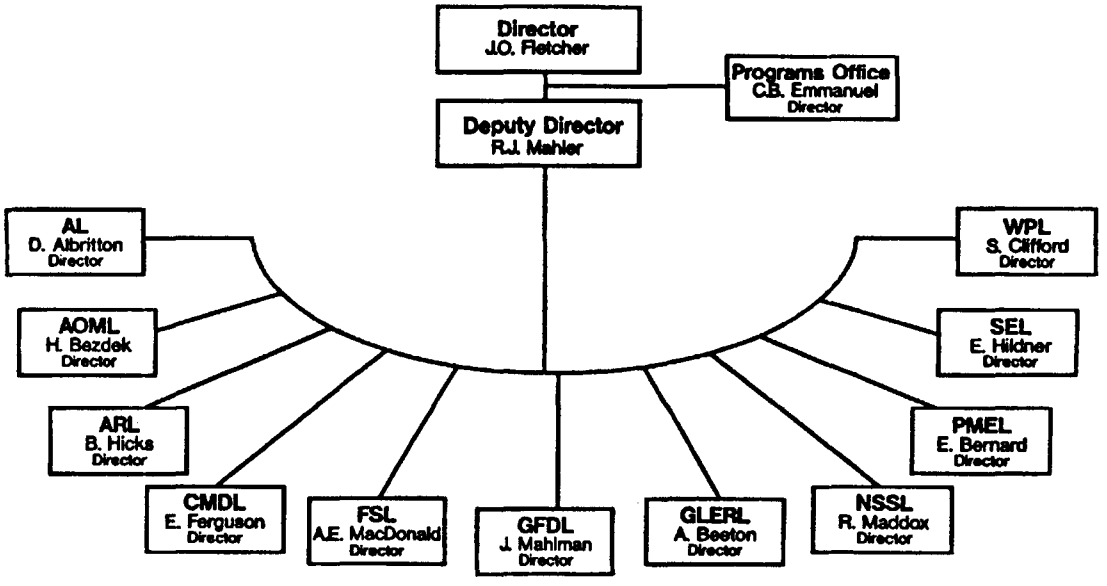


Organization structure of the Environmental Research Laboratories.

The Great Lakes Environmental Research Laboratory (GLERL), located in Ann Arbor, Michigan, is one of eleven environmental laboratories operated by the National Oceanic and Atmospheric Administration (NOAA), Office of Oceanic and Atmospheric Research (OAR), through the Environmental Research Laboratories (ERL) Directorate located in Boulder, Colorado.

GLERL's mission is to conduct integrated interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters, with a special emphasis on the Great Lakes. GLERL's research has traditionally been focused on investigations to improve our understanding of, and ability to predict, the biological, chemical, and physical processes occurring in natural ecosystems. Such processes affect the fate and effects of pollutants, the cycling and through-put of nutrients and energy within the food chain, water quality and water quantity (lake levels and the hydrologic cycle), and may pose a hazard to the human populations using the natural resources of the ecosystem.

In addition, GLERL cooperates closely with other federal, state, and local agencies, private industry, academia, and the general public on major environmental projects in the Great Lakes such as the Green Bay Mass Balance Project (page 25) funded partially by EPA and partially from GLERL base research funds.

The products of GLERL's research are made available on a regular basis as scientific publications, NOAA Technical Series reports, computer programs and computer-based models, brochures, posters, and presentations at scientific and public meetings. These products are used by government, educational, and private organizations for purposes ranging from pure information to actual applications and operations. During FY 89, GLERL authors produced 54 scientific publications and GLERL staff presented 81 talks at scientific and public meetings and in schools.

This annual report describes the significant activities and accomplishments of GLERL staff during the period October 1, 1988 through September 30, 1989. The scientific program descriptions are organized in sections by scientific groups and projects within each group are described.

GLERL in Transition

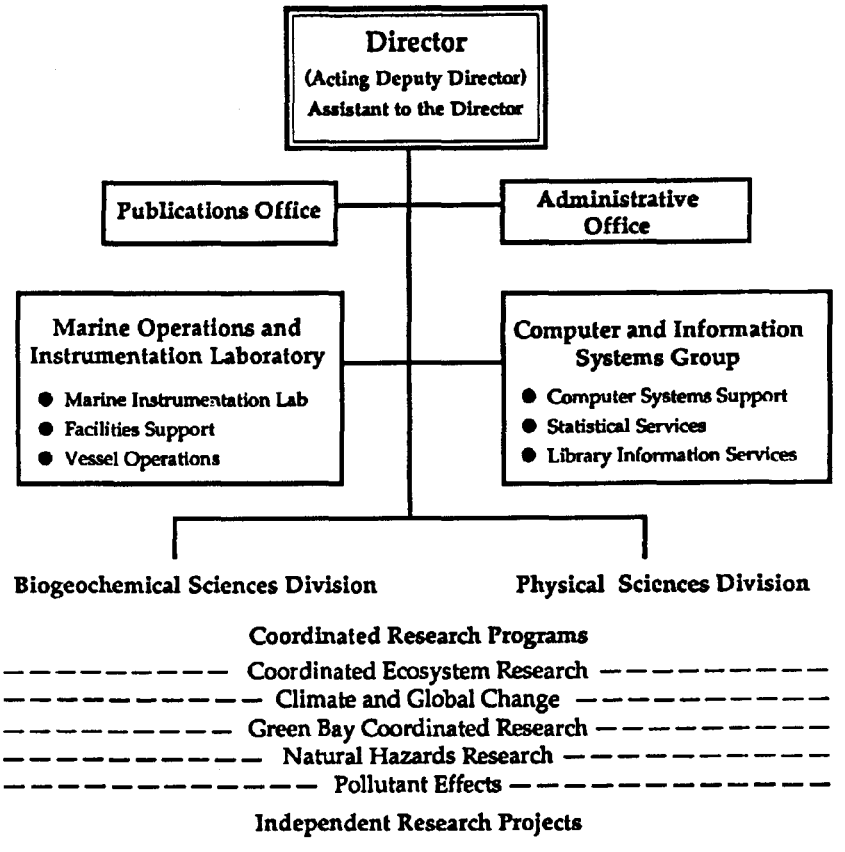


Figure 1. GLERL's current organization, beginning in FY90.

In our FY 88 Annual Report, we noted that GLERL had begun a thorough review of its programmatic and functional organization in a deliberate effort to examine and assess where GLERL should be heading as we enter the 1990s . A planning retreat involving all of GLERL's senior research staff and the Director and senior staff members of ERL was conducted in the fall of 1988. The objective of the retreat was to sharply identify critical environmental problems and to improve the management of GLERL's research activities in view of the limited resources to support these activities. The retreat and other subsequent events, such as a thorough in-house scientific/management review of both existing and newly proposed programs, has produced a major reorganization to develop additional programs directed toward critical global, regional, and national issues.

In the Fall of 1989 the previous structure of five scientific groups was reorganized into Coordinated Research Programs, considered to be critical environmental issues requiring coordinated team efforts, and a number of individual research programs. Two divisions, Physical Sciences and Biogeochemical Sciences, administrate the science in a matrix management configuration as indicated by the chart (Figure 1). It should be noted that the content of this annual report covers the period October 1, 1988 through September 30, 1989 (FY 89) and, as such, reports activities under the old organizational structure (Figure 2).

Organization

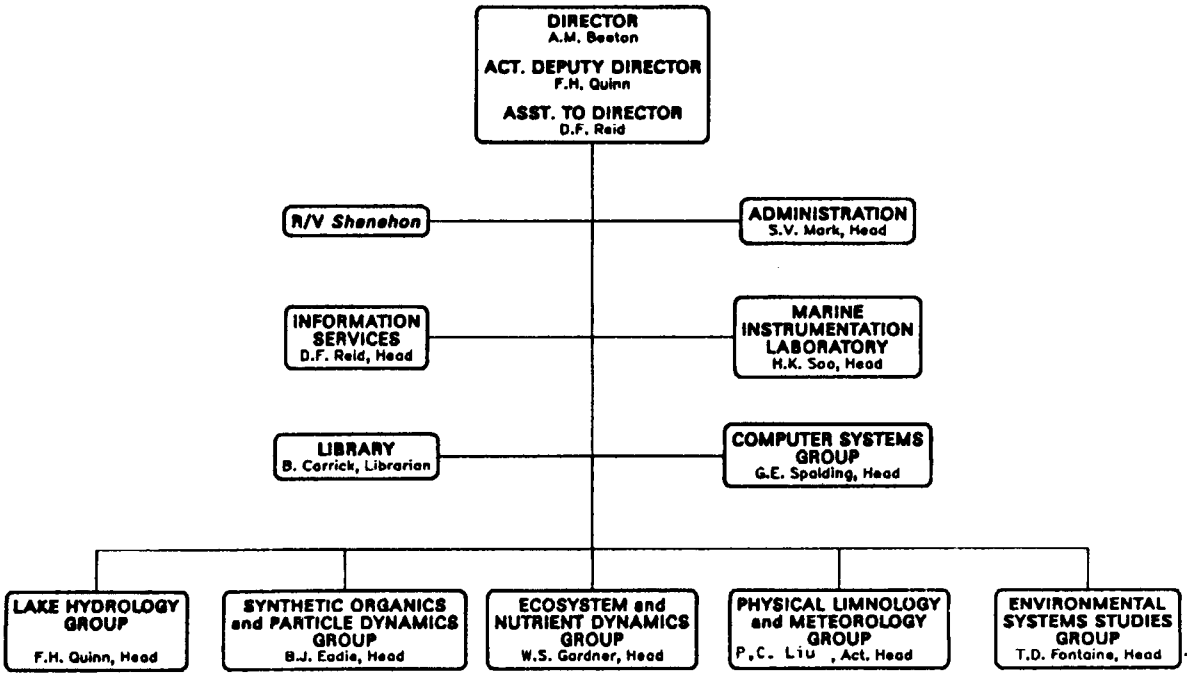


Figure 2. During FY89, GLERL was organized into five scientific groups.

Synthetic Organics and Particle Dynamics Group

studied the processes that control the movement and interactions of trace contaminants in the Great Lakes and coastal marine ecosystems. The group's research increases our understanding of and ability to predict the behavior, fate, and effects of contaminants in the natural environment.

Lake Hydrology Group

investigated the hydrologic and hydraulic processes that affect the water supply to, and the amount of water in, the Great Lakes. This group provides improved methods of forecasting lake levels and simulating river flows, and conducts research to characterize and increase our understanding of the seasonal ice and snow cover in the Great Lakes Basin.

Ecosystem and Nutrient Dynamics Group

studied the ecological systems of the Great Lakes and coastal marine environments, focusing on factors and processes that affect ecological succession and control the flow of nutrients and biochemical energy (and therefore, toxics) through the food web. Group members provide improved information to resource managers who make decisions that impact both water quality and living resources.

Environmental Systems Studies Group

developed models of environmental systems based on the premise that cost-effective management of our natural resources requires consideration of competing human, economic, regulatory, and ecological factors. Group members use these models to evaluate

and compare the probable costs versus benefits of resource management plans, and to identify alternative plans that optimally balance competing and conflicting demands on the marine environment.

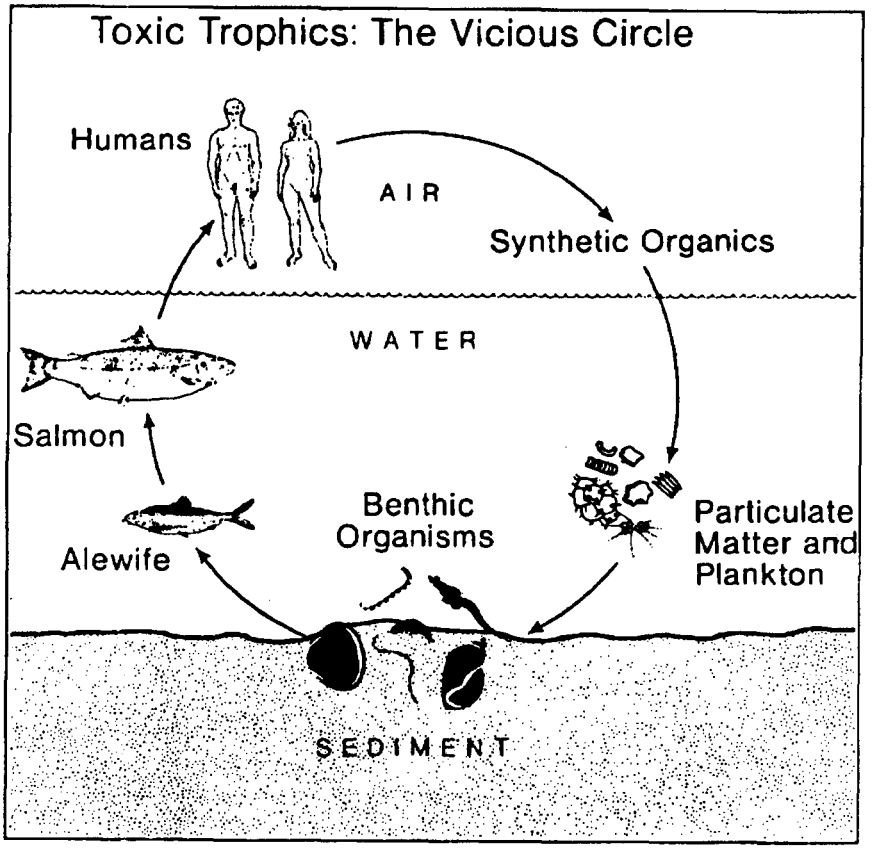
Physical Limnology and Meteorology Group

studied the physical variables that characterize a lake environment and the manner in which those variables change with external forces, such as wind, heat exchange, and connecting channel flows. The results of this research can help resource managers understand, alleviate, or reduce the impact of physical hazards and contaminant transport on both the environment and the people who use it.

A number of support units provide technical, operational, and administrative assistance to the scientific staff:

- a Marine Instrumentation Laboratory, where instruments and systems for hands-on and automated collection of field data are designed, built, and maintained;
- a Computer Systems Group that maintains GLERL's in-house computer network, manages the interface with off-site mainframe and super computers, and provides related user support to the GLERL staff and others;
- an Information Services Group that provides editorial and publications support to the GLERL staff, distributes GLERL publications, and responds to related information requests;
- a Library that maintains a research collection tailored to GLERL staff needs and which offers special retrieval services for materials not in the existing holdings;
- the R/V *SHENEHON*, GLERL's research vessel and the primary platform used by GLERL staff for field operations on the lakes;
- and an Administrative Office that provides personnel, budget, purchasing, and facility information and management.

Synthetic Organics and Particle Dynamics Group



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

Studies by this group involve processes that control the movement and interactions of trace contaminants in the Great Lakes and coastal marine ecosystems; this research increases understanding and predictability of the behavior, fate, and effects of contaminants in the natural environment.

GLERL has a continuing program in collaboration with the EPA, the U.S. Fish and Wildlife Service, and various Canadian agencies to develop and improve our understanding of the processes that control the distribution, cycling and fate of organic contaminants, their toxicology, and their biotransfer. A major focus of this research is on the association of toxic organics with suspended and deposited sediments.

Sediment-Associated Toxic Organics: Fate and Effects

Contaminated sediments represent a large potential source, and in some cases the only apparent source, of contaminants to the food chain. In the Great Lakes, sediment-associated pollutants are implicated as either the major source or one of the major

sources of environmental problems in 41 of the 42 Areas of Concern listed by the International Joint Commission (IJC) for the Great Lakes. A major part of GLERL's research on toxics focuses on the toxicology and bioavailability of contaminants from sediments in the Great Lakes. This project evaluates factors that influence the biological availability and toxicity of sediment-associated organic contaminants and has used selected chlorinated hydrocarbons and polycyclic aromatic hydrocarbons as representative of two major classes of persistent contaminants in the Great Lakes. This work will generate the basic information required to better understand the significance of sediment contamination and to provide the regulatory agencies with models and data for assessing organic contamination. In FY 89:

■ The 28-day mortality bioassay and the sediment avoidance/preference bioassay were performed on samples collected from Saginaw Bay. These included samples from a new station closer to shore than a previous station where there was significant mortality of *P. hoyi*. The new station samples also showed significant mortalityof *P. hoyi* while those collected from the old station did not for this collection. Thus, the mortality-producing contaminant seems to be transient. The most preferred sediment, based on our sediment avoidance/preference design for Saginaw Bay, was that collected from the old station. The order of preference generally increased for sediments taken at increasing distances from the mouth of the Saginaw River.

■ The Gamma Scan System was modified to allow use of a $_{109}$Cd x-ray source to measure the porosity of sediments in a non-destructive manner. This modification permits better compaction and porosity change estimates in sediment microcosms as experiments progress.

■ We exposed oligochaete worms (*Stylodrilus heringianus*) collected from offshore sites in Lake Michigan near Grand Haven and Benton Harbor to sediments also collected from these two sites. The Benton Harbor sediments were toxic to the organisms from Grand Haven, whereas the organisms from Benton Harbor were unaffected by sediments from Grand Haven. These results indicate something quite logical, but rarely demonstrated: the organisms collected from offshore Benton Harbor have developed some tolerance to the generally higher concentrations of contaminants found in these local sediments.

■ *Pontoporeia hoyi* were exposed to four dose levels of a mix of polycyclic aromatic hydrocarbons. The LC_{50} estimate for this mixture of PAH was 601 nmoles g^{-1} dry sediment as the molar sum of the individual PAH congeners. At the highest dose tested, 327 nmoles g^{-1} dry sediment, the LT_{50}, time required for 50% mortality was estimated to be 49 d. Finally, the body burden required to produce 50% mortality was 6.1 µmol g^{-1} wet weight organisms. From these results the mechanism of toxicity was presumed to be by non-polar narcosis. The toxicokinetics for this mixture was characterized by increased rate of accumulation with increased concentration in the sediment to an apparent plateau. These increases were similar for both radiolabeled materials, pyrene and phenanthrene that were present in trace amounts and for non-labelled PAH that was present in much greater quantities. The partition coefficient between the sediment particles and the interstitial water remained constant across the range of PAH concentrations for the two radiotracers. Thus, the increase in the rate of accumulation could not be attributed to changes in the partitioning.

A subsequent experiment examined the role of contact time between contaminant and sediment particles using selected PAH as the model contaminants. The contact times were 3, 60, and 150 d. The exposures were all run at the same time to avoid physiological differences between organisms that occur over the course of a season. The concentration of PAH used was intended to be sufficiently low that no toxicity would occur. Examination of mortality over the time of the experiment showed no significant mortality except in one replicate on the last day of the study. Further, the lipid content of the organisms was not significantly different over the course of the experiment indicating that the organisms were apparently healthy. The partition coefficients between sediment interstitial water and sediment particles increased for the radiotracers, pyrene and phenanthrene, with increasing contact time between the contaminant and the sediments. The uptake clearance for the radiotracers was similar to that from the

previous studies for 3 d aging at similar PAH concentrations. Again, the greater the PAH concentration, the greater the apparent rate of accumulation. The uptake clearance for both phenanthrene and pyrene declined when the sediment aging was 60 d and for phenanthrene the uptake clearance remained constant between 60 and 150 d of aging while for pyrene the uptake clearance increased slightly.

■ The first studies of the role of organic carbon on the bioavailability of sediment-associated contaminants exposed *P. hoyi* to sediments containing three levels of organic carbon plus a fourth sediment where only the fine fraction was dosed. The compounds used were pyrene, benzo(a)pyrene, hexachlorobiphenyl and tetrachlorobiphenyl. The sample analysis showed the organisms exposed to the highest organic carbon content accumulated the lowest concentrations of contaminants. Data analysis is incomplete.

■ An experiment was designed to examine in detail the effect of co-solvents and contact time on the partition coefficient between sediment particles and sediment interstitial water. The study is still in progress, but preliminary data indicate that both factors affect partitioning.

■ An experiment to examine the role of bulk chemical contamination on trace contaminants compared sediments first dosed with selected levels of silicone oil and subsequently with ^{3}H-benzo(a)pyrene and ^{14}C-hexachlorobiphenyl. Due to a calculation error the radiotracers were dosed at too low a level for the kinetics to be accurately determined. The silicone oil at the highest dose did produce mortality, but there were insufficient data to determine an LC_{50}. This experiment will be repeated when time permits.

Sediment and Resuspension Processes

Sediments play a major role in the regulation of aquatic systems and serve as a natural repository of indicators of present and historical changes in ecosystem status and chemical loadings. Our research, while focused on the Great Lakes, encompasses diverse aquatic systems. We emphasize the use of radiotracers to identify and model fundamental lake/watershed sediment transport processes. During FY 89:

■ In collaboration with the U.S. Geological Survey, we completed measurements and theoretical treatment of radionuclide profiles in sediments from the Oahe Reservoir system (SD).

■ In collaboration with Polish scientists and support from the Marie S. Curie Fund administered by the U.S. Department of State, we developed a multi-component model for the response of water, sediments, and fish in Lake Sniardwy (Poland) to contaminants from the Chernobyl reactor accident.

■ In collaboration with scientists at the University of Constance and the West German government, we developed a phase-specific response model for the scavenging of Chernobyl radionuclides from Lake Constance.

■ Completed measurements and theoretical treatment of radionuclide profiles in sediments from Lake Ontario as part of an EPA-sponsored study of dioxin contamination.

■ In collaboration with EPA and the Canada Centre for Inland Waters (CCIW), we developed a long-term fate model for contaminants in Lake St. Clair sediments.

■ Completed theoretical and experimental studies of epilimnetic cycling of natural and fallout radionuclides in Lake Michigan.

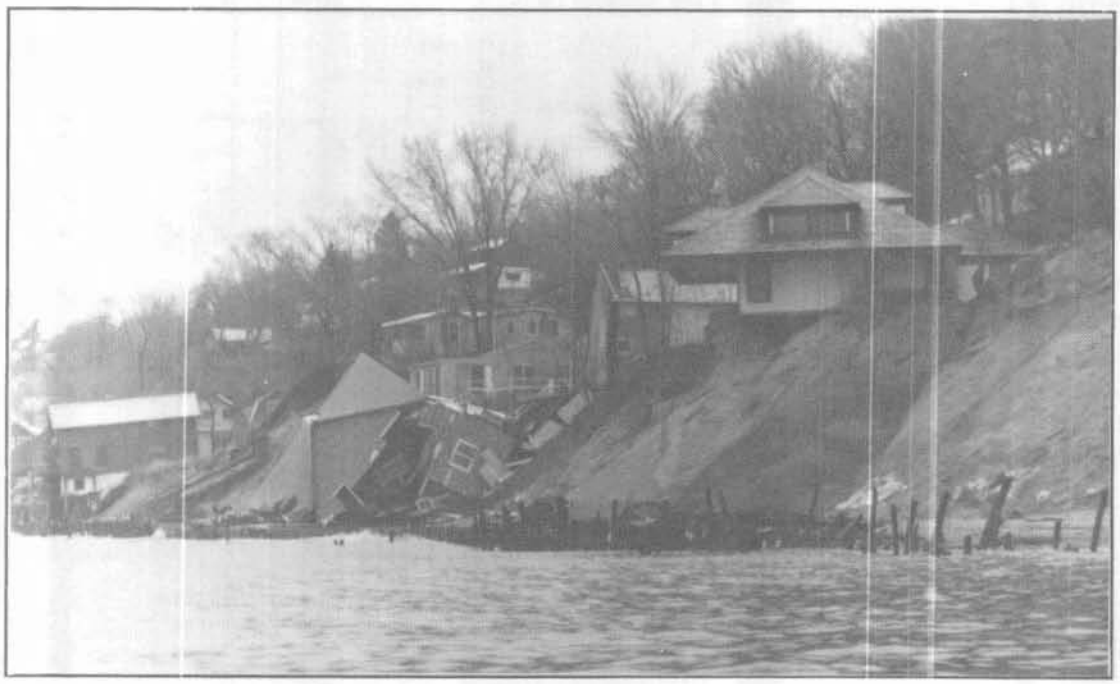
■ Concluded that data from GLERL on the results from a 3-year sediment trap intercalibration can be combined without bias with data from the Canada Centre for Inland Waters (CCIW). This will allow a synthesis of sediment flux information covering all five Great Lakes.

Isotope Biogeochemistry in Limnology

GLERL's stable isotope research focuses on the processes that regulate the major biogeochemical cycles and uses analyses and modeling of the fractionation of natural stable isotopes. During FY 89, sample preparation and clean-up systems for the

stable isotope mass spectrometer were completed, making the isotope facility fully functional. A sediment core from the Mississippi delta was analyzed for stable isotopes to test an hypothesis that nutrient-enhanced productivity is related to increased transport of carbon to the sediments.

Lake Hydrology Group



Storms during high lake levels cause severe damage to shorelines.

Investigate hydrologic and hydraulic processes that affect the water supply to, and amount of water in, the Great Lakes; provide improved methods of forecasting lake levels and simulating river flows, and conduct research to characterize and increase our understanding of the seasonal ice and snow cover in the Great Lakes Basin.

Major changes in water quantity in the Great Lakes are caused by annual and seasonal variations in the water supply, consumptive use, and interbasin diversions. Superimposed upon the natural fluctuations are a number of anthropogenic changes which have had or could have major effects on Great Lakes water quantity. GLERL's hydrologic research program is directed toward improving both our knowledge of the hydrologic and hydraulic processes and our methods of forecasting and simulating water supplies and lake levels.

Lake Evaporation Forecasting and Simulation

Evaporation from the Great Lakes is on the same order of magnitude as precipitation and runoff to the lakes. It therefore represents a significant component of the lakes net supply and its determination is crucial in estimating lake levels. Existing evaporation estimation techniques result in the major portion of forecast errors. Our research seeks to develop working models of lake evaporation that can be used effectively on daily, weekly, and monthly time intervals for each of the Great Lakes. These models will be incorporated into the GLERL water supply and lake level simulation and forecasting procedures. During FY 89:

- A water surface temperature database was constructed for Lake Michigan and used to calibrate the existing model.

■ The evaporation model was evaluated by outside reviewers and relevant strengths and weaknesses were analyzed. This formed the basis for several of our current plans.

■ Work was begun on heat storage concepts and heat storage superposition; wind-mixed aging and mixing of aged heat additions was implemented in the superposition.

■ Bowen's ratio was removed as a means of computing sensible heat transfers and replaced with direct calculation of sensible heat from the computed transfer coefficient and other terms; this improved both the sensible and long-wave flux estimations as compared to other investigators' experiences.

■ Intermediate recalibration and reapplication of the evaporation and heat storage model for each of the Great Lakes were made and represent an available intermediate application for outside agency interests.

Figure 3 compares the Lake Ontario surface energy fluxes as derived weekly during the International Field Year for the Great lakes by Atwater (Pinsak, A.P., and G.K. Rodgers. Energy balance. In *IFYGL-The International Field Year for the Great Lakes*, E.J. Aubert and T.L. Richards (eds.) NOAA, GLERL, Ann Arbor, MI, 169-197 (1981)) and modeled daily with GLERL's lake evaporation and heat storage model. Aside from minor under-estimation of sensible heat by Atwater in May and June, these independent estimates agree remarkably well. Independent verification of GLERL's modeled water surface temperatures by satellite measurements and of heat fluxes by comparison with other investigators' measurements builds confidence in GLERL's lake evaporation estimates on each of the Great Lakes.

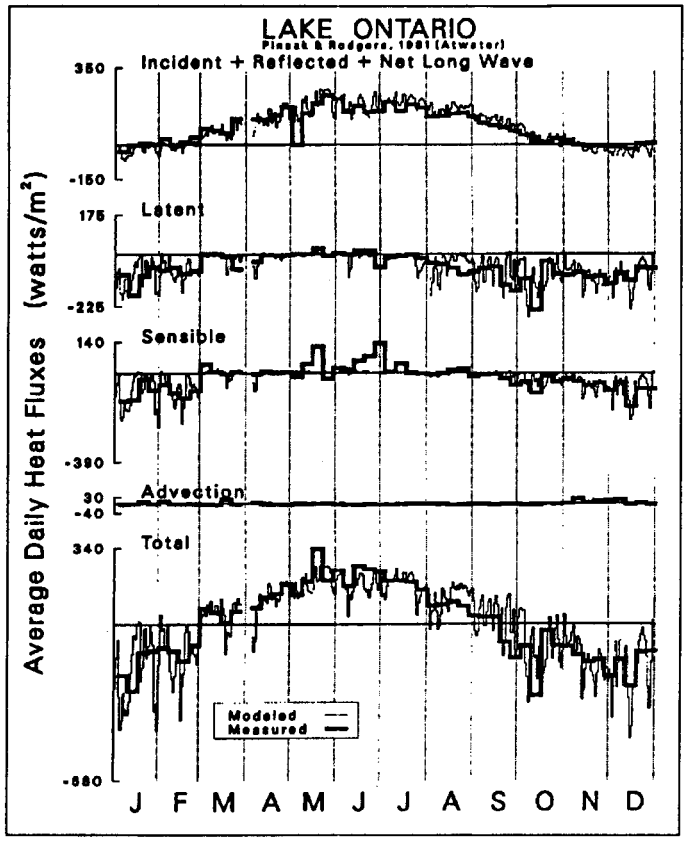


Figure 3. Measured (IFYGL) and modeled (GLERL) Lake Ontario energy fluxes.

Lake Level Management

On August 1, 1986 the Governments of the United States and Canada, pursuant to Article IX of the Boundary Waters Treaty of 1909, forwarded a Water Levels Reference to the International Joint Commission. The Reference requested that the Commission examine and report upon methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin. Given the complexity and unprecedented scope of the Reference, Great Lakes agencies were called upon to contribute to new initiatives and new approaches "far beyond those authorized in previous References." Accordingly, GLERL scientists provided wide-ranging support for the Reference via hydrological and climatological analyses, development of simulation and forecasting techniques, policy and institutional analyses, and ongoing technical support and report preparation. In FY89:

■ We conducted a hydroclimatic study to assess the impact on the Great Lakes of a recurrence of the extremely wet climate regime of 1870-1885; precipitation over that period was about 11% greater than any comparable period since 1900. We developed a database of monthly air temperatures and precipitation for 1870-1885, used the data with conceptual models for each component of net basin supply, and examined impacts on lake levels using existing regulation rules and connecting channel conditions. The study indicated that Lake Erie levels at present are

more sensitive to high precipitation compared to a century ago, probably due to land use changes and/or connecting channel modifications. Consideration of the pre-1900 meteorology highlights the limitations of using only 1900-present meteorology and lake level records to examine the potential for lake level extremes.

■ We conducted reviews of U.S. and Canadian policy and institutions affecting management of Great Lakes levels. This effort focused on three main areas: 1) the structure and adequacy of existing institutions for dealing with Great Lakes levels-related problems, 2) the prospects for using alternative dispute resolution strategies for dealing with lake level management and use conflicts, and 3) opportunities and approaches for developing a U.S.-Canada Water Quality Agreement on the broad principle of guiding water quantity management and based on case studies of other binational water agreements. Ostensibly, the large number of institutions which influence use of the Great Lakes leads to public confusion and a perception of institutional unresponsiveness. However, the exclusive and adversarial nature of traditional agency decision-making processes appears to be a more pivotal problem. Future planning must incorporate processes such as facilitated policy dialogues, collaborative problem solving, or negotiations which seek to build consensus among the various interest groups (agencies included) that have some stake in Great Lakes management decisions. Case studies of other binational water agreements (e.g., the Great Lakes Water Quality Agreement, the Skagit River Treaty) identified common themes for successful dispute resolution involving, 1) necessary conditions to induce binational action on a boundary water issue, 2) procedures for developing a binational agreement, and 3) the structure and operation of a binational agreement.

Great Lakes Snow Cover

Snow cover represents a vast reservoir of freshwater that, during the spring, contributes to the water supply of the Lakes and to the groundwater of the basin. The climatology of the Great Lakes snow cover is largely unknown. Under this project we will develop monthly, yearly, and period of record snow cover maps for the Great Lakes Basin and develop improvements to the methods available to map the Great Lakes basin snow cover which focus on applications of both surface station and remotely-sensed data.

During FY 89, an extensive database of snowfall and snow on the ground was acquired. That database has currently been quality controlled. Preliminary runs using a commercially available program to produce automatic contour maps of snowfall amounts show great promise. Eighty-two stations with long term, nearly continuous records and distributed relatively evenly throughout the basin have been selected for analysis of extreme snowfall events and for evidence of climate variability signals.

Climate Change Impacts on Large Lake Hydrology and Thermal Structure

Global warming or cooling could significantly change the water levels and ice covers on the large lakes of the world, and thus affect related interests. GLERL's research is focused on assessments of (1) the effects of global warming (as represented by a doubling of atmospheric CO_2) on large lake water supplies, lake levels, and ice cover, starting with the Great Lakes, and (2) the potential effects of precipitation in the Great Lakes as great as that recorded for the period 1870-1885 under present basin characteristics, diversions, regulations, and connecting channel regimes. During FY 89 we:

■ Combined, for integrated modeling of Great Lakes hydrology and water levels, GLERL's Large Basin Runoff Model, the early lake evaporation and heat storage model, overlake precipitation, Great Lakes levels regulations plans, connecting channel flow routing models, and lake water balances.

■ Applied data adjustments for an atmosphere with double CO_2 content to our historical data sets to construct climate change scenarios.

■ Performed simulations with the integrated hydrology models and both the historical time series and the $2xCO_2$ time series.

Due to the large and slowly changing storages of water and heat in large lakes, they buffer the effects of most short-term (interannual) meteorological variability and react to, and record, the longer period

fluctuations characteristic of global climate change. Thus, large lakes may be ideally suited for studying the regional effects of global climate change. As a start, GLERL has established a core research program to examine and evaluate the potential effects of climate change on the Laurentian Great Lakes.

We began to examine opportunities and constraints for climate change contingency planning for the Great Lakes Basin. A broad range of potential adaptive strategies was developed within three general policy-objective categories, 1) reducing regional impacts of climate change, 2) reducing vulnerability to climate change impacts, and 3) equitably distributing climate change impacts. Based on a review of existing Great Lakes institutions and policies that have relevance to Great Lakes water quantity management and climate change, a number of strengths and weaknesses were identified as were several themes concerning barriers to further progress in climate change contingency planning. This work provides a basis for understanding the necessary preconditions for fostering regional climate change contingency planning, the appropriate institutional attributes and mechanisms for conducting a contingency planning process, and specific elements that should be included in a contingency plan.

Reconstruction of Long-Term Great Lakes Ice Cover Climatology

Observations of midlake Great Lakes ice cover are sparse prior to the decade of the 1960s. In an effort to provide an historical perspective of midlake ice cover from the turn of the century, daily average ice cover for Lakes Erie and Superior over 86 winters (1897-98 to 1982-83) was estimated using empirical-statistical ice cover models developed in an earlier study. Analysis of these reconstructed ice cycles indicated three ice cover regimes: (1) a high ice cover regime from the late 1890s to early 1920s; (2) a low ice cover regime from the early 1920s to late 1950s; (3) a high ice cover regime from the late 1950s to the early 1980s (Figure 4). Thus, the cover climatologies developed during the 1960s and 1970s may not be representative of ice covers in the low ice cover regime of the 1920s to late 1950s. Further analysis shows long-term average maximal monthly ice cover occurs in February and is 68 percent for Lake Erie and 40 percent for Lake Superior (Figure 5). Midlake ice formation occurs about 1 month earlier on both lakes during severe winters. Average maximal monthly ice cover during severe and during mild winters is 95 percent and 14 percent for Lake Erie and 87 percent and 17 percent for Lake Superior. Severe winters are

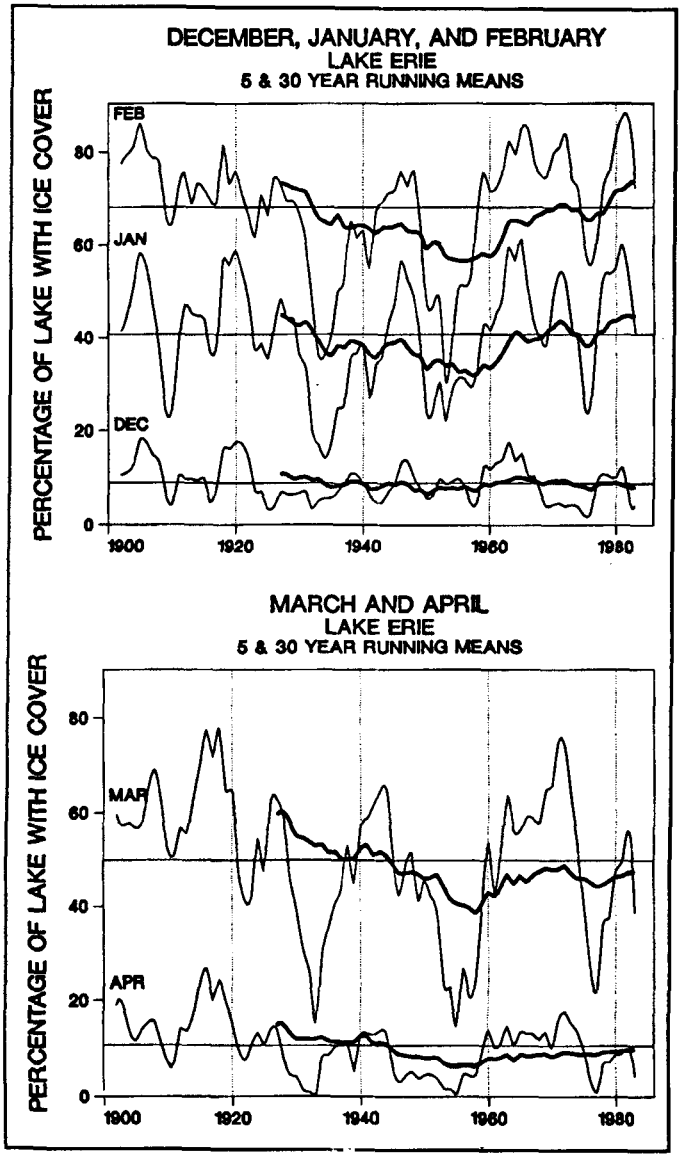


Figure 4. 30-year continuous (thick solid line) and 5-year continuous (thin solid line) averages of the reconstructed monthly ice cover for Lake Erie. The horizontal line on each graph is the long-term (86-winter) average. The 30-year and 5-year continuous averages are plotted on the year they end; for example, the first 30-year continuous average is calculated for the years of 1898 to 1927 and is plotted on the year 1927.

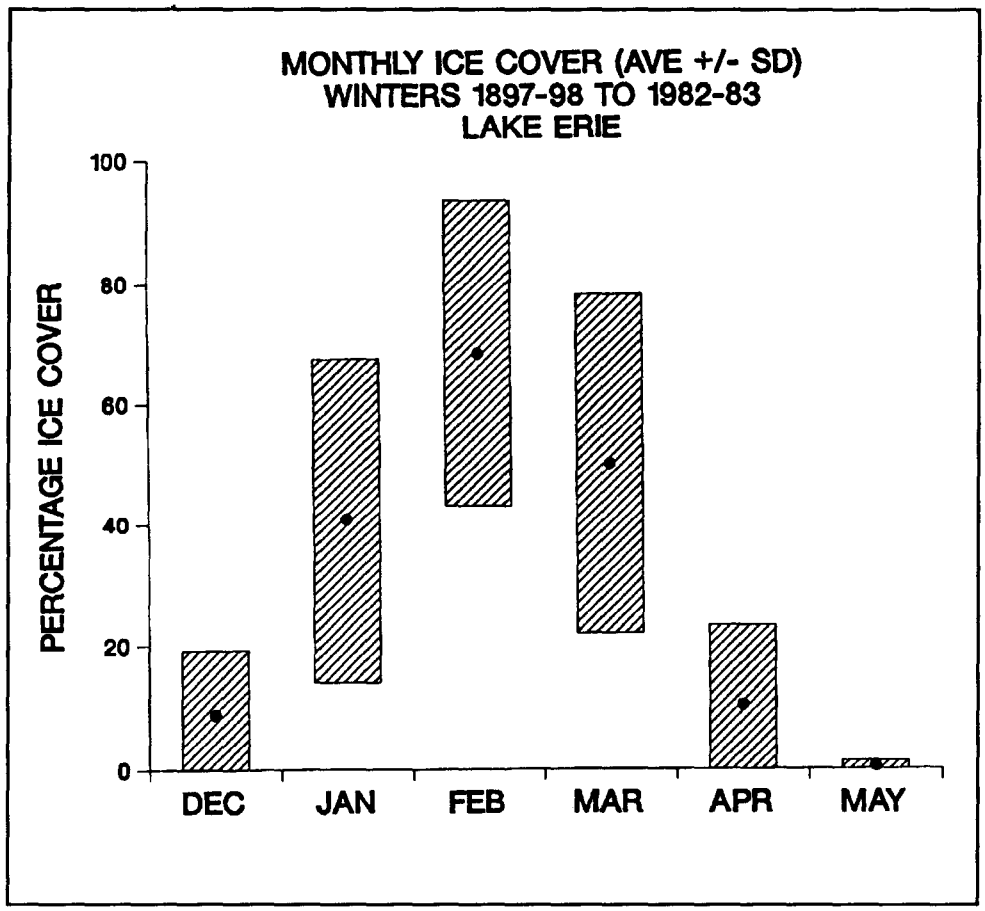


Figure 5. Reconstructed average monthly ice cover for Lake Erie. The hatched areas above and below the monthly average represent the variation over the 86 winters (average plus and minus one standard deviation).

associated with lower 700-mb heights over the eastern United States compared to mild ice cover winters. Thus, accurate 30 to 90 day 700-mb forecasts may be the key to long-range forecasts of above or below normal Great Lakes ice cover. Spectral analysis of the reconstructed total winter ice cover suggests interannual variations in ice cycles correspond with the 2- to 3-year interannual variation in atmospheric variables known as the quasibiennial oscillation.

Detroit River Unsteady Flow Analysis

The Detroit River is a funnel conveying the water from the upper Great Lakes to Lake Erie and serves as the dilution source for many industrial and municipal waste discharges. The flow can vary rapidly in response to storm surges on Lake Erie even reversing (flowing north) at times. These flow reversals disrupt the normal contaminant pathway and could transport contaminants that would ordinarily flow into Lake Erie back into Lake St. Clair. To study the Detroit River flows, especially those that occur during wind setups and storm surges on Lake Erie, an experimental field measurement program was conducted on the River. The measurements consisted of 1) river flow variations with time obtained with an acoustic Doppler current profiler operated at the Ft. Wayne section in the upper river; and 2) of complementary meteorological data (wind speed and direction, and air temperature) recorded at the Grosse Ile micro-met station, which was located at the mouth of the river to reflect over-lake meteorological conditions with a minimum of land effects. During FY89:

- The experimental field measurement program, terminating field operations at the micro-met station (July 1989) and the river velocity section (October 1989), was completed.

■ We completed the Detroit River flow reversal study. The only measured flow reversal in the river occurred on December 15, 1987. Results of the study, which include analysis and comparison of measured and model-simulated flows, were presented at the International Association of Great Lakes Research Annual Conference in Madison, WI, and are described in a journal article (*Journal of Great Lakes Research*, in press).

■ General results of the study indicate that flow reversals in the Detroit River may occur during large wind set-ups in western Lake Erie, and that this flow reversal process can be produced by meteorological factors alone. It was previously presumed that reversals required a large ice jam in the St. Clair River to substantially reduce the inflow to Lake St. Clair and its outflow through the Detroit River. Meteorological measurements (Figure 6) show that the December 15, 1987 Detroit River flow reversal was caused by strong winds blowing steadily from the east and piling water in the shallow western Lake Erie basin. At about 10:00, the wind direction shifted suddenly; high winds started blowing steadily from the southwest, approximately parallel to the western lake shoreline and directly opposite to the river flow, which forced the set-up in western Lake Erie into the Detroit River. At the Ft. Wayne section about 45 km upstream a complete flow reversal, with negative flows in the entire water column, was measured approximately 1 hour later at about 11:00 (Figure 7). This figure also shows that variations in the measured resultant velocity and the extrapolated river discharge are very similar, which means that changes in discharge depend primarily on the variations in velocity and the effect of the cross-section area of the river, the other factor affecting discharge, is secondary even during extreme variations in flow.

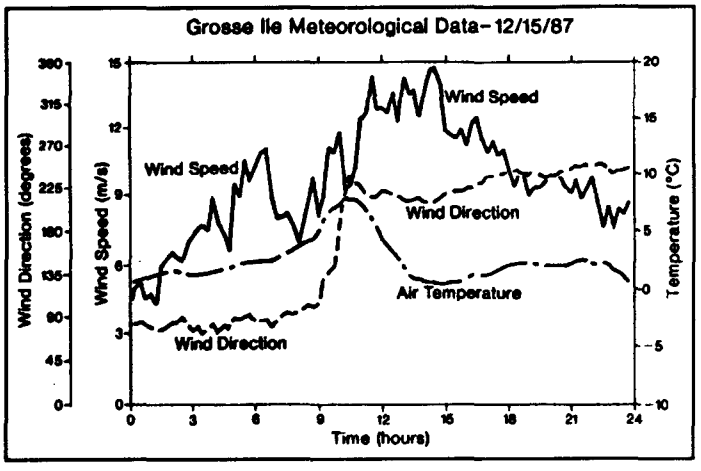


Figure 6. Meteorological data for the 15-min. wind speed and direction and air temperature measurements from Grosse Ile micro-met station at the mouth of the Detroit River on December 15, 1987.

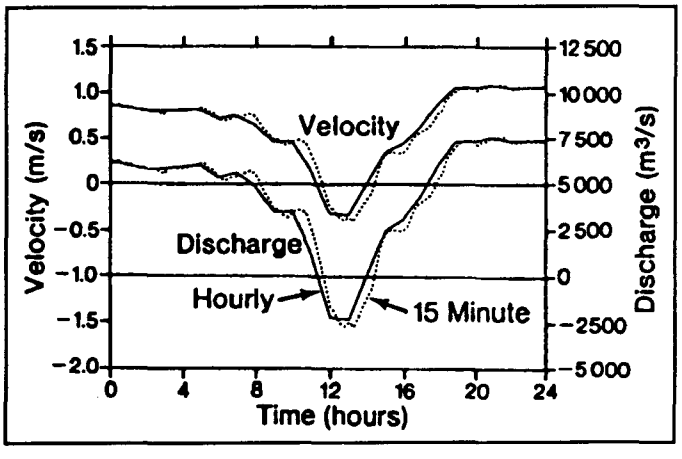


Figure 7. Measured resultant velocity and extrapolated river discharge at the Ft. Wayne section in the upper Detroit River on December 15, 1987 for hourly and 15-minute data.

■ The study also showed that inclusion of wind shear is essential and that 15-minute data inputs (water levels and winds) in the unsteady flow models are needed for the flow reversal simulations to be in reasonable agreement with the measurements. Such simulations would normally be based on hourly water levels, which represent the shortest period of data normally available, and would not include the wind shear effect on flows, since appropriate wind data are normally not available. Consequently, normally-feasible model runs produce substantial underestimation of both the occurrence and the magnitude of flow reversals.

Ecosystem and Nutrient Dynamics Group

GLERL scientists aboard the R/V Shenehon *collect samples for use in research studies.*

Responsible for conducting studies on the ecological systems of the Great Lakes and coastal marine environments, focusing on factors and processes that affect ecological succession and control the flow of nutrients and biochemical energy (and therefore, toxics) through the food web; provide improved information to resource managers who make decisions impacting both water quality and living resources.

Phytoplankton in the Upper Great Lakes

Continued research was conducted to clarify the role of nanoplankton and picoplankton in the Great Lakes ecosystem and to examine the methods and technology for determining primary production.

Our research found that:

■ Protozoan abundances and biomass comparisons for Lakes Huron and Michigan showed similar abundances reported for other oligotrophic environments. Because the biomass of microzooplankton rivals crustacean zooplankton biomass, microzooplankton may be more important grazers than once thought. Because of high turnover rates of ciliates relative to macrozooplankton, ciliates may be far more important in carbon and nutrient cycling than macrozooplankton.

■ Photosynthetic picoplankton are about 30x more abundant than "traditional" phytoplankton and constitute approximately 17% of total photosynthetic biomass. The picoplankton community is dominated by *Synechococcus*, which comprises 80% of the total

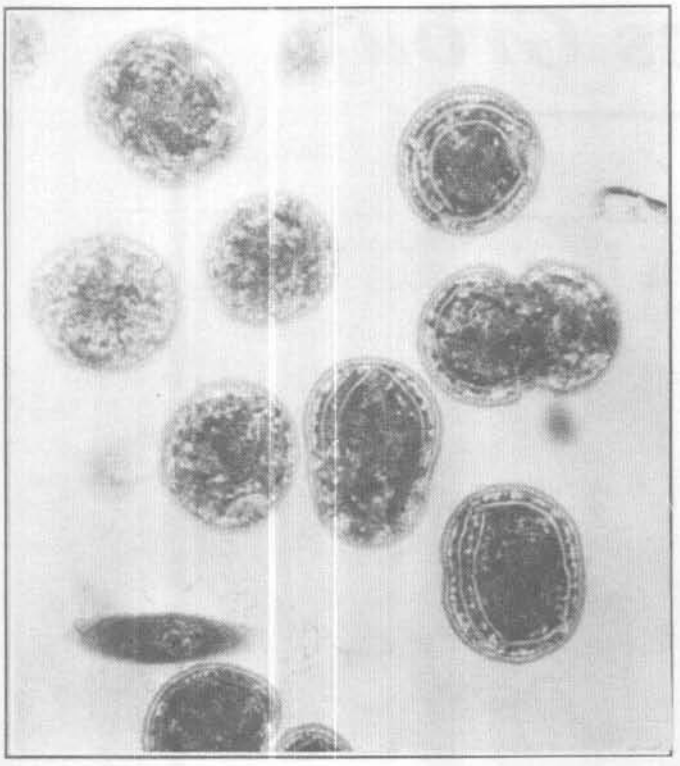


Figure 8. Transmission electron micrographs of Synechococcus.

(Figure 8). On an annual basis, photosynthetic picoplankton contribute about 35% of total upper Great Lakes primary production, with a peak contribution of nearly 75% during the late summer and early fall. These results will change existing ideas about Great Lakes plankton dynamics.

Bacteria in Great Lakes Food Webs

We have been studying the pathways of organic carbon and nutrient recycling mechanisms at the bacterial level as well as the fate of bacterial carbon. This year we completed comparative bacterial uptake experiments using thymidine, amino acids, and glucose as organic substrates. These experiments revealed that thymidine is not readily available as a carbon source to Lake Michigan bacteria during short-term bacterial growth-rate experiments. This is consistent with the assumption that thymidine uptake can be used as a measure of DNA synthesis.

Phosphorus Dynamics and Microplankton Growth in Lake Michigan

To understand phytoplankton-bacterial interactions and the seasonal succession of phytoplankton in the Great Lakes, it is necessary to understand the dynamics of P, the limiting nutrient in the Great Lakes. GLERL continues to study the dynamics of and mechanisms behind seasonal succession of algae in Lake Michigan.

■ A new approach to estimate an upper bound on ambient phosphate concentration was developed and applied to Lake Michigan. This approach allows reliable estimates of ambient phosphate concentration required for testing mathematical models of phosphate cycling in the lower food web.

■ Bacteria in Lake Michigan were shown to rely on organic phosphorus as a principal source of P and apparently take-up P by a transport system similar to that of non-aquatic bacteria.

Feeding Dynamics and Life-Cycle Strategies of Zooplankton

Models of phytoplankton and zooplankton succession usually distinguish between two groups of herbivorous zooplankton: copepods of the genus *Diaptomus* spp. and cladocerans. The biology of *Diaptomus* spp. is less well understood. These highly selective omnivores have been the recent focus of intense study to develop a behavior-based model of food selection and feeding rate, which is necessary to understand seasonal succession of plankton (Figure 9).

■ Wax esters were found to be important components of the total lipids in two species of Great Lakes zooplankton. Wax esters commonly occur in marine zooplankton, but have not previously been observed in freshwater zooplankton.

■ The cladoceran *Bythotrephes*, a northern European invader which was first found in the Great Lakes in the mid-1980s, has undergone a population explosion. We performed experiments to determine their feeding habits and found that their natural prey are the indigenous species of cladocerans, as well as cope-

pod nauplii. *Bythotrephes* (see cover) has the potential to severely disrupt the existing food web.

■ A comparative field study of the seasonal lipid content and composition of *Pontoporeia* from Lakes Michigan and Huron and the Baltic Seas was initiated with scientists from the University of Stockholm. This study is examining the similarities and differences in energy accumulation patterns in *Pontoporeia* from the three ecosystems to provide information about mechanisms of pelagic/benthic energy transfers.

■ Research continued with the Skidaway Institute of Oceanography, Savannah, GA, to investigate copepod life strategies in estuarine, coastal, and offshore waters in the southeastern Bight. This year, nitrogen excretion rates were measured for the offshore copepod, *Eucalanus hyalinus*, under different food and temperature regimes. Understanding the differential abilities of copepods to survive in the three environments will provide needed information about the coastal marine system and useful comparison with Great Lakes organisms.

■ The disposition of the lipophilic contaminants benzo[a]pyrene (BAP) and hexachlorobiphenyl (HCB) in *Pontoporeia hoyi* and *Mysis relicta* was studied using a new "physical" lipid-class fractionation technique. The differential disposition of these contaminants likely affects their transport and fate in the aquatic food web.

Benthic Ecology and Sediment Nutrient/ Energy Transformations

Benthic invertebrates have several important roles in the Great Lakes ecosystem. These organisms form a vital link between primary production and fish production; they feed on material settled from the water column and are, in turn, fed upon by most species of Great Lakes fish. We examine benthic processes related to both organisms and sediments to improve our understanding of how these two benthic components affect, and are affected by, the rest of the system. In FY 89, we completed a study of phosphorus cycling by mussels in Lake St. Clair. Mussel biodeposition may be an important source of nutrients to other biotic components in the lake, such as

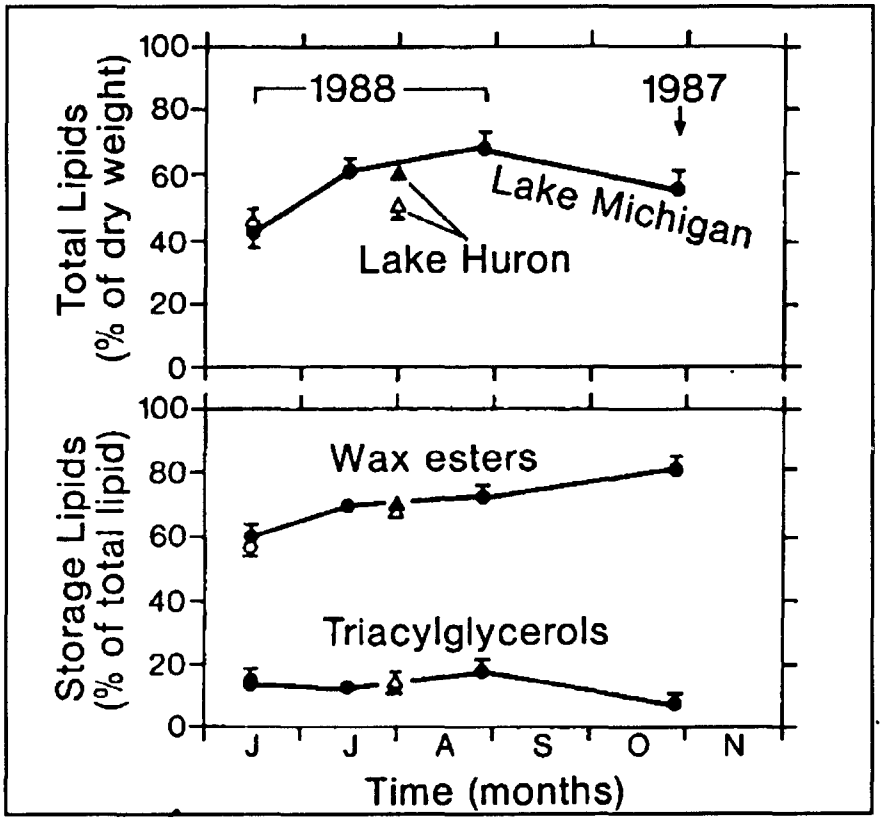


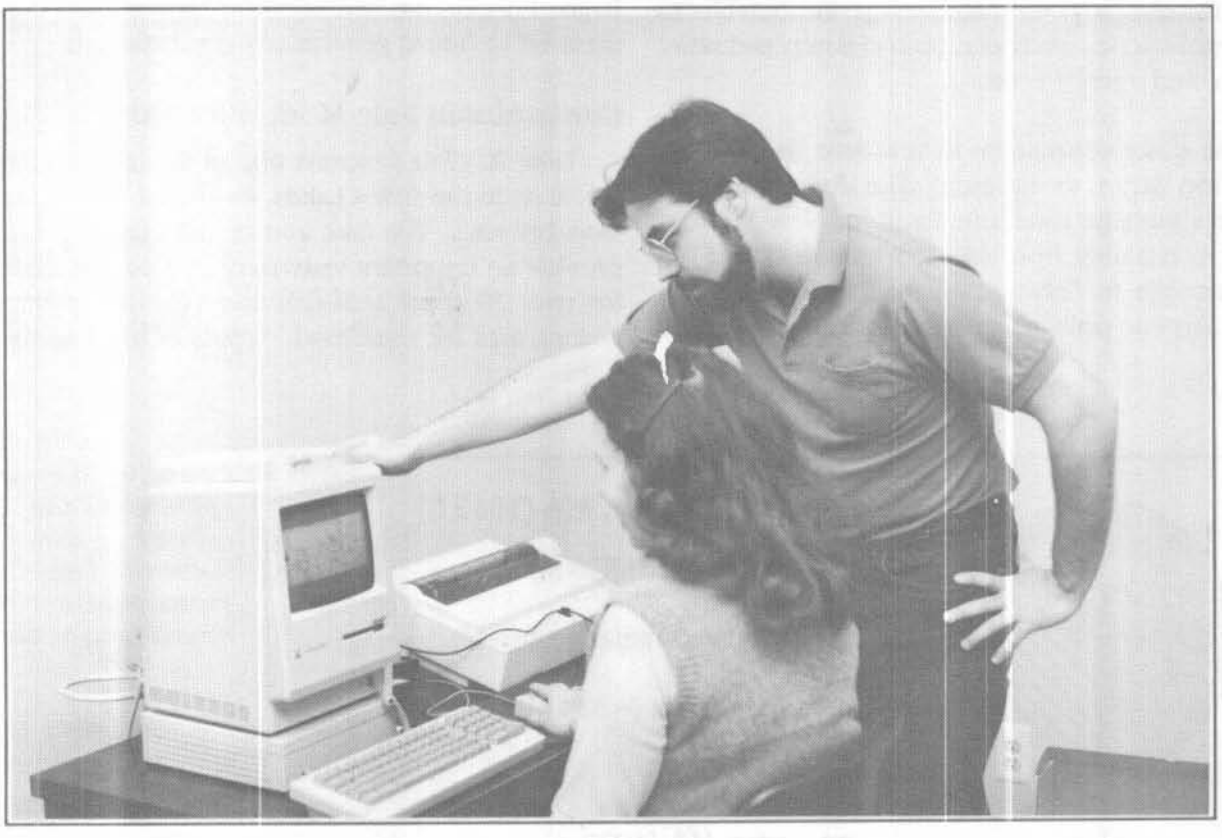
Figure 2. Seasonal trend of total and storage lipids for Limnocalanus macrurus, *June through late October. Open symbols - males; closed symbols - females.*

macrophytes and invertebrate deposit-feeders.

Because of their limited mobility and relatively long life cycles (when compared to plankton), benthic fauna form stable communities that integrate and reflect environmental conditions over long periods of time. GLERL has an established research program to examine trends in benthic populations and to relate these observations to environmental conditions and control measures implemented to improve water quality. During FY 89, benthic organisms in sediments collected from Saginaw Bay, Lake Huron, were sorted and counted to assess long-term trends as a biomonitor of changes in water quality. The data show a two-fold increase in the abundance of pollution-tolerant oligochaete worms since the early 1970s. *Hexagenia* spp., the pollution-sensitive Mayfly larvae, was completely absent. Thus, it appears that the benthic community in Saginaw Bay does not yet reflect recent efforts to improve water quality in Saginaw Bay.

A study with S. Seitzinger of the National Academy of Sciences, Philadelphia, was conducted to investigate mechanisms of nitrogen flux in coastal marine sediments as compared to Great Lakes sediments. Pairing of the ammonium ion with sea salts appears to allow part of the ammonium to diffuse from estuarine sediments before it becomes nitrified and denitrified. This previously unrecognized mechanism affects the amount of nitrogen that can reach phytoplankton as an available form in marine coastal systems. The results from this research were presented at a workshop on the cycling of reduced gases in the hydrosphere held in conjunction with the 1989 SIL Conference in Munich, W. Germany.

Environmental Systems Studies Group



Computers and computer modeling are an integral part of Systems Studies at GLERL.

Develop models of environmental systems based on the premise that cost-effective management of our natural resources requires that we consider the competing human, economic, regulatory, and ecological factors; use models to evaluate and compare the probable costs vs. benefits of resource management plans; and identify alternative plans that optimally balance competing and conflicting demands on the marine environment.

Long-Term Distributed Costs of Environmental Contamination

GLERL is engaged in a study of the long-term costs of pollution that are borne by the public and paid out of public funds. Improper disposal of toxic contaminants costs society far more than just cleanup costs. Agency expenses, costs of research and litigation, and resource damages represent additional costs of pollution. These costs are generally borne by the public rather than by the polluter and are therefore termed "distributed" costs. In a 2-year effort culminating in 1989, several cases of industrial pollution of aquatic systems were analyzed from a distributed costs perspective: PCBs in New Bedford Harbor, MA., and Hudson River, NY; and Kepone in the James River, VA.

Cost analyses for the three sites resulted in a wide variety of distributed cost estimates (Figure 10). Ratios of distributed cost to industry cost ranged from 150:1 (Hudson River) to 0.7:1 (James River) to as yet undetermined (New Bedford Harbor - still in litigation). In all three cases, estimated costs attributable to damaged fisheries exceeded both cleanup and other documented agency costs.

The costs attributable to resource damage are much too large to ignore. The federal natural resources damage assessment suit for New Bedford Harbor is claiming from $40-$55 million (1985$) in PCB damages to fisheries, recreation, and amenity value. Kepone poisoning of the James River caused an estimated $20 million (1980$) in damage to local fisheries. PCBs in Hudson River fish have already cost sport and commercial fishermen an estimated $300 million (1987$). These are in addition to cleanup, agency, and litigation costs, which are also quite large. Further, the cost of deferring costs by passing them on to future generations is substantial.

Contaminant Fate Models for Lake St. Clair

Lake St. Clair supports one of the largest coastal wetlands in the Great Lakes, estimated to be greater than 140 km_2. The lake and its associated wetlands provide an important spawning and nursery habitat for over 70 species of fish and offer an important nesting area for waterfowl. Inputs of toxic contami-

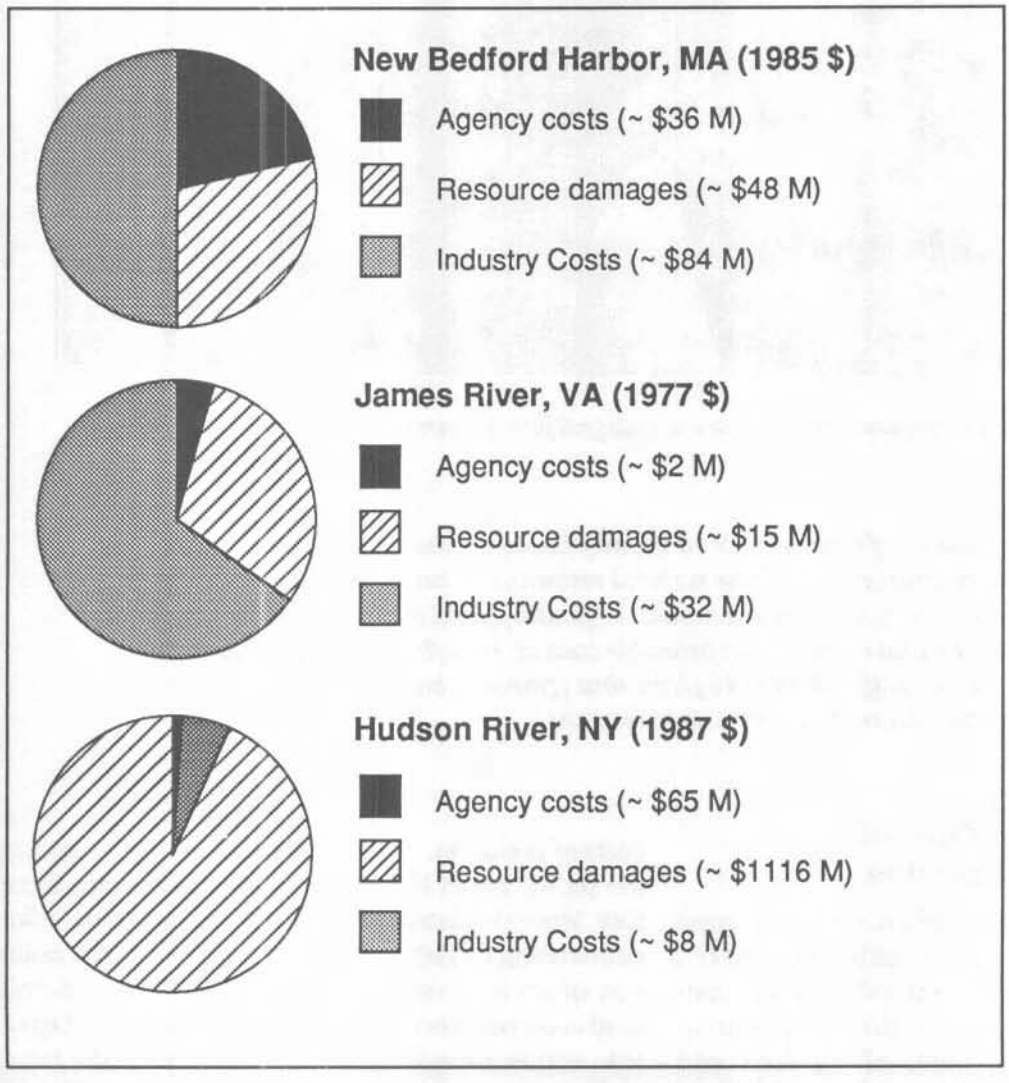


Figure 10. Summary of distributed cost estimates for well-documented environmental pollution episodes at three sites.

Factors Considered	Ranking
	Accumulation and Residence Time
K_{oc}, Loading Site, Wind Direction	K_{oc} >> Loading Site > Wind Direction
Loading Site, Wind Direction	Loading Site > Wind Direction
K_{oc}, Wind Direction	K_{oc} >> Wind Direction
K_{oc}, Loading Site	K_{oc} >> Loading Site
	Transboundary Transport
K_{oc}, Loading Site, Wind Direction	Loading Site >> K_{oc} > Wind Direction
Loading Site, Wind Direction	Loading Site >> Wind Direction
K_{oc}, Wind Direction	K_{oc} > Wind Direction
K_{oc}, Loading site	Loading Site >> K_{oc}

Table 1. Relative importance of chemical partitioning (K_{oc}), loading site, and wind direction on model-simulated steady-state contaminant accumulation (and residence time) and transboundary transport in Lake St. Clair.

nants to the lake are of concern because they can deleteriously affect these desirable ecological characteristics.

Documented storages of organic contaminants, radionuclides, and trace metals indicate the ability of Lake St. Clair's sediments to collect and retain significant amounts of particle-associated chemicals, despite the lake's rapid hydrological flushing. Once contaminants enter the lake, their ultimate fate is controlled by the chemical properties of the contaminant, the location and magnitude of the contaminant load, the composition and distribution of suspended and settled solids, the frequency and size of resuspension events, the wind speed and direction, and the lake's circulation pattern. Quantifying the relative importance of these factors will help to determine their effect on the long-term accumulation of contaminants by the lake's sediments and biota and on potential transboundary contaminant flux.

The contaminant fate and transport model for Lake St. Clair was used to assess the relative importance of three factors--chemical partioning (K_{oc}), loading site, and wind direction--on the steady-state lakewide contaminant accumulation, residence time, and transport across the U.S.-Canadian international boundary. Model simulations showed that K_{oc} had the most significant effect on long-term contaminant accumulation and residence time, followed (in order of appearance) by loading site, and wind direction (Table 1). Alternatively, simulated transboundary transport was most affected by the location of the contaminant load, followed by K_{oc} and wind direction. Note that these findings are based on steady-state analyses; the rankings would likely change for short-term exposure.

Ecological Process Models for Lake St. Clair

A Lake St. Clair ecosystem model was programmed in FORTRAN on GLERL's VAX-CLUSTER Computer System. The model is divided into 12 hydrologically connected segments, each containing a non-stratified water column layer and a sediment layer. This segmentation scheme effectively separates littoral zones from pelagic zones and waters influenced by Lake Huron from those influenced by the Thames River. Water movement through the twelve segments is controlled by wind induced flow fields generated by a Lake St. Clair hydrodynamic model developed by other GLERL researchers.

The model describes the dynamics of three groups of phytoplankton, one group of macrophytes, four groups of benthic invertebrates, Unionidae clams, four groups of zooplankton, and several particle and nutrient compartments. Fish dynamics are not modelled explicitly, although consumption of lower trophic levels by fish is accounted for. This has made it possible to estimate the relative importance of prey items to fish biomass production. Forcing functions incorporated into the model include insolation, temperature, ice cover, nutrient loading, and allocthonous inputs of plankton and non-living organic matter.

Figure 11, a carbon flow diagram of the model, shows that macrophyte gross primary production in Lake St. Clair (53 g C/m_2 • year) is greater than phytoplankton gross primary production (39 g C/m_2 •year). Figure 11 also reveals that the flow of carbon to fish through the benthic pathway is greater than the flow of carbon to fish through the planktonic pathway.

Figure 12 shows simulated community gross production and respiration over a one-year period in Anchor Bay, a largely littoral area of Lake St. Clair

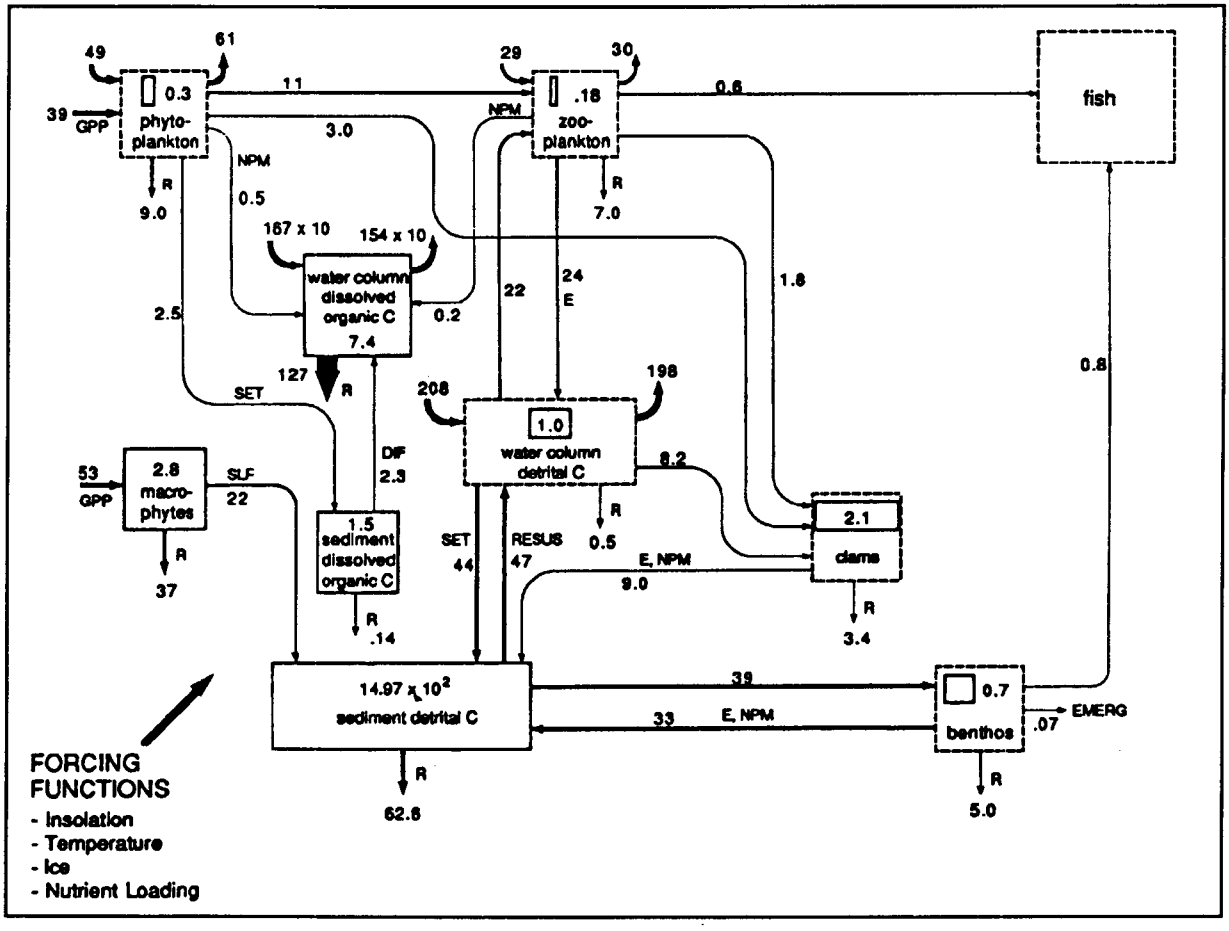


Figure 11. Simplified carbon flow diagram of the Lake St. Clair ecosystem. Arrows represent flows of carbon in grams/m_2 • year. Solid boxes represent the mean annual carbon mass per square meter for each of the model compartments. The solid boxes are drawn in proportion to the compartment sizes and carbon flows respectively. The short, open ended, curved arrows represent imports and exports of carbon to and from the system. Key: DIF = Diffusion, E = Egestion and Excretion, EMERG = Emergency, GPP = Gross Primary Production, NPM = Non Predatory Mortality, R = Respiration, RESUS = Resuspension, SET = Settling, SLF =- Sloughing.

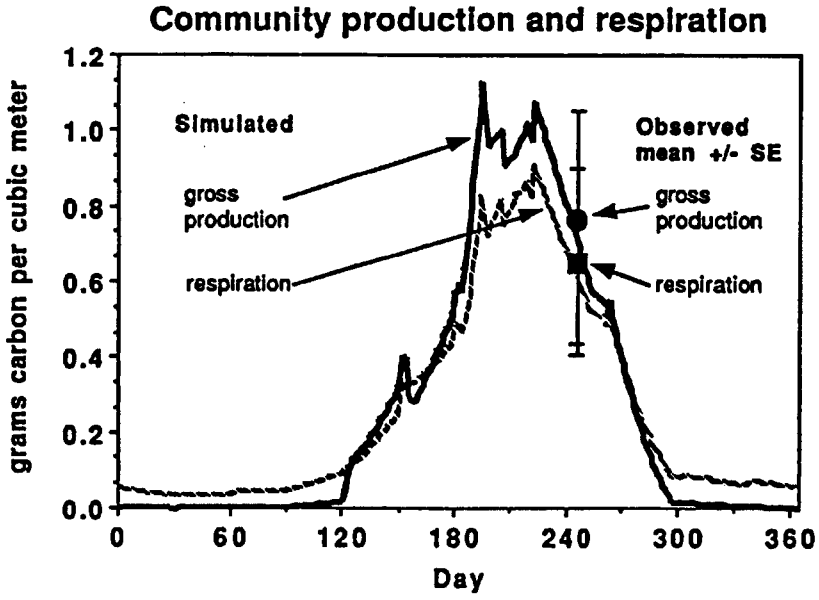


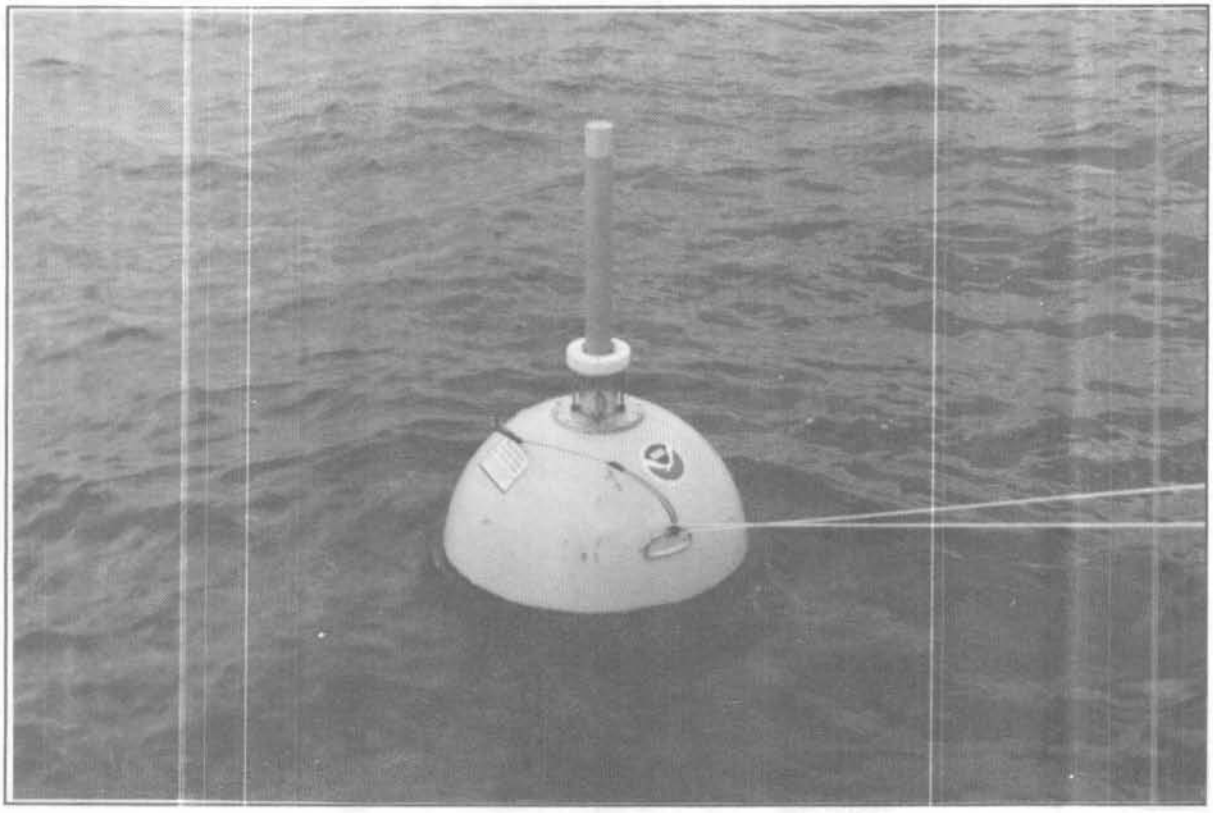
Figure 12. Daily simulated community gross production and respiration in a littoral region of Lake St. Clair (Anchor Bay). Observed values, measured on August 31, 1978, are also plotted. The simulated results fall well within the range of observed values.

where macrophyte density is high. The bay is an important fish spawning and nursery region. Mean observed production and respiration values, and associated standard errors, are also plotted on Figure 12. The simulated community metabolism values are well within the range of observed values. Model runs revealed that insolation and temperature are the two factors that limit primary production in Anchor Bay.

Understanding Fish Foodweb, Nutrient, and Contaminant Dynamics in Green Bay: An Integrated Modeling Approach

To understand the relative importance of the various food and water pathways of PCB accumulation by fish in Green Bay, it is necessary to understand food web relationships, population structure, and the bioenergetics of the fish. GLERL is developing a predictive model of fish population dynamics and variability in Green Bay. During FY 89 bioenergetics models of alewife, perch, and walleye populations were developed and calibration of these models was started.

Physical Limnology and Meteorology Group



Waverider buoys are used by the Physical Limnology and Meteorology Group in wave measurement research.

Study the physical variables that characterize a lake environment and the manner in which those variables change with external forces, such as wind, heat exchange, and connecting channel flows; the results of this research help alleviate or reduce the impact of physical hazards and contaminant transport on both the environment and the people who use it.

Exchange Processes in Coastal Environments

This research is motivated by a number of pressing environmental issues which are often associated with increasing population densities in coastal regions and with man's increased usage and exploitation of coastal resources over the past several decades. The longer-term effects of man's day-to-day activities and the shorter-term crisis situations induced by various environmental "incidents" are taking a significant toll on the health of coastal ecosystems.

The central focus of this research activity is the examination of processes contributing to the advective exchange of environmentally significant fields in coastal environments. Generally speaking, processes which mediate the exchange of physically, biologically, or chemically significant fields in coastal regions

are poorly understood. As a result, associated models of and predictive capabilities for the variability of associated fields are crude.

Several studies were initiated during FY 89 as part of this project.

■ Field studies of the physical and biological variability across the springtime thermal front in Lake Michigan were initiated in collaboration with University of Michigan researchers. Transect data were gathered from ships to delineate the detailed structure of the front in physical, chemical, and biological fields.

■ Field studies of mixing phenomena in deep coastal basins continued in the Santa Cruz Basin in the Southern California Bight. This work was performed in collaboration with scientists from the Lamont Doherty Geological Observatory and from the University of Washington.

■ Plans were laid for studies of processes governing the exchange of fresh water flowing from the Mississippi River into the Northern Gulf of Mexico.

■ Preliminary plans were formulated for process-oriented studies of the exchange mechanisms associated with the Gulf Stream front and the shelf waters of the South Atlantic Bight.

Lake Michigan Circulation and Dynamics of the Bottom Boundary Layer

We are studying the physics of the benthic boundary layer, with focus on bottom currents and resuspension. An experiment was conducted near Grand Haven, MI in April 1989 during which acoustic Doppler profilers were deployed alongside the Benthic Layer Interactive Profiling System (BLIPS) developed at Louisiana State University. The BLIPS provided measurements of sediment concentrations and fine-scale current structure within the lower 1.5 m of the water column (the logarithmic boundary layer), while our Doppler profilers measured and recorded Ekman layer currents.

Surface Waves and Water-Level Fluctuations

GLERL research in these areas includes field and analytical investigations to develop simulation and prediction models of over-water wind and wind waves, water surface oscillations, storm surges, and flooding.

We are assessing the importance of shallow water effects on wind waves in the Great Lakes by identifying the circumstances and locations in which shallow water effects have a significant impact on wave growth, propagation, or decay, and by quantifying the extent of that impact. Our theoretical approach focuses on the GLERL/Donelan deep water parametric wave prediction model. It will be tested against shallow water data sets to determine the limitations of its applicability. For the region from the shoreline to where the deep water model is no longer applicable, we will compare predictions of several existing theories and models of wind wave behavior in shallow water, including the Kitaigorodskii shallow water modification to the JONSWAP spectrum (so called TMA spectrum), empirical techniques suggested in the literature, and a third-generation numerical wave prediction model (WAM).

■ A WaveRider Information Processing System (WRIPS) buoy was deployed in Green Bay to obtain data on waves in this shallow embayment.

■ An initial study was conducted to compare the most advanced third-generation WAM model and the GLERL/Donelan model for prediction of surface waves on Lake Michigan. Results of both models were closely similar for the 10-day test in October 1988.

Green Bay Studies

Green Bay, a large embayment on the west side of Lake Michigan, is plagued with toxic organics, especially PCBs, in the water, sediment, and biota. The USEPA initiated a major interagency study of Green Bay in FY 88 to develop as complete and accurate a whole-bay mass balance for PCBs as possible, given funding and technical constraints. During FY 89, with partial funding from EPA and the balance from GLERL's base, GLERL conducted projects on water volume transport and sediment resuspension in Green Bay.

The models necessary to develop a comprehensive Green Bay contaminant mass balance require a knowledge of water volume fluxes throughout the Bay, its tributaries, and to and from Lake Michigan. In

this program GLERL is responsible for measuring water volume exchanges between the upper and lower parts of Green Bay and between the Bay and Lake Michigan. Winter current meter moorings established in Green Bay in late FY 88 were recovered in May 1989 and an array of 18 current meter moorings and four thermistor chains were deployed to determine the circulation in Green Bay during the summer and fall seasons.

Because most of the PCB reservoir in Green Bay is found in sediments, resuspension information is needed to develop a Green Bay mass balance model. GLERL is using both instrumented tripods and a bottom-resting flume in which the flow can be controlled to develop an empirical relationship between bottom resuspension and current velocity.

- Four instrumented tripods were deployed in Green Bay near the sites of seasonal current meter moorings, and a meteorological station was established to measure overlake winds and air and water temperatures.

- The measured water transparency during the winter was greater than during the summer at most locations, but the suspended material appeared to have the same properties during both seasons.

- Analyses of initial data from the test tripod deployment during FY 88 showed that wave action was a significant resuspension agent at a station 9 m deep; three resuspension events correlated with high wave activity.

Potential Changes in Thermal Structure and Cycle of Lake Michigan Due to Global Warming

A one-dimensional numerical model was used to estimate present and possible future temperature structures in Lake Michigan. The estimates were based on model simulations of the 1981-1984 offshore temperature field. After estimating water temperature climatology, three scenarios were examined based on general circulation models in which atmospheric CO_2 was doubled. The models were those of the Goddard Institute of Space Sciences (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), and Oregon State University (OSU).

This study does not forecast what may happen to Lake Michigan's temperature structure and cycle; it is a sensitivity study. Bearing this in mind, the potential changes to Lake Michigan suggested by the three scenarios include the following:

- Surface water temperatures would be higher throughout the year, with colder bottom temperatures in late summer and autumn.

- The heat content of the water column would also be higher, with the largest increases in winter, although after cold winters the OSU model showed that the autumn heat content may be less than under present conditions.

- The surface mixed layer and thermocline would be shallower in summer, and the temperature gradients across the thermocline would be stronger. Thus, more energy would be required to effect large scale vertical mixing.

- The summer stratified period would extend up to 2 months longer. The biggest change would be earlier springtime onset to full thermal stratification.

- Under the GISS and GFDL scenarios, the lake may no longer turn over fully during most winters. Thus, the deeper regions of Lake Michigan may experience a permanent thermocline with a shallower seasonal thermocline superimposed (as for most of the world's oceans). If this occurs, and if these regions are polluted and deep enough for the presence of a permanent thermocline, then the potential reduction in large scale vertical mixing could further degrade water quality at these sites.

The most important conclusion from this research is recognition of the critical need for permanent monitoring of offshore waters of the Great Lakes in order to generate high quality, long-term data sets which will advance our knowledge of the long-term behavior of basic physical and biological processes.

Facilities and Services

The sample processing lab where much of GLERL's sediment analyses is conducted.

GLERL's research facility is a modern building with over 24,600 square feet of usable space, including 19 laboratories (4,100 sq. ft.), conference rooms (990 sq. ft.), a library (1,250 sq. ft.), and computer resources (1,220 sq. ft.). In addition to general laboratory equipment, GLERL has a fully-equipped low-level radioisotope analysis laboratory, a stable isotope mass spectrometer (SIMS), several gas chromatographs and liquid scintillation counters, a high pressure liquid chromatography system, a multi-channel Coulter Counter, a full complement of growth chambers and incubators, stereo and inverted microscopes, and a fully equipped multi-purpose epifluorescence microscope.

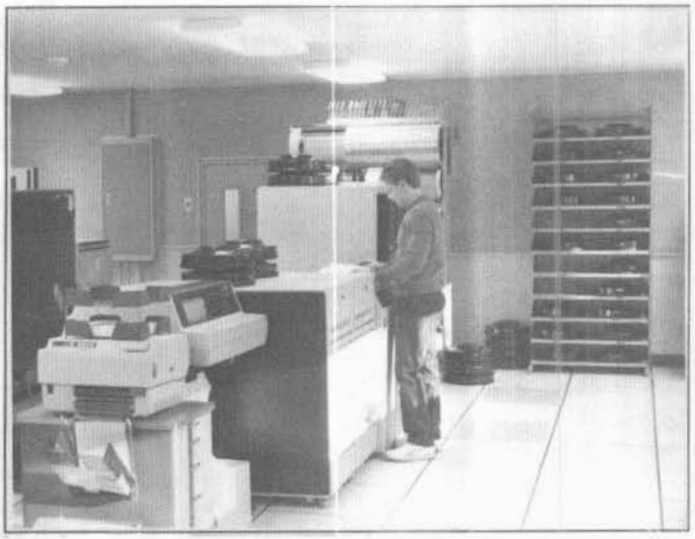
GLERL also maintains and operates a High Speed Microcinematography Laboratory housed in a temperature-controlled environmental chamber. The combination of high-speed (500 frames per second) and precise control of temperatures between 1° and 30°C allows advanced studies of the feeding behavior of zooplankton over the broad range of temperatures found in the natural Great Lakes environment. In addition, a separate Cold Room is maintained for conducting experiments and growing biological cultures at low temperatures.

Computer Facility

The GLERL Computer Facility consists of a Local Area VAXcluster (LAVc) of eight VAX

computers on site and the capability of accessing a Cyber 855 mainframe and a Cyber 205 supercomputer at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. GLERL is one of five remote nodes to the NIST facility, which is known as the Department of Commerce Consolidated Scientific Computing System (CSCS).

User terminals and microcomputers throughout the GLERL facility are hardwired to a communications switch that allows users to access the LAVc as well as the Cyber computers in Gaithersburg. Off-site access to the system is available through telephone lines and a private network that links NIST and all remote connections to the CSCS systems.



GLERL's computer facility.

A variety of applications, including real-time and near-real time data acquistion, data reduction, graphics, large scale modeling, statistical and mathematical analysis, telecommunications, and word processing, support more than 80 accounts. Laboratory office automation, administrative/accounting functions, and scientific applications are supported by more than 70 loosely networked microcomputers.

Library

The GLERL library staff provide library and related services in support of GLERL's research activities . A program-oriented research collection is maintained and special retrieval services are available when the existing collection cannot meet the needs of individual researchers. Library services include acquisition, circulation, interlibrary loan, reference, and online information retrieval for laboratory-affiliated personnel. The library staff expedite on-demand document retrieval and provide expanded reference capability through direct access arrangements with The University of Michigan libraries. GLERL library facilities and collections are available for public use on-site during normal business hours.

Collection holdings include 3,990 books, 4,772 unbound periodical volumes, and 3,073 technical reports in the areas of climatology, contaminant organics, hydrology, hydraulics, ice, limnology, mathematical modeling, meteorology, nutrients, oceanography, sedimentation, and wave motion with emphasis on the Great Lakes Basin. The library also receives 194 current periodical titles. The technical reports collection is supported by the GLERL library reports catalog database and may be searched on-site.

During FY89 two new databases: the NOAA libraries union catalog, and the GLERL periodical catalog, improved access to GLERL's book and periodical collections. A self-contained catalog station received from the NOAA Headquarters Library provides access to the NOAA catalog using interactive, Boolean search options and CD-ROM (Compact Disk - Read Only Memory) applications. New books are added to the NOAA catalog as they are acquired and cataloged by GLERL library staff. A local, online periodical database was created and placed on the GLERL computer. Using menu driven operations, library users may now search the periodical catalog by title to verify detailed holdings and to identify shelving locations. The catalog is continually updated by library staff.

In FY90, the library staff hopes to complete the update of periodical holdings in The Michigan Union List of Serials. Retrospective catalog-

ing of books for inclusion in the Online Computer Library Center's (OCLC) catalog is also under consideration. Older books included in the online database would be reflected in the NOAA libraries union catalog and could be searched on-site by library users using the new CD-ROM based catalog station.

The GLERL library is a member of the Michigan Library Consortium (MLC), Washtenaw-Livingston Library Network (WLLN), Federal Library and Information Network (FEDLINK), NOAA Library and Information Network (NLIN), and the Online Computer Library Center, Inc. (OCLC).

Information Services - Publications Unit

The Publications Unit staff are responsible for providing editorial and publications support to the scientific staff, for distributing GLERL publications, and for responding to publications and information requests from the public. They also produce and update brochures and informative fixed and portable displays concerning GLERL's work and/or important environmental issues.

For FY 89 the Information Services Group completed displays that were exhibited at the following events:

- Michigan Collegiate Job Fair held in West Bloomfield, MI.
- The 2nd Annual Government Career Day held at Michigan State University in E. Lansing, MI.
- Symposium on Ice and Climate sponsored by the International Glaciological Society in Seattle, WA.
- Great Lakes Festival in South Haven, MI.

Displays were also completed and exhibited for a visit to GLERL by delegates from the National Symposium on the Environment, and also for a media tour of GLERL sponsored by the Northeast Midwest Institute.

Research products generated during FY 89 include 54 scientific articles, reports, and books, and 81 formal presentations. There were over 1,400 documented requests for GLERL information, with over 2,900 items mailed as a result of those requests.

The Publications Unit maintains and updates eight mailing lists for GLERL products. New NOAA-series publications are automatically distributed according to these mailing lists. All new publications, including journal articles and books, are added to our six-month update listing of new publications, which keeps our users informed of GLERL's latest product releases.

Research Vessel *Shenehon*

The *Shenehon* is owned and operated by GLERL. It is based at the U.S. Army Corps of Engineers' boat yard at Grand Haven, Michigan, and is the primary platform used in support of GLERL's open lake field investigations. The vessel is 65.6 feet long, has a 6.5-ft mean draft, a 700-nautical-mile cruising range, and a 10-knot cruising speed. Navigational equipment includes a Sperry Gyrocompass, Raytheon Radar, two LORAN-C units, a Sperry Auto Pilot, and a Raytheon Depth Sounder. A 55-channel radiotelephone is available for ship-to-shore communications. The electrical system was modernized during FY 89 by installing a new 20-kW, 3-phase Onan generator. An electro-hydraulic articulated crane is used for deployment and retrieval of water and bottom sediment samplers and heavy instrument moorings. Electro-hydraulic winches handle hydrographic wire and multiconductor cable for water samplers and in-situ measurements of water variables. An onboard wet laboratory is available for onsite experiments and sample processing. Scientific equipment includes various sizes of Niskin samplers, reversing thermometers, and bottom samplers including a small box corer. A data acquisition system, separate from the Shipboard Environmental (Data) Acquisition System (SEAS), records and plots data from a Sea Tech transmissometer coupled to an electronic bathythermograph. The system includes equipment to record water tem-

perature data collected using Sippican Expendable Bathythermograph (XBT) probes.

The *Shenehon* is a designated NOAA weather reporting station and has an SEAS installed by the National Ocean Service. This system, the first installed in the Great Lakes, provides increased capability to collect and transmit weather data using satellite communications.

A 25-foot Bertram cruiser has been modified for use as an auxilliary research platform. Navigational equipment includes radar, magnetic compass, a 91-channel radiotelephone, a Loran-C and a 50-kHz depth sounder. An electric winch is available for deployment and retrieval of light sampling equipment.

During FY 89 cruises were made in Lake Michigan, northern Lake Huron and Saginaw Bay, and several longer cruises (48 days) were made into Green Bay. The Green Bay cruises were part of a cooperative study with the Environmental Protection Agency.

Sediment traps were deployed at two stations in Lake Michigan and at five stations in Green Bay to monitor the vertical mass and chemical flux. Instrument tripods were tested in Lake Michigan and deployed over the winter in Green Bay to study bottom currents and the resuspension of sediments.

Current meters and temperature sensors were tested in Lake Michigan and deployed in Green Bay over the winter as part of a bottom boundary layer study and to determine water currents in Green Bay. ARGOS drifters were also deployed in Green Bay to chart the near-surface water current fields. A Waverider was deployed in Green Bay and at a later date near Frankfort, MI to determine the effects of shallow water on wind waves.

The majority of the work supported by the *Shenehon* and the Bertram launch was connected with biological studies in Lake Michigan, northern Lake Huron, and in Saginaw Bay. These studies included benthic, planktonic, and bacterial experiments relating to algal growth, zooplankton grazing, food chain transport in the aquatic environment, fate and effects of sediment associated toxic organics, and long-term trends of benthic fauna.

The R/V Shenehon *is fully equipped for oceanographic studies and is the primary vessel used throughout the Great Lakes to collect the data used in most GLERL products.*

The 100-meter station off Grand Haven, MI continued to be monitored using sediment traps and periodic water and plankton samplings to study temporal variations in water quality as well as vertical mass and chemical flux as determined by trap samples. Particular emphasis was placed on carbon pools and rates of transfer. Several cruises were made using both the *Shenehon* and the Bertram launch for studies of frontal processes along traverses off Grand Haven and between Grand Haven and Sturgeon Bay, WI.

Drifters were deployed and retrieved in southern Lake Michigan as part of a cooperative study to test experimental equipment for the U.S. Navy.

The *Shenehon* participated in a 3-day open house sponsored by the Maritime Museum at South Haven, MI. The event was well attended by the public, and GLERL received beneficial TV, radio, and newspaper coverage. One short cruise for school children was made from Grand Haven.

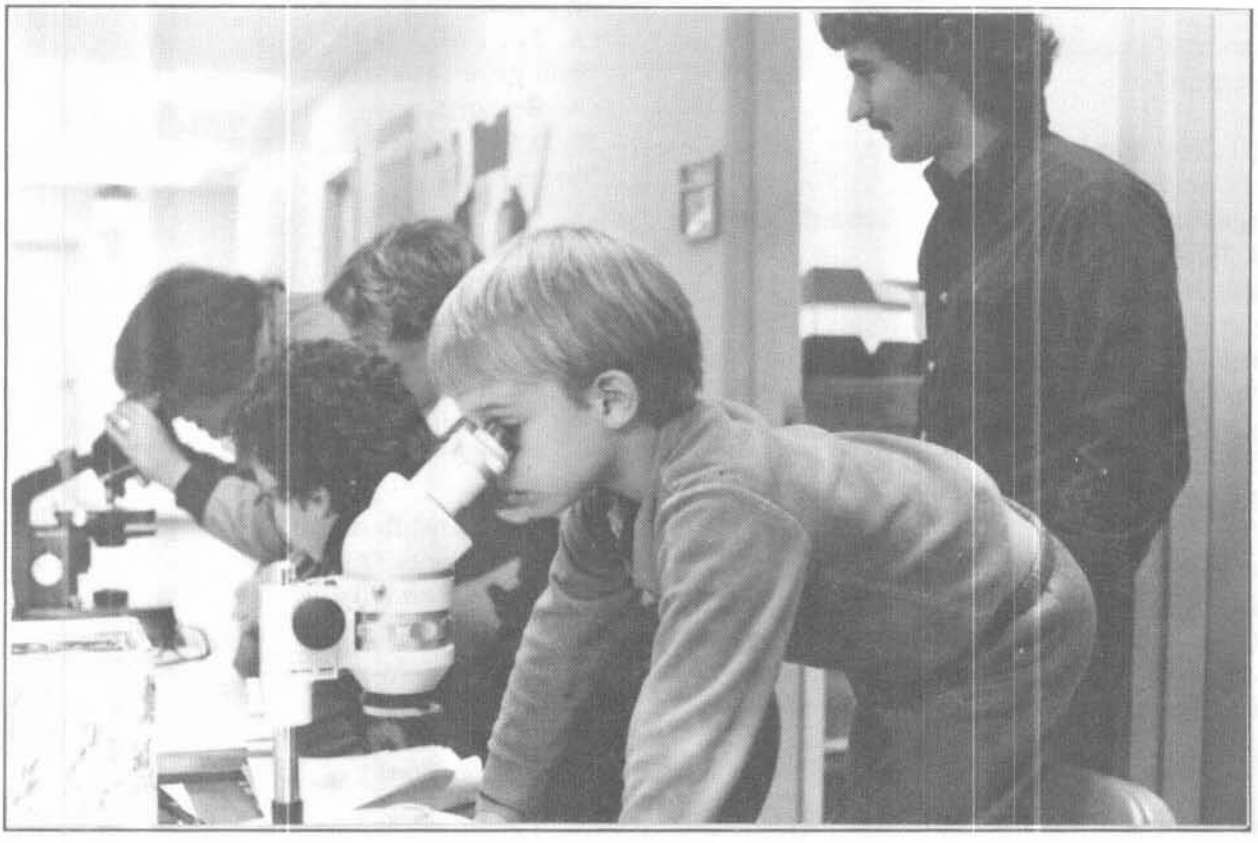
The wire line sweep technique developed by GLERL was successfully used again to recover two sediment trap moorings and one current meter mooring from submerged positions in Lake Michigan and Green Bay. The technique continues to pay dividends in rapid recovery of lost equipment, no loss of data, and no need of contract divers.

Marine Instrumentation Laboratory

The Marine Instrumentation Laboratory (MIL) staff select, calibrate, repair, and, when necessary, adapt or design 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 their needs. MIL staff also participate in field experiments by providing support for the deployment and retrieval of field equipment, assistance with the collection of samples and data, and in-field maintenance or repair of equipment. GLERL's data collection equipment includes 44 AMF Vector Averaging Current Meters, 16 AMF Acoustical Releases, 7 Mini-TOD Drifter Buoys, 1 Damo-Rupp Waverider WRIPS Buoy, 5 Aanderaa Thermistor String Recorders, 5 Marsh McBirney 585 Current Meters, and 1 RD Instrument Co. RDRR-1200 Acoustical Doppler Current Profiler.

During FY 89, MIL engineers and technicians participated in the Green Bay Project for measurement of water movement and sediment transport. An NBS time routine was installed on the GLERL VAX computer's Real-time Data Collection Package. A highly successful lagrangian measurement experiment was done with several LORAN-C drogues developed at MIL for high resolution position tracking. Enhancements were made to the Gamma-Scan System with integration of a position-monitoring device and active radiant source holder.

Outreach Activities



As part of the Partners for Excellence Program with the Ann Arbor Public Schools System, GLERL hosted an open house for school children.

The GLERL mission includes the development of environmental information, data, and service tools for users in government and private organizations. Identifying the environmental information needed to fulfill this mission is a vital activity of GLERL staff and helps guide our research programs. Participation on boards, commissions, task forces, and committees is an essential part of this effort. Equally important is the role played by the Publications Unit, which supports all aspects of publishing GLERL's products, making them available to those who need them, answering information requests, and creating displays and general literature concerning GLERL's products and work.

International and Interagency Participation

Staff participation on boards, commissions, task forces, and committees provides a mechanism for defining new research initiatives, identifying user needs, and guiding the development of usable products. Participation also helps to maintain staff involvement in programs concerned with environmental problems and issues of water- and land-oriented resource development and management issues.

During FY 89, GLERL staff participated as members of the following boards, committees, and task forces:

International Joint Commission

- Great Lakes Science Advisory Board (A. Beeton, U.S. Chair)

- Council of Great Lakes Research Managers (D. Reid, Alternate)

■ Corporate Management Committee (A. Beeton)

■ Great Lakes Water Quality Board, Surveillance Work Group
- Great Lakes Surveillance Subcommittee (B. Eadie)
- Lake Michigan Task Force (B. Eadie)
- Lake Erie Task Force (J. Robbins)
- Lake Huron Task Force (T. Nalepa)
- Workshop on Applications of Mass Balance to the Management of Toxic Substances in the Great Lakes (B. Eadie, Co-chair)

■ Great Lakes Water Levels Reference
- Functional Group 1: Hydrology, Hydraulics, and Climate (F. Quinn)
- Functional Group 3: Socio-Economic and Environmental Impact Assessment Group (H. Hartmann)

■ Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data
- Hydrometeorology and Modeling Subcommittee (T. Croley)
- River Flow Subcommittee (F. Quinn)

■ International Great Lakes Levels and Flows Advisory Board (F. Quinn, U.S. Co-chair)

Other interagency, professional society, and international activities:

■ International Association for Great Lakes Research
- Board of Directors (D. Schwab, Treasurer) (T. Nalepa)
- IAGLR Membership and Endowment Committee (M. Quigley, Chair)
- *Journal of Great Lakes Research* (F. Quinn, Associate Editor)

■ National Research Council
- Postdoctoral Program (A. Beeton, H. Vanderploeg, P. Landrum)

■ The University of Michigan
- Cooperative Institute for Limnology and Ecosystems Research (CILER) (A. Beeton)
- Biological Station Executive Committee (A. Beeton)
- Ph.D Committee (A. Beeton, S. Tarapchak)

■ Ohio Sea Grant
- Zebra Mussel Project (A. Beeton)
- Lake Erie Ice Studies (S. Bolsenga)

■ American Society for Testing and Materials Sediment Toxicity Subcommittee (P. Landrum)

■ Assessment and Remediation of Contaminated Sediments (ARCS, USEPA)
- Toxicity/Chemistry Work Group (P. Landrum)
- Management Advisory Commiteee (D. Reid)

■ *Chemosphere*, Board of Editors (P. Landrum)

■ Department of Commerce Consolidated Scientific Computing System Technical Committee (G. Spalding)

■ Great Lakes Commission
- Drought Management and Great Lakes Water Levels Task Force (H. Hartmann, F. Quinn)
- Great Lakes Speakers Bureau Directory (G. Laird, F. Quinn, H. Hartmann)
- Task Force on Emergency Preparedness (D. Reid)

■ Great Lakes Environmental Action Program (Great LEAP) (A. Beeton, H. Hartmann, G. Leshkevich)

■ Great Lakes Protection Fund
- Technical Advisory Committee (A. Beeton)

- Great Lakes Water Quality Agreement EPA Policy Committee (A. Beeton)
- Green Bay Mass Balance Study (USEPA)
  - Field Operations Committee (N. Hawley)
  - Management Committee (A. Beeton)
  - Modeling Work Group (J. Saylor)
  - Technical Advisory Committe (B. Eadie)
  - Lake Ontario Dioxin Superfund Management Panel (B. Eadie)
- *Handbook of Environmental Chemistry*, Advisory Board (P. Landrum)
- Huron River Watershed Council (S. Tarapchak, Advisor)
  - Portage Lake Project (A. Beeton)
- Institute of Global Affairs of Michigan
  - Muskegon Vessel Base (A. Beeton, D. Reid, S. Bolsenga, G. Bell)
- International Mathematics and Statistical Library (IMSL) North American Users Group (L. Herche, Co-chairman)
- International Association of Theoretical and Applied Limnology (A. Beeton, U.S. Representative)
- Lake Ontario Nutrient Cycle/Foodweb Modeling Workshop (S. Tarapchak)
- Michigan Technology Council of Washtenaw Community College (A. Beeton)
- NOAA Coastal Ocean Program
  - Coastal Fisheries Ecosystem Component Interline Office Development Team (G. Fahnenstiel)
- NOAA/ERL Satellite Requirements Committee (S. Bolsenga, G. Leshkevich)
- NOAA Estuarine Habitat Research Workshop (W. Gardner)
- NOAA Mississippi River Plume/Gulf Shelf Region Research Planning Workshop (W. Gardner)
- NOAA Technical Subcommittee, New Bedford Superfund Action (B. Eadie)
- NOAA NECOP Technical Advisory Committee (B. Eadie)
- NOAA/NESDIS Coastwatch Program (G. Leshkevich, D. Schwab, G. Spalding)
- Regional Response Team (RRT), Region V
  - Department of Commerce Alternate Representative (D. Reid)
- Sea Grant Research Advisory Committee (J. Saylor)
- Sediment Toxicology and Chemistry Workgroup for the Assessment and Remediation of Contaminated Sediments Program (US EPA) (P. Landrum)
- State of Michigan, Department of Natural Resources
  - Great Lakes Information System Technical Advisory Committee (A. Beeton)
  - Michigan Great Lakes Fund (A. Beeton)
  - Toxic Substances Control Commission (A. Beeton, Commissioner)
- State University of New York (SUNY) Buffalo, Great Lakes Programs
  - Advisory Board (F. Quinn)
- U.S.-Canada Ice Information Working Group
  - Great Lakes Ice Issues Subcommittee (R. Assel)
- International Great Lakes - St. Lawrence Ice Information Working Group (S. Bolsenga, G. Leshkevich)
- U.S. Soil Conservation Service (A. Beeton, Technical Advisor)

- U.S. Department of State
  - Cooperative Study on Chernóbyl Fallout in Masurian Lakes, Poland (J. Robbins)

- Waterloo Natural History Association (H. Hartmann)

GLERL scientists also:

- Conducted cooperative research on Chernobyl Fallout in Masurian Lakes, Poland, sponsored by the U.S. State Department.

- Conducted cooperative research with scientists from the University of Konstanz, W. Germany on a comprehensive study of Chernobyl Fallout in Lake Konstanz.

- Conducted cooperative research study of evaporation and climate change with scientists from the USSR Academy of Sciences.

- Continued to develop a cooperative research program with the People's Republic of China.

- Hosted a four-month visit by a hydrobiologist from the VNIIVO Institute, All-Union Scientific Research Institute for Water Protection in Kharkov, USSR, as part of the Environmental Protection Exchange Program.

- Established a cooperative zebra mussel monitoring effort with the U.S. Coast Guard wherein Coast Guard staff survey and report zebra mussel infestations on navigation buoys as they are recovered for winter storage.

- Participated in an ad-hoc international "mussel watch" committee to act as a clearinghouse and validation point for reported zebra mussel sightings. This committee has been instrumental in attempting to control unfounded rumors about the spread of the zebra mussel,and in providing accurate, verified data.

- Assisted Michigan State Police in the recovery of a drowning victim off Mackinac Bridge, and in an educational program for State Police and County Sheriff professional divers.

- Conducted cooperative research project with the Department of Pathology at The University of Michigan Medical School.

- Conducted cooperative research with scientists at Michigan State University, Department of Fish and Wildlife.

- Provided statistical consulting to scientists from The University of Michigan and the University of British Columbia.

- Worked with EROS Data Center in Sioux Falls, SD on obtaining and installing LAS image-processing software at GLERL.

- Fostered coordination with the Midwestern Climate Center and the Illinois State Water Survey to develop a Midwestern Climate Information System (MICIS).

- Conducted cooperative research with scientists at NASA/Goddard to measure bidirectional reflectance of ice.

- Conducted cooperative research with the Naval Ocean and Atmospheric Research Lab (NOARL).

- Served on a doctoral committee at The University of Michigan.

- Collaborated with scientists at Michigan State University.

- Conducted cooperative research with the U.S. Fish and Wildlife Service on under-the-ice ecology.

- Served as adjunct professors at The University of Michigan.

- Served on an expert advisory/review panel for Carnegie-Mellon University's Physical-Technical Systems Class on Catastrophic Spills on the Great Lakes.

- Participated in Cooperative Student Programs with The University of Michigan and Eastern Michigan University.

- Measured lipids for scientists at the University of Waterloo, Canada.

- Measured lipids in marine zooplankton for a cooperative study with Memorial University of Newfoundland, Canada.

- Conducted a cooperative study on lipids with scientists from the University of Stockholm, Sweden.

Meetings and Presentations

An integral part of the scientific development of GLERL staff is attendance and participation in scientific and technical meetings. During FY 89, GLERL sponsored 39 in-house seminars as part of the GLERL Informal Seminar Series. Our staff made 81 presentations concerning GLERL's work at public and professional meetings. Also, in FY 89, GLERL scientists organized and chaired a two-session workshop on Large Lakes and Global Climate Change at the 24th Congress of the International Association of Theoretical and Applied Limnology held in Munich, W. Germany (A. Beeton, F. Quinn, and D. Reid). Five other GLERL scientists were invited to make presentations at the same meeting (R. Assel, G. Fahnenstiel, W. Gardner, J. Robbins, and T. Croley). A GLERL staff member also served as co-chair of the session on Nutritional Biochemistry, Behavior, and Physiology at the National Science Foundation workshop "Future Directions in Zooplankton Biology" (H. Vanderploeg).

Technology Transfers

GLERL staff responded to approximately 1,400 requests for information during FY 89 and provided 2,900 items to service those requests. Many of the products that GLERL produces and distributes involve, to some degree, a transfer of both technology and data. During FY 89 GLERL's outreach of this nature involved the transfer of the following:

Great Lakes Freezing Degree Day Ice Cover Model

- Canadian Climate Center

Hydrologic Response Model

- University of Minnesota
- Provided continuing assistance to the US Army Corps of Engineers, Detroit District

Net Basin Supply Forecast Package

- US Army Corps of Engineers, Detroit District
- US Army Corps of Engineers, Buffalo District
- US Army Corps of Engineers, Hydrologic Engineering Center
- New York Power Authority

Thiessen Weighting Package

- Michigan State University
- University of Florida

Satellite Drifter Programs

- Scripps Oceanographic Institute

Large Basin Runoff Model

- Michigan State University
- The Water Network

Lake Evaporation Model

- Atmospheric Environment Service

Real-time Interactive Data Acquisition Software

- R.D. Instrument Co.

GLERL's data gathering equipment was shared with:

- The University of Michigan, Great Lakes Research Division
- Michigan State Police

Plans for construction of sediment traps were shared with:

- Environment Canada

- Ocean Science Center, New Foundland

Lipid Methodology

New micro-methods developed at GLERL to measure lipids in aquatic invertebrates were transferred to:

- National Water Research Institute, Burlington, Ontario
- National Hydrology Research Institute, Saskatchewan, Canada.
- U.S. Fish and Wildlife Service

GLERL and Great Lakes Education - Partners for Excellence

In conjunction with NOAA's desire to better inform the public of its research efforts, GLERL is involved in a number of Great Lakes community educational programs. In FY 89 GLERL continued its involvement with the Science Department of the Ann Arbor Public Schools' Partners for Excellence Program (T. Nalepa, GLERL Coordinator). The partnership seeks to enrich the public schools' curriculum in the area of environmental science, particularly with respect to the Great Lakes and aquatic sciences. Designated partnership activities included:

- Providing mentors to help students with Science Fair projects.

- Providing practical "hands-on" experience to promising science-oriented students via participation in a Student Volunteer Program.

- Providing information on careers in environmental science and acting as consultants for the science curriculum.

- Inviting science teachers to laboratory-sponsored seminars.

Southeast Michigan Science Fair

In conjunction with the 1989 Southeast Michigan Regional Science Fair, GLERL sponsored awards for Outstanding Projects in Aquatic Science in each of the Science Fair divisions: Senior Projects, Junior Projects, and Junior Models and Collections. GLERL staff (T. Croley, M. Quigley, D. Schwab, T. Nalepa, and A. Beeton) acted as general Science Fair judges and also as judges for the GLERL award.

Student Volunteer Program

GLERL and the Ann Arbor Public Schools established a Student Volunteer Program authorized by the Civil Service Reform Act of 1978 (Public Law 95-454). This program provides selected high school students with the opportunity to perform volunteer work at GLERL after school. Each participant will be assigned to a GLERL research scientist who will supervise the student's work and activities related to an active GLERL research project.

Teacher-at-GLERL Project

During FY 89 GLERL scientists (A. Beeton, D. Reid) initiated a project to host a middle school science teacher at GLERL for a one-semester sabbatical funded by the Ann Arbor Public Schools System. After several discussions with AAPS officials and a formal written proposal, the project was accepted and sabbatical funds were allocated for the 1991 school year. Ms. Sandy Aquino, a science teacher at Tappan Middle School, has been selected for the project and will be resident at GLERL from January to June, 1991 to develop curriculum enhancements in the area of aquatic environmental science.

GLERL Seminars

Date	Name and Affiliation	Seminar Topic
October 6, 1988	Tsanis, I. McMaster University.	Directional wave spectra in Lake Ontario.
October 12, 1988	Strickler, J.R. Woods Hole, MA.	Physical and biological energy flow: The role of turbulence at the zooplankton/ phytoplankton interface.
October 18, 1988	Spigel, R. University of Canterbury, New Zealand.	Selective withdrawal in reservoirs.
October 19, 1988	Privalsky, V. Water Problems Institute; Moscow, USSR.	Dynamic stochastic models and linear prediction of water level fluctuations in terminal lakes.
October 20, 1988	Spigel, R. University of Caterbury, New Zealand.	Geothermal heating in Lake Rotoiti, North Island, New Zealand.
October 24, 1988	Webb, T. Brown University.	Vegetation and climate change during the past 18,000 years in Eastern America.
October 27, 1988	Bernstein, R.L. Seaspace.	Satellite sea surface temperature data: Impact on California coastal circulation studies.
November 3, 1988	Lehman, J. The University of Michigan.	Lake trophic state and the role of food web structure.
November 8, 1988	Wright, S.J. The University of Michigan.	Mixing mechanisms for slightly buoyant point source discharges.
November 15, 1988	Breaker, L. National Meteorological Center.	Inter-annual and related variability in sea surface temperature along the California coast.
November 16, 1988	Kitchell, J. The University of Wisconsin.	Indicators and idiosyncracies of food web interactions in the Great Lakes.
November 30, 1988	Tessier, A. Michigan State University.	Zooplankton communities of the Northeastern United States.

Date	Name and Affiliation	Seminar Topic
January 5, 1989	Liu, P.C. GLERL.	Generalizing and improving the JONSWAP wind-wave spectrum.
January 11, 1989	Brandt, S., and D. Stewart. SUNY-Syracuse.	System level management and production in the Great lakes: Bioacoustics, bioenergetics, and multi-lake comparisons.
January 13, 1989	Hitchcock, G. NOAA/AOML.	Phytoplankton dynamics in realtion to meso-scale processes.
January 18, 1989	Fahnenstiel, G. GLERL.	The role of phototrophic picoplankton in the Great Lakes.
January 25, 1989	Webb, P. The University of Michigan.	Effects of boundaries on fish locomotor functional morphology.
February 1, 1989	Quigley, M. GLERL.	Energetic implications of O:N ratios in the amphipod *Pontoporeia hoyi.*
February 7, 1989	Barns, P. U.S.G.C., Menlo Park.	Coastal processes involving sea ice.
February 8, 1989	Weisenburg, D. Texas A & M University.	Biological responses to physical processes at oceanic fronts.
February 15, 1989	Robbins, J. GLERL.	A recent history of "biogenic" silica accumulation in Lake Erie sediments and the saga of the Great Black Swamp.
February 16, 1989	Arts, M.T. National Hydrology Research Institute.	Young-of-the-year perch predation on *Holopedium* [Cladocera]: Indirect effects of reduced body size.
February 21, 1989	Brinkmann, W. The University of Wisconsin.	Local trees and teleconnections. Ways to improve the reconstruction of net basin supply to the Great Lakes.
February 22, 1989	Landrum, P.F. GLERL.	Update on bioavailability from sediments.
March 1, 1989	Vanderploeg, H. GLERL.	Feeding mechanisims, selectivity, feeding rates, and life-cycle strategies of freshwater and marine zooplankton: Some interesting narratives and myths.
March 8, 1989	Jude, D. The University of Michigan.	Stock discrimination in Great Lakes populations of yellow perch and walleyes: Lord of the Rings.

GLERL Seminars

Date	*Name and Affiliation*	*Seminar Topic*
March 14, 1989	Ledwell, J. Lamont-Doherty Geological Observatory.	Mixing experiments in Southern California basin.
March 15, 1989	Tarapchak, S. GLERL.	Phosphorus plankton dynamics: Organic phosphorus transport by bacteria.
March 22, 1989	Hawley, N. GLERL.	Field observations of sediment trasport in the Great Lakes or "How I Spent My Last Four Summers."
March 28, 1989	Nalepa, T. GLERL.	Distribution, abundance, role in phosphorus cycling, and other aspects of freshwater mussel populations in Lake St. Clair.
April 5, 1989	Adams, C. Louisiana State University.	BLIPS: A system for studying benthic boundary layer dynamics.
April 12, 1989	Strickler, R. Boston University Marine Program.	Physical and biological energy flow: The role of turbulence at the zooplankton/phytoplankton interface.
April 19, 1989	DeMott, W. Indiana/Purdue University at Fort Wayne.	Food detection and discrimination by zooplankton.
June 21, 1989	Magnuson, J. The University of Wisconsin.	Potential influence of climate change on Lake Michigan fishes.
June 22, 1989	Ahir, S. National Cancer Institute.	Hormonal regulation of N-nitrosamine metabolism in the kidney of BALB/C Mice.
June 28, 1989	Ortner, P. NOAA/AOML.	Fine-scale biological observations within the Sheilikof Straits.
September 15, 1989	Muzzi, R. GLERL.	Improving satellite-tracked drifter buoy resolution by using LORAN-C.
September 19, 1989	Osborn, T. Johns Hopkins University.	Physical processes in planktonic feeding.
September 28, 1989	Gooch, J. Chesapeake Biological Laboratory.	Structure activity relationships for induction of the hepatic mono-oxygenase system of a marine telost by PCBs.

FY 89 Staff

	Full Time	Part Time	Student
Office of the Director	15	0	0
Ecosystem and Nutrient Dynamics Group	12	1	13
Environmental Systems Studies Group	4	1	2
Lake Hydrology Group	13	1	5
Physical Limnology and Meteorology Group	13	1	4
Synthetic Organics and Particle Dynamics Group	6	4	6
TOTAL	**63**	**8**	**30**

Office of the Director
Beeton A.M. - Director
Noble, P.E. - Secretary
Reid, D.F. - Ass't to the Director

Administration
Mark, S.V. - Head
Lashbrook, E.K.
Mull, R.C.
Lee, J.P.

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

Information Services
Reid, D.F. - Head
Darnell, C.M.
Hubbard, B.D.

Environmental Systems Studies Group
Fontaine, T.D. - Head
Dillingham, L.E. - Secretary
Clites, A.H.
Rybczyk, J.M.
Lang, G.A.
Wells, J.R.†
Ratkos, J.M .†

Physical Limnology and Meteorology Group
Saylor, J.H. - Acting Head
Dillingham, L.E. - Secretary
Gottlieb, E.S.*
McCormick, M.J.
Jackson, C.W.*
Miller, G.S.
Hawley, N.
Muhr, G.C.
Liu, P.C.
Schwab, D.J.

Marine Instrumentation Laboratory
Soo H.K. - Head
Booker, H.L.
Muzzi, R.W.
Dungan, J.E.
Hartung, S.F.*
Kistler, R.D.
Zick, S.I.*
Miller, T.C.

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Patton, T.R.†
Belz, L.K.*
Gordon, W.M.†
Quigley, M.A.
Bowerstock, K.L.†
Hentz, N.G.†
Ropek, R.E.*
Breitspecher, M.B.*
Hohmann, J.†
Scavia, D.
Carrick, H.J.
Laird, G.A.
Szymanski, D.B.†
Cavaletto, J.F.
Liebig, J.R.
Tarapchak, S.J.
Fahnenstiel, G.L.
Malczyk, J.M.
Vanderploeg, H.A.
Ford, M.A.*
Nalepa, T.F.
Wimmer, M.†

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Bolsenga, S.J.
Markham, R.A.†
Croley, T.E., II
Mazure, S.R.*
Derecki, J.A.
McCardell, C.V.†
Hartmann, H.C.
Norton, D.C.
Hunter, T.S.
Sellinger, C.E.
Jankuski, D.A.†
Thomas, J.D.†
Kelley, R.N.

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Threm, S.M.

Synthetic Organics and Particle Dynamics
Eadie, B.J. - Head
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Morehead, N.R.
Faust, W.R.
Niester, J.M.*
Gagalis, L.J.†
Pear, E.J.†
Gossiaux, D.C.*
Rae, G.K.*
Keilty, T.J.*
Robbins, J.A.
Landrum, P.F.

R/V Shenehon
Morse, D.V. - Master Mate
Burns, W.R.
Grimes, J.E.

* - Indicates WAE Employee
† - Indicates Co-op Employee

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