Great Lakes Environmental Research Laboratory

ANNUAL REPORT FY 1983

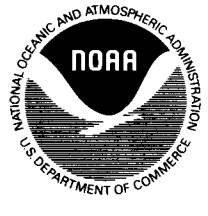
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Environmental Research Laboratories

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

ANNUAL REPORT FY 1983

December 1983

Eugene J. Aubert, Director



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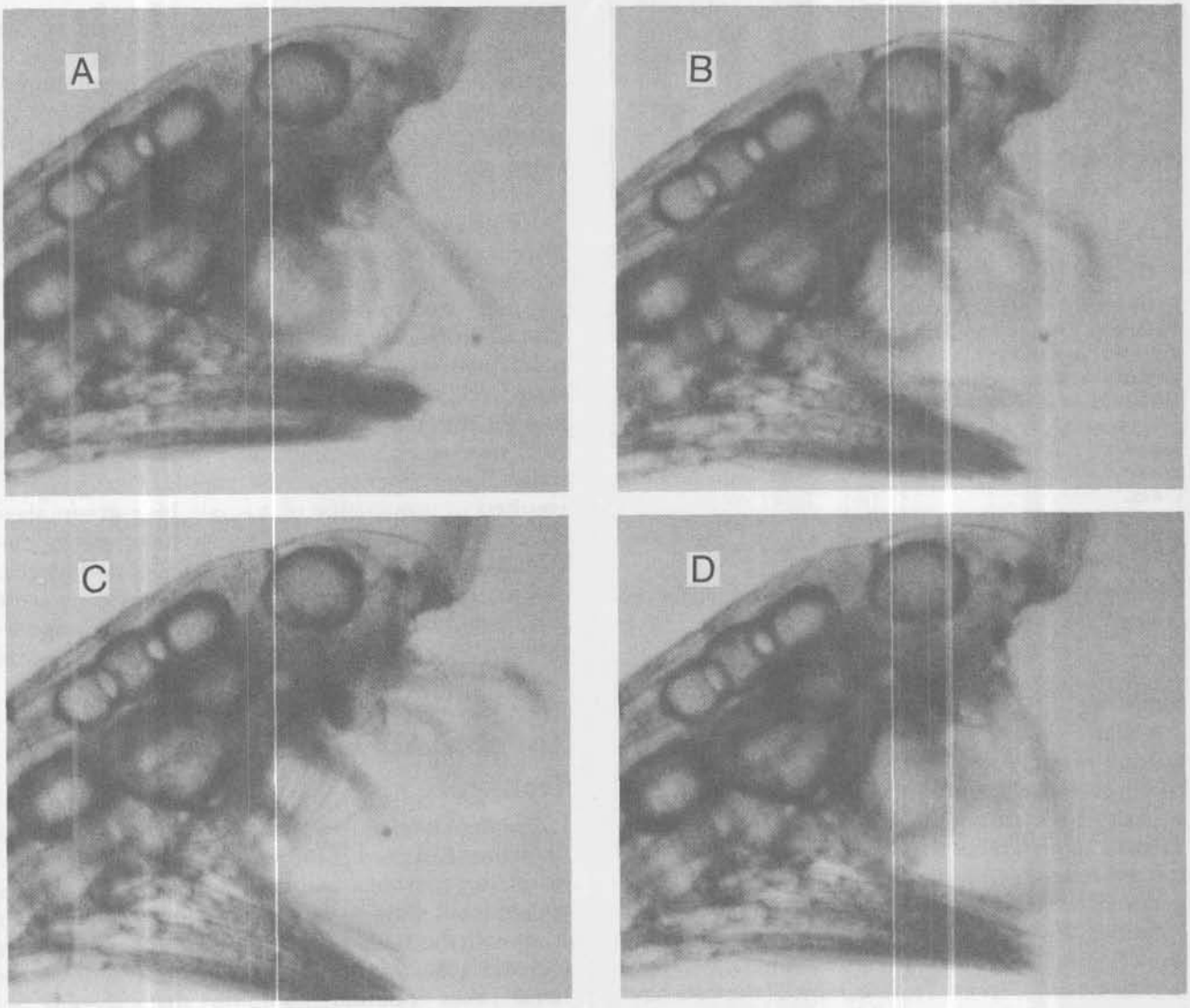
cies previously examined, *D. sicilis* used both the active and passive feeding modes simultaneously, allowing capture of small particles at all times. The continual operation of the small particle capture mode may be important in freshwater systems, where small particles are very abundant. The mechanisms observed on film suggested that *D. sicilis* may not be an optimal forager, but exhibits invariant selectivity at all times. Traditional feeding experiments are being run in the laboratory to test this hypothesis.

Other field-laboratory studies on zooplankton feeding processes provided information about competitive interactions among species and about the effects of zooplankton on living and nonliving food



Microscopic photographs of *Diaptomus sicilis* (shown here at 72 times actual size) capturing an alga. This sequence of photographs was taken with a high-speed motion picture camera focused through a microscope. The animal was held in place inside a small aquarium by a fine hair glued to its back. The mechanisms of active capture shown are as follows:

(A) Time: zero. The maxilliped, having responded to the smell of the alga, is pulled toward the body. This brings the cell closer to the animal's mouth even though the maxilliped doesn't actually touch it because, at this length scale, water is as viscous as honey.

(B) Time: 6 milliseconds. The alga has moved a little closer to the mouth and the legs now begin to open (flap) to aid capture.

(C) Time: 10 milliseconds. Second maxilla and legs flap open to aid capture by producing a suction.

(D) Time: 38 milliseconds. Cell is in filter basket formed by second maxillae.

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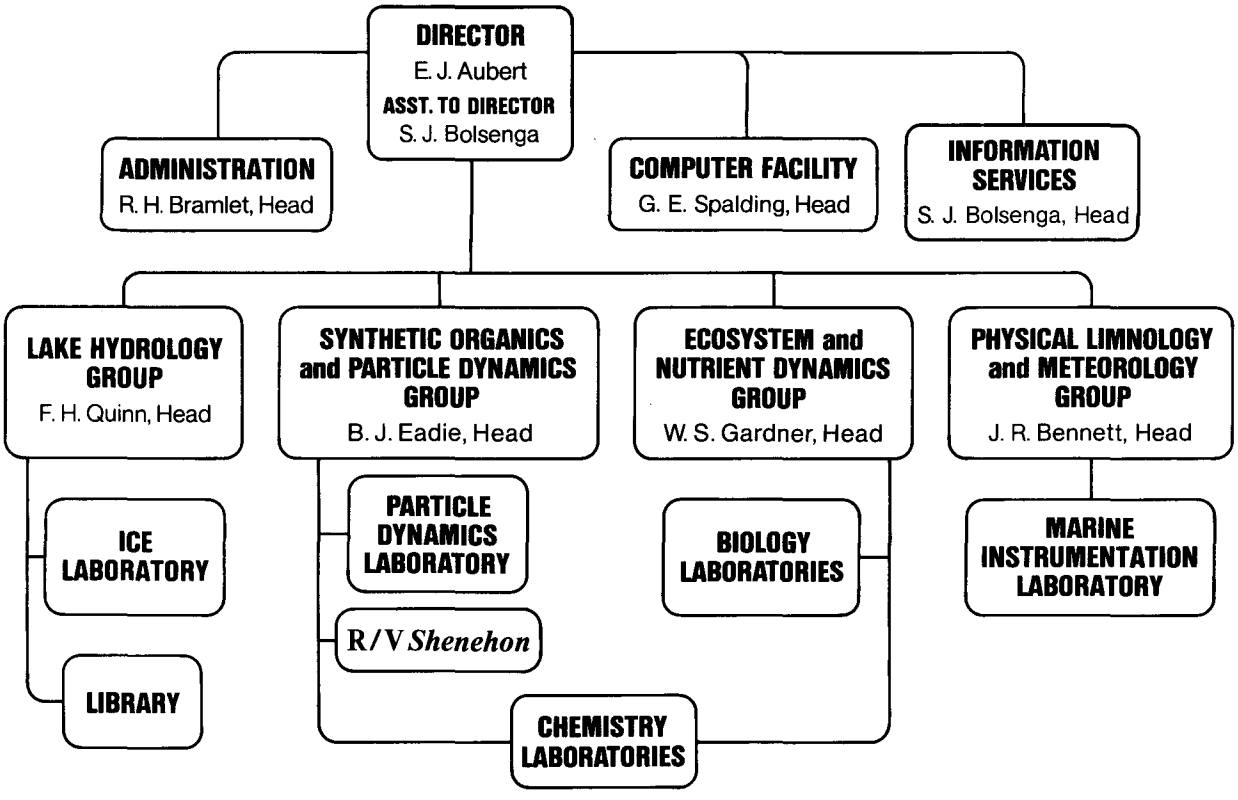
GLERL ORGANIZATION CHART



HIGHLIGHTS

For 9 years the Great Lakes Environmental Research Laboratory (GLERL) has conducted research on significant processes and problems in the Great Lakes Region and other coastal and estuarine waters. GLERL research is diversified in form. As is shown by the organization chart, process research is aligned along four primary disciplines. But problem-oriented multidisciplinary research, using staff from more than one group, is also conducted. The in-house research program is supplemented by grants and contracts with private institutions. In turn, GLERL supports the efforts of other government agencies. GLERL research products are disseminated by publications or presentations and discussions at scientific and user meetings. During FY 1983, 67 papers authored by GLERL staff and 9 papers by contractors were published, and 68 papers prepared by GLERL staff were presented at meetings.

Research

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

●*Ice-Cover Forecasting.* Research on St. Marys River ice has resulted in improved forecast techniques for freezeover, ice growth, and breakup at five different sites. Projections can be made up to 2 months in advance for freezeover and 1 month for maximum ice thickness and breakup.

●*Estimating Longshore Momentum Balance.* Careful analysis of wind, wave, and current measurements made during four storm episodes in the 1981 Lake Erie experiment has revealed the relative importance of acceleration, pressure gradient, bottom stress, wave radiation stress, and wind stress terms in the inner and outer regions of the coastal boundary layer. In the outer region, the wave radiation stress is smaller than in the others, but the radiation stress is passed through to the inner boundary region. In this area, where refraction is occurring and the waves have not yet broken, all of the terms in the momentum balance are important. Inside the breaker zone, the momentum balance is basically between radiation stress and bottom friction. These results are important in the development of conceptual and numerical models of transport and diffusion in the coastal boundary layer.

●*Dynamic Wave Forecasting for the Great Lakes.* A parametric dynamical wave prediction model developed by M. Donelan of the National Water Research Institute, Canada Centre for Inland Waters, has been adapted, modified, and compared with extensive measurements of wave height and direction. The model, after being tested in ideal lake geometry, was modified to take account of the influence of cross-wind gradients of wave height on wave direction. The results were found to correspond closely to the analytical solutions for both wave direction and wave height. The model was applied to the Lake Erie directional wave measurements conducted during 1981 and measurements made by the NOAA Data Buoy Center (NDBC) Nomad buoy in western Lake Erie during the same time period. The results have shown that, with locally measured wind data as input, the model provides remarkably close estimates of the general wave characteristics.

●*Synthesizing NDBC Nomad Buoy Data.* The eight NDBC Nomad buoys deployed in four of the Great Lakes in 1981 provided over 33,000 hours of simultaneously recorded wind, wave, water, and air temperature data. These data have been cataloged and analyzed in terms of long-term statistics, parametric correlations, wave growth characteristics, and comparison with model outputs.

●*Wind Stress Effect on Lake Levels.* A study was completed on the effect of mean wind stress on water level gage elevations with respect to Great Lakes chart datums. It was found that mean setup can have a significant influence on the gage-transfer method, particularly in Lake Erie. Correction factors for gage elevations in Lake Erie were determined and submitted for consideration to the IJC committee on the new Great Lakes water level datum. The results of the mean momentum balance calculations corroborated elevation adjustments for Fairport, Ohio, and Erie, Pennsylvania.

●*Nutrient Release by Benthic Invertebrates.* The patterns and rates of nitrogen (ammonium and amino acids) release by Great Lakes benthic invertebrates were quantified and compared to phosphorus release rates for the same animals. This work implies that benthic invertebrates' excretion is an important source of nutrients in aerobic nearshore environments.

●*Phosphorus Release by Benthic Invertebrates Independent of Substrate.* In contrast to previous studies on respiration by benthic invertebrates, phosphorus release rates of chironomids, tubificids, and *Pontoporia hoyi* were found to be independent of the presence of a particle substrate. This simplifies laboratory quantification of benthic invertebrate excretion rates.

●*New Microchemical Techniques for Nutrients.* New microchemical techniques were developed and adapted to measuring nutrient regeneration in small systems containing water, sediments, and organisms

from lake and marine systems. These techniques are being used to assess the relative importance of microbes versus invertebrates to nutrient mineralization and to analyze field samples for phosphate and nitrate.

●*Complexation of Toxic Organics by Natural Organic Matter.* High concentrations of toxic organic compounds, such as polychlorinated biphenyls (PCB's), DDT's, and polycyclic aromatic hydrocarbons (PAH), have been found in the pore waters of the Great Lakes. The question of whether these compounds were truly dissolved or complexed with the high concentration of naturally occurring organic matter is important to the long-term fate of these compounds. Our laboratory studies have shown that complexation does occur and partitioning coefficients of 10^4-10^7 have been measured.

●*Bioavailability of Complexed PAH.* In studies done by GLERL scientists, PAH compounds, such as benzo(a)pyrene and anthracene, have been shown to form complexes with naturally occurring organic matter. Laboratory experiments indicate that the complexed form of the PAH is very much less available to the benthic amphipod *Pontoporia hoyi*. If this is common to the majority of benthic organisms, then it will mean that sediments play a smaller role as a source of contaminants than is currently believed.

●*Cores From Great Lakes High Sedimentation Areas.* In a joint effort with the Canada Centre for Inland Waters, the Universities of Minnesota and Michigan, and Argonne National Laboratory, nine box cores were collected from Lake Superior. Collections from the other four Great Lakes, completed last fall, focused on the regions of highest sediment accumulation. Less is known about Lake Superior, which required coring in three of its basins. Extensive biogeochemical analyses of these cores is currently underway.

●*Biogeochemical Analysis of High Sedimentation Cores From Lake Ontario.* Analysis of two Lake Ontario cores, one from the site of highest sediment accumulation and one 3 kilometers away with approximately 50 percent of the high accumulation rate, has been completed. To fit the data, modifications and improvements had to be made to GLERL's sediment advection-diffusion model. Calibrating with the radionuclides lead-210 and cesium-137 has enabled scientists to predict the vertical cross section mercury profile very well. Attempts to predict organic contaminant profiles have been less successful, primarily because of poor knowledge of the time-dependent source function and the relative movement of pore waters. Improvements in the model will be made with each set of cores analyzed.

●*Beryllium-7 Analysis Scheme.* Beryllium-7, a natural radionuclide with a 59-day half-life, can be used to gain insight into short-term particle dynamic processes. This radionuclide enters the lakes through the atmosphere, sorbs onto indigenous particulate matter, and migrates to the sediments. GLERL scientists have developed the capability to analyze for this compound in various sample matrices and expect its use will provide important information on seasonal processes.

●*Monthly Estimates of Particle Fluxes for Offshore Lake Michigan.* Data from sediment traps at a station 35 kilometers offshore in 100 meters of water have been collected monthly for the past year. Biogeochemical and contaminant analyses are underway. Initial results from cesium-137 and beryllium-7 show that traps placed above the seasonal thermocline are isolated from the pool of sediments that can again become suspended. This indicates that traps could be used in stably stratified water as integrating surveillance tools for contaminant loads to lakes (and oceans) from the atmosphere. Fluxes of resuspended material measured during winter (when the density profile is unstratified) confirm earlier findings that the sediments form a "leaky trap" for contaminants.

●*Large Basin Runoff.* The GLERL Large Basin Runoff Model was improved with regard to snowmelt and evapotranspiration. Its calibration was improved, formalized, and encapsulated for semiautomatic use in a calibration package that is efficient and easily used. A probabilistic outlook package for forecasting of Lake Superior net basin supply and attendant suitability studies have been completed. The outlook package was applied to evaluate the worth of experimental snow water equivalent measurements made from aerial gamma radiation surveys conducted in a joint United States-Canadian effort over the Lake Superior Basin.

●*Joint Sedimentation Study.* Cooperative research on upland erosion mechanics between GLERL, the U.S. Department of Agriculture, and the U.S. Geological Survey has produced new understanding of unsteady overland sedimentation on the microscale associated with prediction, runoff, and erosion. The joint field experiments in nonprismatic rilled topographies have been completed, and kinematic flow theory for prismatic channel sedimentation has been extended for nonprismatic channel developments. These results improve understanding of the mechanics of various nonpoint-source pollutants, and may facilitate the modeling of pollutant transport from agricultural lands.

●*General Numerical Models for Computing Currents.* An improved spill model is now available for

testing. Improvements include increased resolution, multiple spill capability, zoom, and conformance to the GLERL modeling system. Using an analytic solution as the standard, numerical model test results showed that a 5-kilometer grid resolution yielded acceptable results and a 2.5-kilometer solution was nearly perfect.

●*Green Bay Circulation.* Analysis of current and water temperature data collected from Green Bay showed persistent high speed flow out of the bay in the upper levels, while cold hypolimnetic water flowed far into the bay. This water exchange with Lake Michigan accelerates bay flushing; thus, prior estimates of mixing times between the waters of Green Bay and Lake Michigan have been too long.

●*Computation of Rotational Normal Modes.* A comparison of theoretical and experimental rotational mode structures in the southern basin of Lake Michigan for the period April-November 1976 shows that modeled and observed currents agreed only in the frequency range corresponding to the maximum energy in the meteorological forcing, approximately 0.125-0.3 cycles per day. In this range, spectral peaks occur at identical frequencies for the wind, observed currents, and modeled currents. At lower and higher frequencies, the model underestimates kinetic energy observed in the currents.

●*Satellite-Tracked Current Drifters.* Satellite-tracked current drifters have proven to be a valuable tool for monitoring near-surface currents in the Great Lakes. Position accuracy tests conducted at four land locations around the lakes showed that errors were less than 1 kilometer, and did not vary with latitude, longitude, transmitter age, or battery condition. Wind drift was estimated to be 0.7 percent and was verified with dye and oil spills. Eight months of drifter track data have been compiled and statistically analyzed.

Information Services

During the past year, as part of GLERL's Information Services, over 3,000 research products were provided in response to almost 2,000 documented requests. Of these, 37 percent came from institutions of higher learning, 34 percent from private citizens, 12 percent from foreign government agencies, 7 percent from industry and private organizations, 6 percent from U.S. Federal Government agencies, and 4 percent from State Governments. This activity is in addition to regular mailings to a list of recipients who have indicated interest in a 6-month listing of one or more of the five types of GLERL publications. There were five Draft Environmental Impact Statements evaluated during the year.

International and Interagency Activities

This past year GLERL staff members were active in several International Joint Commission boards and committees, including the International Great Lakes Diversions, International Great Lakes Levels and Flows Advisory, and International Great Lakes Technical Information Network Boards, the Ecosystem Objective Committee Work Group, Science Issue Panel, and Task Forces on Modeling and for Surveillance. GLERL participated in the activities of the Great Lakes Commission through membership on the Natural Resources Management Committee. Other activities include participation in such varied activities as the Joint United States-Canadian Ice Information Working Group, the International Coordinating Committee on Hydraulic and Hydrologic Data, the Interagency Great Lakes Hydromet Steering Committee, and the International Association for Great Lakes Research.

Facilities

Five Tiros satellite-tracked drifter buoys used in Lake Michigan this past winter and summer were modified by marine instrumentation laboratory engineers and technicians. The buoys, designed to be expendable, can now be recycled. These improvements involved development of a radio-direction finder to pinpoint the locations of the buoys.

The chemistry laboratories' staff has been following the uptake and release rates of selected PAH by benthic organisms. This work uses radiotraced compounds, high-performance liquid chromatography, and liquid scintillation counters.

The computer facility has acquired a Digital Equipment Corporation VAX 11/780 computer system to be installed early in FY 1984. This new equipment should greatly enhance computing support for GLERL scientists.

In addition to the deployment and retrieval of various instruments and sample-collecting traps, the research vessel *Shenehon* was used to make measurements at the NDBC NOMAD buoy. Since data collected from this buoy are routinely used by both GLERL and the National Weather Service (NWS), periodic verification of output is important. Other work supported by the *Shenehon* included benthic, planktonic, and bacterial experiments studying nutrient cycling in the aquatic environment. This past year, boat operations were confined to Lake Michigan and rivers feeding into it.

STAFF AS OF SEPTEMBER 30, 1983

	Permanent Employees	
	Full Time	Part Time and Intermittent
Office of Director	11	1
Lake Hydrology Group	10	1
Ecosystems and Nutrient Dynamics Group	7	5
Synthetic Organics and Particle Dynamics Group	8	5
Physical Limnology and Meteorology Group	11	4
TOTAL	47	16

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

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

SYNTHETIC ORGANICS AND PARTICLE DYNAMICS

The Synthetic Organics and Particle Dynamics Group concentrates on studies of the movement and fate of synthetic contaminants in the Great Lakes and coastal marine ecosystems. This work is grouped into the areas of toxic organic cycling, the role of benthic invertebrates in the fate of pollutants, synthetic organic partitioning, lake particle flux dynamics, and studies of early diagenesis in Great Lakes sediments.

With the increase in population and industrial activities over the last half century, more human-induced pollution has been added to the Great Lakes. Many of these contaminants are foreign to the biosphere and some are highly resistant to decomposition. Because many of these pollutants are highly toxic and tend to concentrate as they move up the food chain, it is vitally important that water resource managers and other decision-makers have precise information on their nature and movement. Often the toxics sorb onto particles and move through the water and sediments in that way, making it important to understand the movement of particles within the lakes.

Models have proven to be the best method of supplying fast, accurate information on the movement, storage, and resuspension of chemicals and particles in the water and sediments of the Great Lakes, as well as coastal marine ecosystems. Recent modeling efforts have concentrated on the movement and distribution of PCB's and fallout radionuclides, such as cesium-137. Studies on the adsorption and desorption of synthetic organics, the movement of total suspended matter, the composition of sediments, and xenobiotic biotransformation (the way in which living organisms alter the foreign chemicals they encounter in the water and ingest) will provide the basis for additional modeling work.

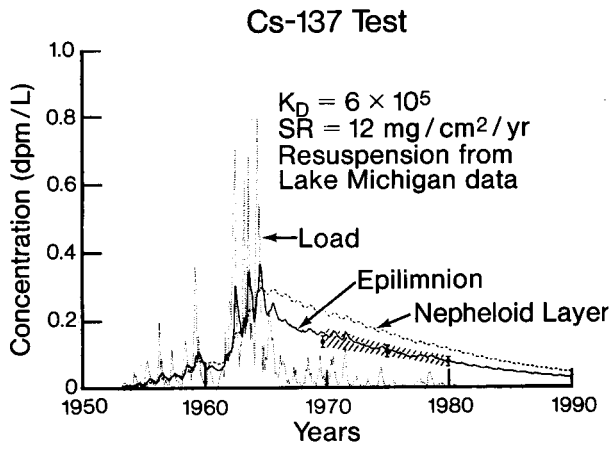
Toxic Organic Cycling

The 1978 Water Quality Agreement between the United States and Canada included language designed to minimize future pollutant loads and mitigate the impact of existing contaminants. It is necessary to improve our understanding of how such chemicals move through a large aquatic ecosystem so that regulation and management of trace contaminants can be effective.

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

A predictive capability requires models. Therefore, an in-house modeling team, consisting of chemical, toxicological, ecological, and physical scientists, has been established. This modeling group is supported by researchers working on primary ecosystem processes. Most of the process research has been conducted either in-house or at the University of Michigan; however, the program has now been expanded to include several research groups, an arrangement that allows for a maximum of flexibility.

Early GLERL modeling results indicated that the contaminant concentrations in biota appear to come into relatively rapid equilibrium with the water column and that water column concentrations are mediated by sorption, settling, and resuspension. Benthic organisms appear to be somewhat different and are discussed below. During the past year, efforts have been made to design a toxic cycling model that includes the effect of sediment resuspension and reequilibriation of sediments with the water column. Initial calibration runs for this model have been made using cesium-137 (a fallout radionuclide) data. This isotope was employed for several reasons: 1) there are extensive data on the load to the lakes (monthly for 30 years), water column and sediment distributions, and 2) cesium-137 exhibits similar partitioning behavior to many of the trace organics. A simulation was done for southern Lake Michigan and compared to resuspension rates estimated from sediment traps. The model appears relatively insensitive to 50-percent changes in resuspension. Recent field work with traps indicates that month-to-month changes can be nearer to an order of magnitude and may have significant impact on the model. Current results indicate that resuspension is acting as a scrubbing mechanism and is continuing to reduce the annual average concentration of cesium-137 in the water column. Initial efforts to model organics with this simulation have encountered the major problem of lack of load information. This is being addressed through the analysis of care-



Resuspension model calibration run for cesium-137. The dotted line (load) represents monthly cesium-137 load data. The other two lines (epilimnion and nepheloid layer) are model output. The epilimnion simulation is in good agreement with the nine available data points, which all fall within the hatched area. The two "tuning" variables, partition coefficient (K_D) and sediment accumulation rate (SR), are well within reported values.

fully studied cores of recent sediments from which we plan to reconstruct lake loads.

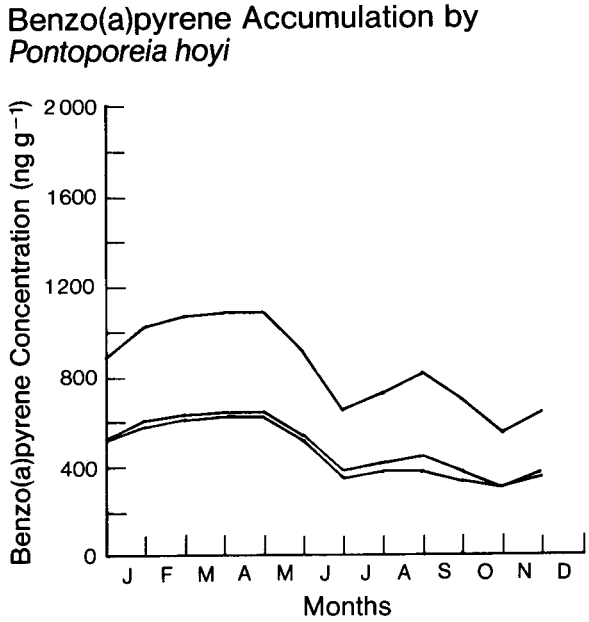
Role of Benthic Invertebrates in the Fate of Pollutants

Many of the major pollutants of concern in the Great Lakes are primarily associated with sediments. One probable mode of entry of these contaminants into the food chain is through ingestion of sediments by benthic organisms, remobilizing the compounds. Benthic organisms may play an additional role in the fate of pollutants through xenobiotic biotransformation. This would result in a direct decrease in the pool of potentially toxic compounds. There have been few studies on accumulation of toxics from sediments. Thus, there is little known about the interaction of infauna with contaminated sediments.

Scientists in the Synthetic Organics and Particle Dynamics Group continue to examine the kinetics of uptake, depuration, and biotransformation of selected PAH by *Pontoporeia hoyi* and other selected benthic organisms. These studies include the influence of temperature and concentration, as well as sediment sorption, on the bioconcentration kinetics of PAH. The studies are being performed in temperature controlled chambers of both static and flow-through design. Complementing these studies is a field program to measure the PAH content in benthic organisms, sediments, pore waters, and overlying waters.

During the past year, studies have continued on the uptake of sediment-sorbed PAH. The uptake rate constant in *Pontoporeia hoyi* for benzo(a)pyrene (BaP) was small but reasonably reproducible, 0.0022 ± 0.0013 grams dry sediment per gram of animal per hour. These rate constants were used in conjunction with the uptake rate constant from water and the depuration rate constant to predict steady-state body burdens of phenanthrene and BaP for three different depths in Lake Michigan. The steady-state body burdens compared well for the predicted and measured vaules. The sediment-associated BaP is predicted to contribute 6-45 percent, while the sediment-associated phenanthrene was predicted to contribute 8-88 percent of the steady-state body burden.

A kinetics model for the bioaccumulation of PAH in *Pontoporeia hoyi* was developed to incorporate the uptake from water and sediments. The rate constants were allowed to vary with season, as had been determined for BaP, and temperature. The seasonal variation with temperature was taken from a relationship determined for whole-lake data for Lake Ontario. The



Predicted concentrations of benzo(a)pyrene (BaP) in *Pontoporeia hoyi* throughout most of one year at 60-meter (upper curve), 45-meter (middle curve), and 23-meter depths (lowest curve). The model incorporates the seasonal and thermal dependence of the uptake of the contaminant from water and sediments, as well as the seasonal and thermal dependence of the depuration rate. The animals exposed to sediments with the highest concentrations of BaP have the highest bioaccumulations. The predicted overall variability of the model will be tested against field and laboratory data.

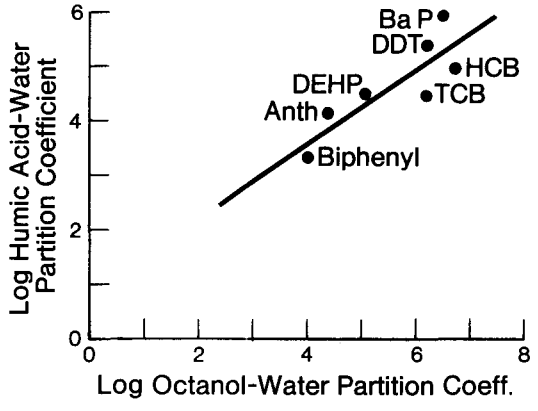
results of this model predicted that the body burden of PAH for the *P. hoyi* would vary with the season, with the highest concentrations in winter and spring and the lowest in fall. Field and laboratory experiments are currently underway to verify these results.

Synthetic Organic Partitioning

The association of synthetic organic contaminants with particles in an aquatic system plays an important role in determining the compounds' behavior and fate. This association is generally expressed as a ratio of concentrations in the two phases, termed the partition coefficient (K_p). The magnitude of K_p is a function of the compounds' water solubility, the organic carbon content of the solid substrate, and the concentration of substrate.

Recent work indicates that PAH and other hydrophobic compounds can be bound up in a complex with natural organic matter. This phenomena has important implications to both the sorption behavior of compounds and to their bioavailability.

A reverse phase separation technique was used to determine the binding of carbon-14-radiolabeled organic pollutants [benzo(a)pyrene; anthracene; biphenyl; pp'-DDT; 2,4,5,2',4',5'-hexachlorobiphenyl; 2,5,2',5'-tetrachlorobiphenyl; and bis-diethylhexylphthalate] to humic materials in aqueous solution. This approach is based on the assumption that contaminants associated with humic materials in water will pass through Sep-Pak® columns, whereas unassociated hydrophobic contaminants will be retained by the column when the contact times are short. The partition coefficient [(grams of pollutant bound per grams of organic carbon) divided by (grams of pollutant freely dissolved per milliliter of water)] did not depend on pollutant concentration, but was inversely proportional to the concentration of dissolved organic carbon (DOC) in solution. At low DOC (1-2 milligrams per liter), the partition coefficient was approximately equal to the octanol:water partition coefficient and inversely proportional to the compound's water solubility. Initial laboratory results indicate that the bioavailability of the complexed contaminant to the amphipod *Pontoporeia hoyi* is significantly lower than that of the "freely dissolved" compound.



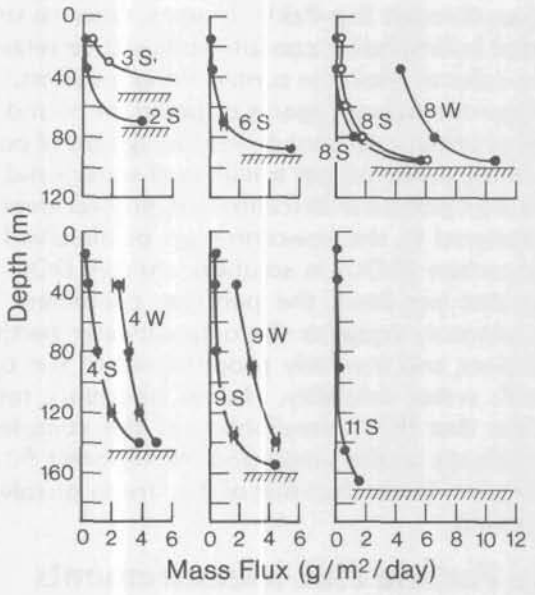
Graph of the binding of selected xenobiotics (materials foreign to the ecosystem) to humic acid versus the lipophilicity of the xenobiotic. The binding of selected xenobiotics to Aldrich humic acid was proportional to the lipophilicity of the xenobiotic. This finding reduces the amount of "freely dissolved" compound in solution in the presence of humic and fulvic acids. Xenobiotics included here are anthracene (anth.), biphenyl, diethylhexyl-phthalate (DEHP), DDT, tetrachlorobiphenyl (TCB), benzo(a)-pyrene (BaP), and hexachlorobiphenyl (HCB).

Lake Particle Flux Measurements

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

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

During the past year, traps were deployed at 12 stations throughout Lake Michigan and samples were collected for the total period of stratification and for the total unstratified period. Particle fluxes indicate strong near-bottom resuspension throughout the year, with an intense injection of resuspended matter



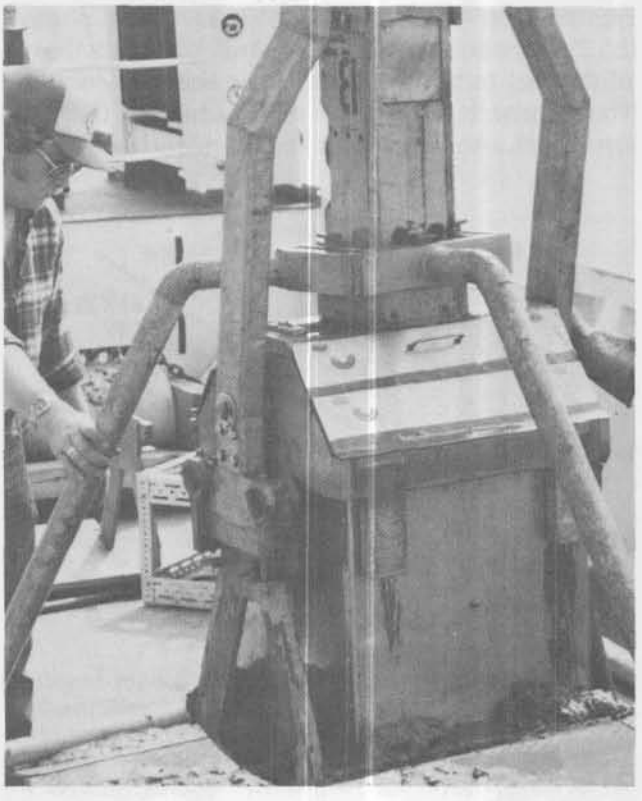
Particle mass flux profiles from six sediment trap deployments in Lake Michigan. Particle mass flux is smaller during the stratified season (summer—S) because the various temperature layers tend to inhibit the vertical movement of particles out of the sediments. Also, there are more storms to disturb the water during the unstratified season (winter—W). The stratified season is from mid-June through mid-November, and the unstratified season from mid-November through mid-June. Open and closed points are for clarity only.

onto the surface waters during winter. These large winter fluxes, when incorporated into GLERL models, play an important role in determining water column concentrations and residence times for hydrophobic contaminants. Major field experiments are currently underway to improve understanding of this process.

Studies of Early Diagenesis in the Great Lakes

As part of the study of the long-term behavior and fate of toxic organic compounds in the Great Lakes, GLERL scientists carefully collected box and gravity cores from locations of maximum sediment accumulation from the four lower lakes. At the same time, cores were collected from a few kilometers away, where accumulation was significantly slower, on the assumption that the distribution of compounds reaching these locations would be similar. The field program could not have been conducted without the assistance of the U.S. Environmental Protection Agency (EPA), Region V, and the Canada Centre for Inland Waters (CCIW). The aim of this study is 1) to build an optimally self-consistent description of sedimentation, bioturbation, diffusion, and reaction for contaminants (inorganics, organics, and radionuclides) in a series of cores from each of the Great Lakes to aid development of long-term modeling efforts, and 2) to use historical records of contaminant fluxes reconstructed from self-consistent diagenetic models as a form of ground truth for models describing the behavior of contaminants in the water column. The distribution of cesium-137 has been determined in essentially all the Lake Erie cores collected last year. In addition, distributions of beryllium-7 (with a half-life of 53.4 days) have been measured in three of these cores.

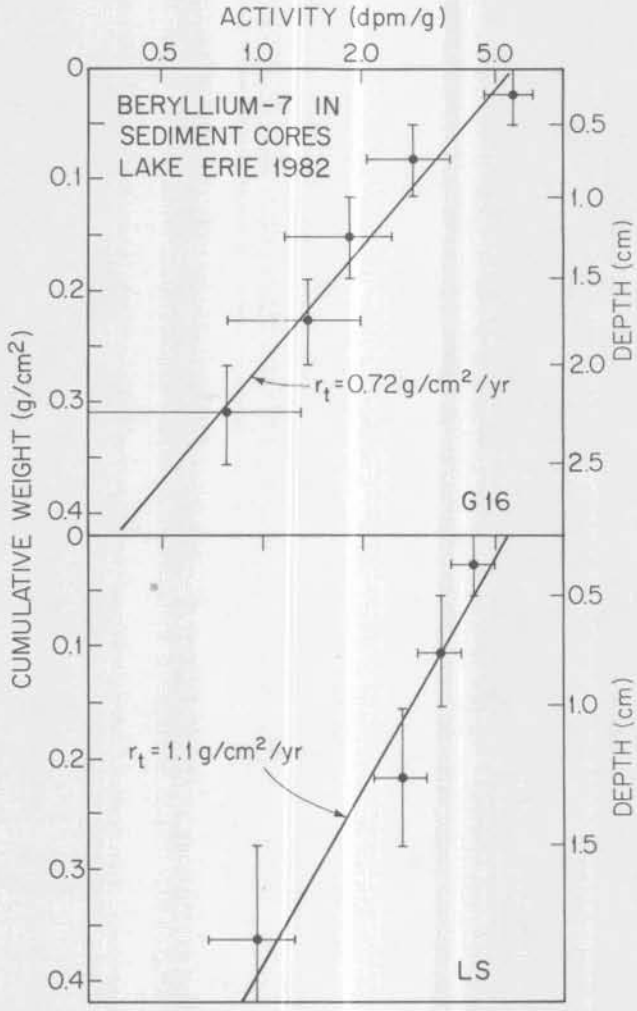
An example of results is the cesium-137 profile in a core from the eastern end of Lake Erie. It extends all the way to the bottom of the box core. The sedimentation rate at this location is one of the highest in the Great Lakes (0.3 grams per square centimeter per year or about 1 centimeter per year). The 1963-64 peak fallout occurs at 21 centimeters deep. The theoretical result based on the steady-state mixing model indicates roughly 6 centimeters of long-term mixing. This extent of mixing implies a time resolution of roughly 5 years in this core. The distribution expected in the



Box corer used to collect sediments from the Canadian survey ship *Limnos*. As part of a cooperative study between the Canada Centre for Inland Waters and GLERL, sediments are being collected from each of the Great Lakes.

United States and Canadian scientists subsampling a box core by inserting plastic tubes into undisturbed sediments. Cores are subsequently sectioned and analyzed by several participating laboratories. Such sediment core studies are aiding researchers in reconstructing the history of lake pollution and the role of sediments as a source, as well as a sink, for contaminants.

absence of mixing (same sedimentation rate) if transfer from air to sediments were immediate corresponds to past 1963-64 atmospheric testing episodes. Their appearance within the mixed zone indicates that mixing is not complete. The distribution of beryllium-7 in the same core further illustrates that sediment mixing cannot be treated as an instantaneous process (at least on seasonal time scales). The activity of this isotope decreases exponentially with depth within the mixed zone. Rates of advective mixing inferred from this profile compare favorably with the rate calculated from densities of conveyor-belt feeding zoobenthos at this location. The steady-state mixing model has been modified to properly take account of the conveyor-belt type of sediment redistribution in the Great Lakes. Initial results indicate that details such as those seen in profiles of cesium-137 in the eastern Lake Erie cores and beryllium-7 can be described correctly by that approach. In this study, field work alone has extended over a 3-year period in which Lake Ontario was cored in June 1981, Lakes Huron and Michigan in October 1981, Lake Erie in 1982, and Lake Superior in 1983. While the field phase of the study is largely complete, the analytical work is expected to continue for several years, with cores collected earliest generally analyzed soonest.



Distribution of naturally occurring beryllium-7 (which has a half-life of 53 days) in Lake Erie sediment cores. This nuclide, which is produced in the atmosphere by cosmic rays, reaches sediments, where it is mixed downward by benthic organisms. Thus, its exponential distribution can be used to determine the rate of sediment mixing. This rate, which varies with location on the lake bottom, is needed to describe seasonal to annual variations in levels of contaminants resuspended into the water column.

ECOSYSTEM AND NUTRIENT DYNAMICS

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

To accurately predict the effects of man-induced changes on the Great Lakes or marine coastal ecosystems, critical factors affecting the biota must be recognized and quantified as parts of a mathematical model of the system. Conceptual and mathematical models developed at GLERL and elsewhere have demonstrated that nutrient limitation is a major force controlling the quantity and composition of plankton in photic zones of the Great Lakes. Mechanisms controlling nutrient cycling must therefore be understood before changes in the biota and water quality of the lakes can be predicted. The close interrelationships between nutrients, phytoplankton, and aquatic invertebrates require an interdisciplinary research program so that critical processes can be quantified and integrated into simulative and predictive models. The Ecosystem and Nutrient Dynamics Group is investigating factors controlling nutrient cycling and ecological succession in the Great Lakes and is integrating experimental results into ecosystem models applicable to the Great Lakes, as well as to other freshwater and coastal marine ecosystems.

Lake Michigan Ecosystem Experiment

A free-drifting, satellite-tracked drogue was used to conduct a major Lagrangian ecosystem experiment in Lake Michigan. The purpose of this study was to define and quantify biological and chemical processes causing dynamic short-term and seasonal ecological changes in the Great Lakes. The reason for the Lagrangian approach was to minimize the complicating influence of physical transport on the interpretation of biological and chemical measurements. Data were collected to evaluate the ability of the drogue to track a water mass. These studies include use of satellite remote sensing of particle and thermal patches, dyes, drogue clusters, and flow meters attached to the drogue systems.

Specific objectives of the ecological study were to describe, understand, and eventually simulate temporal changes in dissolved and particulate nutrients, phytoplankton, and zooplankton. Each 5-day experiment followed the same general scheme. Water samples were taken on the first and last day to characterize the vertical structure of mixed-layer nutrient chemistry and phytoplankton and zooplankton composition from a location 25-30 kilometers offshore of Grand Haven, Michigan. On the first day, a satellite-tracked drifter buoy was released, with drogue and attached sediment trap array set to the depth of the mixed layer. A series of bottles for algal dilution-growth rate experiments were also attached to a drogue at various depths. The drifter system was then visited each day over the 5-day experiment to collect water and to perform experiments to determine rates of ecosystem processes contributing to species-specific phytoplankton dynamics. These experiments were designed to estimate species-specific algal growth rates via 1) *in situ* 24-hour carbon-14 incubations, 2) photosynthesis versus light incubations at shore coupled with light versus time and depth measurements, 3) 5-day *in situ* incubations of a natural algal assemblages diluted with filtered lake water, and 4) zooplankton manipulation experiments.

Algal sinking rates were determined through long-term (5-day) sediment collection in traps suspended below the drogue and through short-term (2-4 hour) sinking rate experiments in specifically-designed sedimentation bottles that are filled with lake water, suspended at depth for 2-4 hours, and then partitioned, top from bottom, before retrieving.

Algal loss rates due to zooplankton grazing were determined from zooplankton manipulation experiments. By measuring the rate of loss or gain of algal species as a function of manipulated zooplankton abundance, zooplankton-dry-weight-based algal loss rates could be determined. When coupled with observations of zooplankton at the drifter, *in situ* loss rates could be calculated.

Mixing of algal cells out of the upper layer, across the thermocline, will be calculated via vertical diffusion coefficients determined by successive temperature traces and/or calculations from a model driven by observed meteorological conditions.

Related experiments, carried out during each cruise, include nitrogen and phosphorus regeneration by zooplankton, phosphorus and amino acid uptake kinetics by phytoplankton and bacteria, bacterial growth rates, dynamics of the subthermocline chlorophyll maximum, diurnal migration of zooplankton, and a suite of experiments testing potential artifacts in the algal growth rate experiments.

The importance of this program is its potential ability to document intrinsic process-level influence on species-specific ecosystem dynamics. Because large aquatic systems such as the Great Lakes are physically dominated, it has been extremely difficult to document and simulate biological and chemical processes underlying state-variable dynamics. Taking advantage of the satellite-tracked drifters and the new technology developed at GLERL for successful retrieval and redeployment, GLERL scientists have begun this Lagrangian approach to study biological and chemical processes. Combining results from all five cruises will allow differentiation of long seasonal changes from short-term ecological variability and will provide information needed to develop accurate numerical ecosystem models.

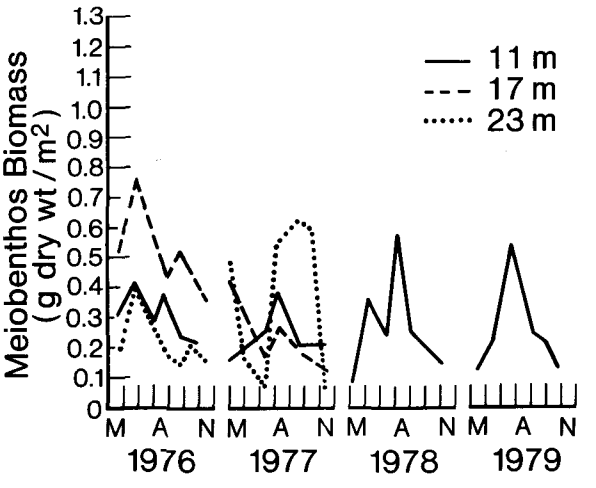
Lake Assessment

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

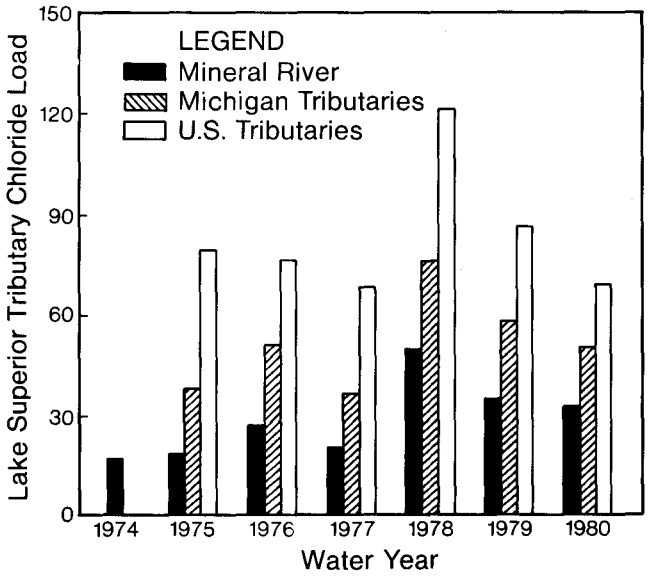
Progress in picking, sorting, and identifying benthos collected in Lake Michigan in 1980-81 continued. All organisms from samples collected in May 1980 (240 samples) have been identified, their dry weights have been determined, and these data have been coded for inclusion in a computer file. Separation and enumeration of benthic invertebrates was continued in sectioned sediment cores. The data will eventually be compared with physical and chemical sediment profiles to identify major variables determining vertical distribution of benthos. A data set on the vertical distribution of certain microcrustaceans in the sediment-water column has been fully verified and is now on line. Temporal and spatial variations in the meiobenthos of nearshore Lake Michigan were described. This work is the first documentation of the abundance of biomass and meiobenthos in the Great Lakes and demonstrates their importance relative to macroinvertebrates.

Sediment core samples from Lake Ontario were analyzed for different forms of phosphorus (total phosphorus and sodium hydroxide extractable organic and inorganic phosphorus) to gain insight into the nature of phosphorus inputs to the lower Great Lakes and into diagenic processes affecting phosphorus in the sediments. This information will be interpreted in conjunction with lead-210 dating and with chemical information provided by other scientists in a cooperative program. The changes in phosphorus content with depth were not dramatic (less than a factor of two), but could be completely accounted for by changes in extractable inorganic phosphorus. The apatite phosphorus and extractable organic fractions did not exhibit dramatic changes with depth or changes in oxygen content. Future examination of other cores should help determine whether sediment core analysis can be used to trace the history of phosphorus inputs into the lakes.

Diffuse and point-source loads of various forms of phosphorus and nitrogen, chloride, and suspended solids were estimated for Lake Superior. The Mineral River was established as the major source of chlorine to Lake Superior and may provide an ideal site to



Mean biomass (dry weight) of the meiobenthos at the 11-meter, 17-meter, and 23-meter water depths on each sampling date. Because of the high metabolic rates of the meiobenthos, its materials flow (energy, nutrients) was estimated to be 33-80 percent of the flow through the macrobenthos on an annual basis. This indicates that future studies on organic utilization or energy flow through the nearshore benthic communities in the Great Lakes should include the meiobenthos.



Chloride load into Lake Superior from the Mineral River, Michigan Tributaries, and U.S. tributaries. The Mineral River, located in the Upper Peninsula of Michigan, contributes more than one-third of the total U.S. tributary input. This unusual loading is largely due to the mine dewatering process used by a copper company. It is postulated that increased chloride concentrations may promote the introduction and adaptation of marine organisms into the Great Lakes.

investigate ecological changes resulting from increased salinity.

Ecological Modeling

A major problem in testing the predictive effectiveness of ecosystem models is the limited amount of comprehensive long-term field data available for aquatic ecosystems. Physical, chemical, and biological data collected continuously from Lake Washington over the last 30 years are being used to test a generalized ecosystem model for natural waters, including the Great Lakes. The long-term goal of this work is to develop and test a "next-generation" ecological model of lakes. To date, most of the data have been summarized, digitized, and transferred to NOAA's computer facility. A temperature-diffusion model has been calibrated for the 20-year data set and estimates of vertical diffusion coefficients have been summarized. Current efforts test those values by simulation of a mostly conservative substance, total alkalinity. Initial results indicate the existence of previously undocumented sources of total alkalinity in the Lake Washington environment. In the near future, total nutrient models will be tested and then used to analyze the effects of production on those nutrients. Evaluating the ability of the model to simulate ecological succession in Lake Washington will help determine its usefulness for predicting biological and chemical trends in the Great Lakes and other coastal ecosystems.

Microscale Heterogeneity

Research continued in a study to evaluate the potential importance of microscale heterogeneity in controlling phytoplankton species composition. Experiments testing the effects of nutrient patchiness on pure culture populations of algae were performed on three species. The following effect was clear and common among the species: Cultures exposed to a patchy nutrient regime grew on less average phosphorus per cell than did cultures grown at the same rate on homogeneous supply. Nutrient patchiness also appeared to produce smaller cells (for reasons that are unclear at this time). The effects of nutrient patchiness on natural assemblages of algae were tested in laboratory experiments. Preliminary results suggest that the heterogeneous supply produced a final species assemblage unlike the one produced under homogeneous nutrient supply. Patchy supply resulted in dominance of a single blue-green algal species; homogeneous supply resulted in co-dominance among the blue-green, flagellated greens, and a diatom. Studies of the effect of patchy nutrient supply on unialgal populations indicate that populations in a patchy phosphorus environment use that nutrient more efficiently.

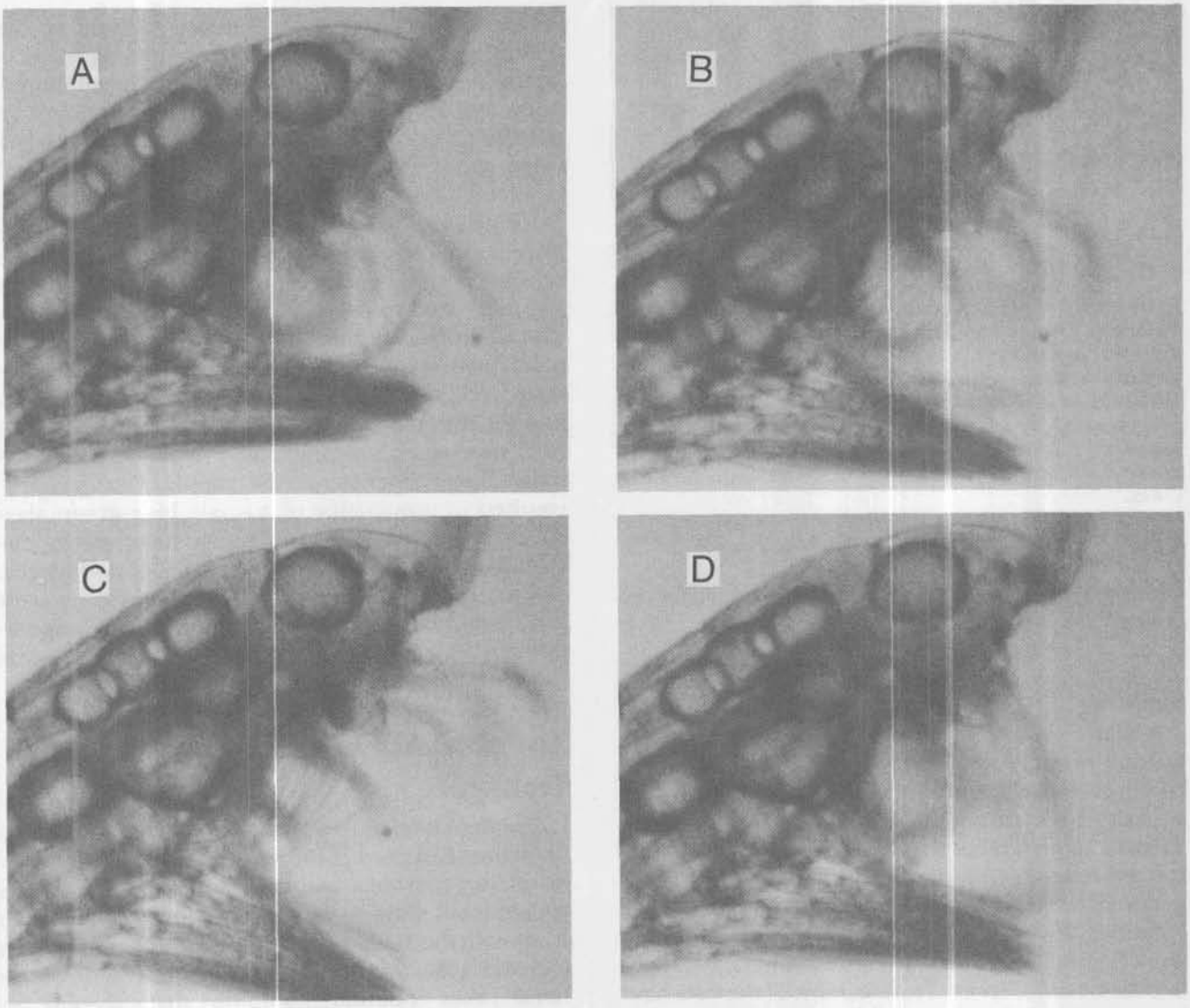
Zooplankton Feeding and Particle Transport

Zooplankton feeding processes and rates should be understood to predict the role of these invertebrates in cycling nutrients and controlling phytoplankton successional patterns in the lakes. In a cooperative study with the Skidaway Institute of Oceanography in October 1982, more than 100 films were made of the Great Lakes copepod *Diaptomus sicilis* feeding on three different-sized species of the diatom *Chlamydomonas*. Microcinematography, the technique used, provides high-speed (500 frames per second) filming for "direct observation" of the zooplankton feeding process.

Although *Diaptomus sicilis*, like marine copepods, was able to capture large particles by actively responding to the scent of the particle, this was the first copepod study demonstrating the passive mechanism of small particle capture. In contrast to marine spe-

cies previously examined, *D. sicilis* used both the active and passive feeding modes simultaneously, allowing capture of small particles at all times. The continual operation of the small particle capture mode may be important in freshwater systems, where small particles are very abundant. The mechanisms observed on film suggested that *D. sicilis* may not be an optimal forager, but exhibits invariant selectivity at all times. Traditional feeding experiments are being run in the laboratory to test this hypothesis.

Other field-laboratory studies on zooplankton feeding processes provided information about competitive interactions among species and about the effects of zooplankton on living and nonliving food



Microscopic photographs of *Diaptomus sicilis* (shown here at 72 times actual size) capturing an alga. This sequence of photographs was taken with a high-speed motion picture camera focused through a microscope. The animal was held in place inside a small aquarium by a fine hair glued to its back. The mechanisms of active capture shown are as follows:

(A) Time: zero. The maxilliped, having responded to the smell of the alga, is pulled toward the body. This brings the cell closer to the animal's mouth even though the maxilliped doesn't actually touch it because, at this length scale, water is as viscous as honey.

(B) Time: 6 milliseconds. The alga has moved a little closer to the mouth and the legs now begin to open (flap) to aid capture.

(C) Time: 10 milliseconds. Second maxilla and legs flap open to aid capture by producing a suction.

(D) Time: 38 milliseconds. Cell is in filter basket formed by second maxillae.

particles in the Great Lakes: 1) Comparative feeding experiments of two Great Lakes copepods indicated that *Diaptomus ashlandi* feeds more rapidly than *Diaptomus sicilis* per unit body weight, regardless of particle size or shape. These results suggest that *D. ashlandi* is a better competitor than *D. sicilis* for the limited food supplies in the Great Lakes. 2) An effective food concentration feeding construct was further refined by combining previous results on invariant selectivity with food concentration data to predict feeding rates. 3) Microscopic analysis of particles resulting from Great Lakes feeding experiments provided insights into the influence of algal morphology on the ability of a zooplankter to ingest algae. This may be an important factor controlling species composition and succession in the Great Lakes. 4) Calcite at concentrations found in Lake Michigan had only a modest effect on zooplanton feeding rates. However, fecal pellets settle much faster (20 meters per day) when calcite is ingested than when it is not (2 meters per day). Calcite may therefore have an indirect, as well as direct, effect on particle transport in the Great Lakes.

Pelagic Nutrient Regeneration

Biological regeneration of nutrients is a major source of nutrients to phytoplankton in the Great Lakes. Animal excretion is particularly relevant to recycling of nutrients in lakes because released nutrients are directly available to phytoplankton. GLERL research has continued to elucidate important mechanisms of nutrient cycling and regeneration from organic sources in the pelagic and benthic zones.

Work continued on the impact of food supply on nutrient regeneration by pelagic zooplankers. Ammonium excretion by *Daphnia* feeding in bottles containing suspensions of heat-killed algae was measured and directly compared to ammonium excretion determined by a previously described flow-cell method. These experiments supported the usefulness of the heat-killed cells and showed that the flow-cell method approximates, but may slightly underestimate, ammonium excretion by *Daphnia magna*. This underestimation probably results because the animals do not display their full ammonium excretion potential unless feeding on suspensions of algae.

Ammonium excretion rates by several life stages (nauplii to adult) of the marine copepod *Eucalanus pileatus* were measured in two controlled food environments to assess the importance of life stage and food abundance on nutrient regeneration by zooplankton. When food was abundant, animals of all stages released ammonium at similar rates per unit ash-free dry weight. However, at low food levels, late-stage juveniles and adult females released ammonium significantly more slowly than did the nauplii or early-stage juveniles.

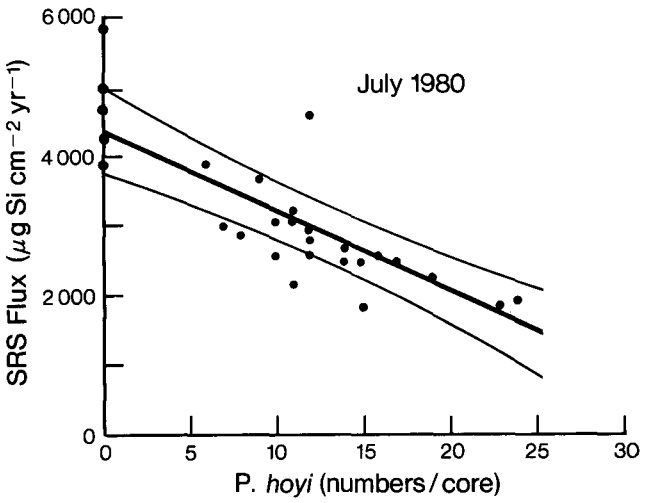
To evaluate the mass balance approach often used to calculate pelagic nutrient regeneration rates, the accuracy of calculated regeneration rates for dissolved silica, nitrate-nitrogen, and phosphorus in the epilimnion of an offshore station in Lake Michigan was examined. Results of first-order uncertainty analysis demonstrated high uncertainty in estimating regeneration rates of each nutrient. Approximately 80 percent of the variance for phosphorus regeneration was a result of uncertainty in the phosphorus to carbon ratio, and 90 percent of the variance for silica and nitrate-nitrogen regeneration was due to onshore-offshore transport. Regeneration rates calculated by mass balance can, therefore, be meaningful only if uncertainty due to vertical advection and cellular stoichiometry are minimized.

Benthic Nutrient Regeneration

Regeneration from sediments appears to be an important source of nutrients to phytoplankton in nearshore zones of the Great Lakes. Although phosphorus is not as readily released from aerobic sediments (as occur in the Great Lakes) as from anoxic ones, recent work implies that phosphorus is indeed supplied to overlying waters from Lake Michigan sediments. Benthic macroinvertebrates contribute to this process by mineralization (metabolic conversion of detritus into dissolved inorganic nutrients) and bioturbation (mechanical mixing) of the sediments to enhance nutrient release into overlying waters.

Laboratory microcosm experiments were conducted to determine the effects of benthic invertebrates on phosphorus release from aerobic Lake Michigan sediments. Phosphorus concentrations of the overlying waters in the microcosms were monitored over a period of about 70 days. The amount of phosphorus released from sediments into overlying waters was far greater in microcosms with invertebrates than in those without invertebrates, and more phosphorus was released in microcosms containing sand than in those containing silt. This implies that invertebrates have a substantial effect on sediment phosphorus regeneration in these nearshore regions of the Great Lakes.

Rates of excretion (or release) of ammonium and amino acids by Lake Michigan chironomid larvae and tubificid worms were measured to quantify metabolic aspects of nitrogen regeneration by these benthic invertebrates. Ammonium release rates were similar



Pontoporeia hoyi abundance versus soluble reactive silica (SRS) release in intact sediment cores. This indicates that resident amphipod populations in nearshore Lake Michigan may slow silica regeneration rates through mixing and selective feeding on sediment particles.

for both groups and on average ranged from 3 to 14 nanograms atom per milligram ash-free dry weight per hour at temperatures from 10° to 22°C. Kinetic data indicated that ammonium release by these animals is primarily an endogenous metabolic process and is probably not caused directly by breakdown of food in the animals' guts. In contrast, free amino nitrogen release rates often decreased with time after food removal and may have reflected egestion of partially digested food from the animals' guts. Based on previous measurements of phosphorus release, mean molar ammonium to phosphate ratios in excreted materials were calculated to be 15:1 for chironomids and 35:1 for tubificids at 20°C. Thus benthic invertebrates appear to be at least as important for the mineralization of nitrogen as for phosphorus.

To verify the validity of excretion experiments and to improve future experimental design, the effect of a sand substrate (presence versus absence) and the effect of water medium (lake water versus distilled water) on excretion rates of Lake Michigan macroinvertebrates were examined. The presence or absence of a substrate had no effect on excretion rates of tubificids, chironomids, or *Pontoporeia*, thus indicating that realistic determinations of phosphorus excretion in these taxa can be obtained without a substrate present. The type of water medium used, lake or distilled, also had no effect on excretion rates of tubificids and chironomids, but excretion rates of *Pontoporeia* were significantly higher in distilled water. It is therefore preferable to conduct excretion experiments in real or simulated lake water rather than in distilled water.

The relative importance of benthic invertebrates versus microbes to the mineralization process (conversion of organic nutrients to inorganic forms) in lake sediments was evaluated using new techniques developed at GLERL. Results imply that benthic invertebrate excretion may supply at least half of the nutrients mineralized in the near-surface sediments.

In contrast to phosphorus and nitrogen, silica is not excreted metabolically, but is regenerated by dissolution of diatom frustules that have settled to the sediments. Correlation of benthic invertebrate abundance with measurements of nutrient release from intact sediment cores indicated that *Pontoporei hoyi* may actually suppress dissolved silica release from sediments by burying the silica-rich surficial floc layer.

Experimental measurements of the rates of phosphate uptake by phytoplankton assemblages are used to evaluate the intensity of species competition in nature and to verify the accuracy of complex ecosystem model predictions. The uptake of this nutrient is generally characterized by fitting data to the Michaelis-Menton equation. However, GLERL tests demonstrated that phosphate uptake by natural assemblages of algae does not conform to the Michaelis-Menton equation because uptake rates at low phosphate concentrations are much higher than those predicted by the model. This discrepancy can be readily observed by plotting the reciprocal of the rate constant for phosphate uptake at high and at low phosphate concentrations. The value of the transport constants obtained from fitting uptake rates to the model at high concentrations are much higher than those obtained from model fits of the rates at low concentrations. These results show that commonly used constructs in ecosystem models will severely overestimate phosphate uptake rates and that traditional methods of fitting uptake rates to the Michaelis-Menton model must be modified to obtain accurate estimates of the kinetic constants.

LAKE HYDROLOGY

The emphases of the Lake Hydrology Group are on the hydrologic cycle, including channel hydraulics, and on ice research. The objectives of the hydrologic research are to develop improved methods of predicting and simulating water supplies, lake levels, connecting channel flows, and flows in tributary streams and to improve understanding of hydrologic processes. The objectives of the ice research are to improve the prediction of freeze-up, breakup, areal extent, and the thickness of ice in the Great Lakes and their bays, harbors, and channels and to improve understanding of the natural variability and physical properties of lake ice cover. The research involves an integrated program of data collection, data base development, analysis, prediction, model development and testing, and advisory service.

Prediction and simulation information on water supplies, lake levels, and flows is necessary for water resource planning and management and for the solution of problems with water supply, water quality, shore erosion, hydropower, navigation, recreation, and flooding. Primary users of hydrologic information are the U.S. Army Corps of Engineers, the Great Lakes shipping industry, the U.S. EPA, recreational boating enthusiasts, the power utilities, the Great Lakes States, and the general public.

The amount, type, and extent of ice on the Great Lakes is of interest to all those who use the lakes in winter. Prediction information on Great Lakes ice is of value to shoreline engineering, winter navigation, hydropower generation, water supply management, and waste disposal. Primary users of ice information are the U.S. Army Corps of Engineers, the U.S. Coast Guard, the NWS, the St. Lawrence Seaway Development Corporation, the Great Lakes shipping industry, and the general public, including shoreline property owners.

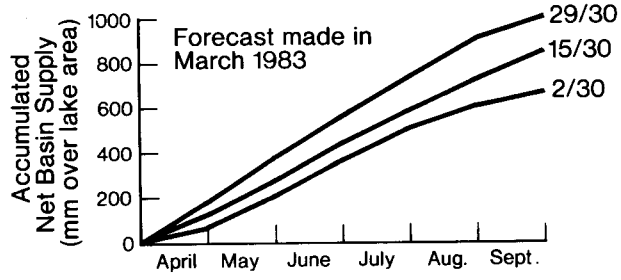
Hydrology

Lake Hydrology scientists continue to develop mathematical models to simulate and predict basin runoff into each of the Great Lakes. Runoff predictions are necessary to water supply and lake level forecasting. The models will also help scientists understand the response of watersheds to natural forces. The GLERL Large Basin Runoff Model is an interdependent tank-cascade representation of basin runoff that uses analytical solutions of climatological considerations relevant to large watersheds. A mass balance is coupled with physically-based concepts of linear-reservoir storages, partial-area infiltration, complementary evapotranspiration and evapotranspiration opportunity based on available supply, and heat balance determinations of snowmelt and net supply. Daily air temperature, precipitation, and runoff data are used to calibrate the model's nine parameters.

The model, applied to Lake Ontario subbasins last year, has been refined and applied to new major data sets this year. Data acquisition and reduction for all Great lakes basins (about 148 flow station and 217 meteorological station records, representing 25-30 years of daily values) is completed. These data are now reduced to hydrometeorological data sets for each of the 121 subbasins around the lakes.

The model was applied to Lake Superior data and grouped for 22 subbasins around the lake, as well as for the entire basin above Sault Ste. Marie. Both lumped- and distributed-parameter approaches were used to apply the model. Twenty subbasins and the entire basin were modeled at daily, weekly, and monthly mass-balance computation intervals by using daily data for the daily and weekly models and monthly data for the monthly model.

The large basin runoff model is an accurate, fast model of weekly or monthly runoff volumes from large watersheds and has relatively simple calibration and data requirements. Parameters have physical significance and their values are reasonable and consistent between daily, weekly, and monthly applications. For the Lake Superior Basin data, weekly applications make better use of available data on a monthly basis than do the monthly applications. The distributed-parameter applications are better than the lumped-parameter applications, but cost 20 times as much to use. The weekly distributed-parameter application to Lake Superior yielded a weekly correla-



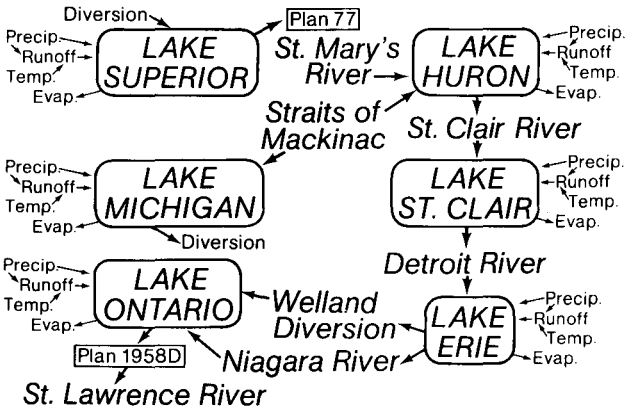
Forecast of Lake Superior accumulated net basin supply exceedances, 1983. Accumulated net basin supply is plotted with time for three probabilities of exceedance. The number associated with each line in the plot represents the probability that what actually occurs will be exceeded by (below) that line.

tion of 0.93 and a monthly correlation of 0.94. The model is now being applied to the Lake Michigan Basin.

The model has good potential for use in predictive studies since basin storages are represented directly. It was used this year in connection with the joint United States-Canadian experimental gamma radiation snow water equivalent and soil moisture surveys conducted over the Lake Superior Basin during the 1982-83 winter. The model used measured snow water equivalent as a boundary condition in a 6-month probabilistic outlook of net basin supply into Lake Superior. An extended streamflow prediction (ESP) procedure was used to estimate future supplies from present conditions in the basin and from past meteorological histories. Such outlooks enable both the assessment of the worth of the gamma surveys and regulation determinations for Lake Superior outflow. The model will continue to be used in the next 4 years of experimental gamma surveys. Additional probabilistic outlook packages are under development to enable use of the model on a distributed-parameter basis, as well as with only monthly near real-time data. Although predictions are limited by available meteorological information, forecasting is practical if data can be supplied on a near real-time basis. This may soon be possible for many areas of the Great Lakes Basin since the requisite data are precipitation and air temperature. Work is underway for the necessary data links with agencies in the United States and Canada.

The International Great Lakes Technical Information network Board of the IJC has chosen to use the model in their assessment of data network needs in the Great Lakes Region. This year their committees used the model in assessments of the information content of the climatological hydrometeorological data network within the Great Lakes Basin, as exemplified by the Lake Superior Basin. It appears that calibration of the Large Basin Runoff Model changes little as the number of meteorological stations are reduced from 54 to between 20 and 30 for Lake Superior. Thus, efforts at implementing a near real-time reporting network can be directed at fewer stations with regard to runoff estimation. Likewise, a substantial reduction in runoff stations is possible with little loss of runoff information with regard to estimation of net basin supply to Lake Superior.

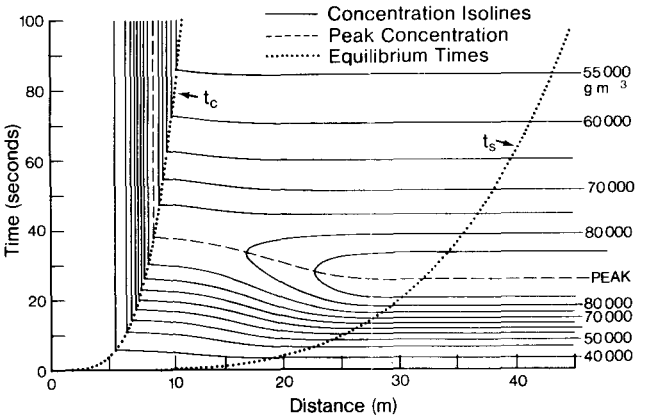
The rainfall-runoff models will be incorporated into the Great Lakes Hydrologic Response Model, which represents the hydrologic water balance of the lake system. The response model integrates the hydrologic components and routes the water through the system and into the St. Lawrence River. The model



Great Lakes Hydrologic Response Model proposed schematic representation. The Great Lakes Hydrologic Response Model will be used to trace the flow of water through the entire Great Lakes system and out the St. Lawrence River.

provides the resulting lake levels for each of the Great Lakes and Lake St. Clair and flows in the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers.

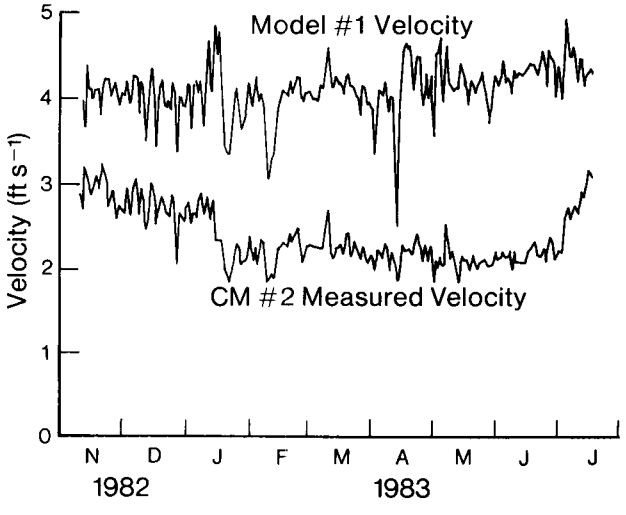
Theory application to the first series of experiments for the Unsteady Overland Sedimentation Project was completed last year. GLERL provided the theoretical developments for experiments conducted by the U.S. Department of Agriculture's Science Education Administration (SEA). Refinements made to the theory last year included the specification of flow-dependent geometry, which allows fluid flow equilibrium times to exceed sediment concentration equilibrium times. The resulting one-dimensional kinematic equations can be solved by the method of characteristics, and complete analytical solutions describe the



Sediment characteristics solution of equations of motion with kinematic approximation. Solid lines give the sediment concentration at any time and location in a developing rill on an overland surface. The fluid flow equilibrium time (t_c) and the sediment flow equilibrium time (t_s) are represented by dotted lines.

unsteady, nonuniform development of channels, flows, and sediment concentrations of an overland rilled surface. Alternate mechanisms for sediment concentration peaks in the outflow were identified. This theory may be useful in assessments of sediment loadings to the lakes from agricultural lands. The theory provides physical understanding of the processes involved from which to build expanded models of overland sedimentation. Other applications include modeling of atmospheric transport of pollutants to the Great Lakes and other coastal and estuarine ecosystems.

The study of the winter flow regimes of the St. Clair and Detroit Rivers was continued with completion of the second field season (November 1982-July 1983) of continuous velocity measurements in the St. Clair River at Port Huron. Preliminary arrangements were also made and additional current meters obtained for simultaneous measurements in the Detroit River at Fort Wayne. Because the meters sometimes indicated erroneous velocity direction during the first field season (October 1981-May 1982), the second field season represents the first long-term time series of velocity data with both speed and direction ever collected in the connecting channels. However, problems are still being encountered with these river velocity data. They are now being analyzed. Both the current meters and selected water level gages in the river were monitored throughout the field season to provide the relationship between river flow and ice-cover conditions. Because of an unusually mild winter, there were no severe ice problems, but operation of the meters during the last winter still provided useful information. An ice monitoring program was developed, based on past river stages as indicated by the water level gages. The monitoring program was successful, providing correct indication for the formation of two short periods of heavy ice concentration (several days each) in the lower river (river delta) during January and February 1983. Operation of the meters also permitted identification of two overnight periods of frazil ice formation associated with supercooling during January 1983. During these episodes, ice clogged the Port Huron City water intakes, located about 150 feet downstream from the meters. In general, there was reasonably good agreement between current meter velocities and water level data or velocities computed by dynamic flow models during this mainly open-water winter season for the wind induced short periods (several days duration), but poor agreement for longer periods indicated seasonal trends. The current meter data indicate progressive reduction of river velocities during the season, which is not substantiated by the water levels and computed model flows. Flow measurements conducted by the U.S. Army Corps of Engineers for the calibration of meters during May 18-24, 1983, also verify computed flows and show considerably higher velocities than the meters at corresponding depths. The field data also appear to be related to the Port Huron City water intake temperature without apparent reason for such a relationship. The field data from the current meters appear to indicate instrument error, but extensive laboratory testing after removal of the meters failed to verify this. Instrument testing and data analysis are being continued to evaluate the problem before the 1983-84 field program.



Simulated (by model number 1) and measured (at current meter 2 at Port Huron, Michigan) flow velocities in the St. Clair River for November 1982 through July 1983. This comparison demonstrates that the dynamic flow model, which does not take into account the effects of ice cover, fails to adequately simulate winter flows.

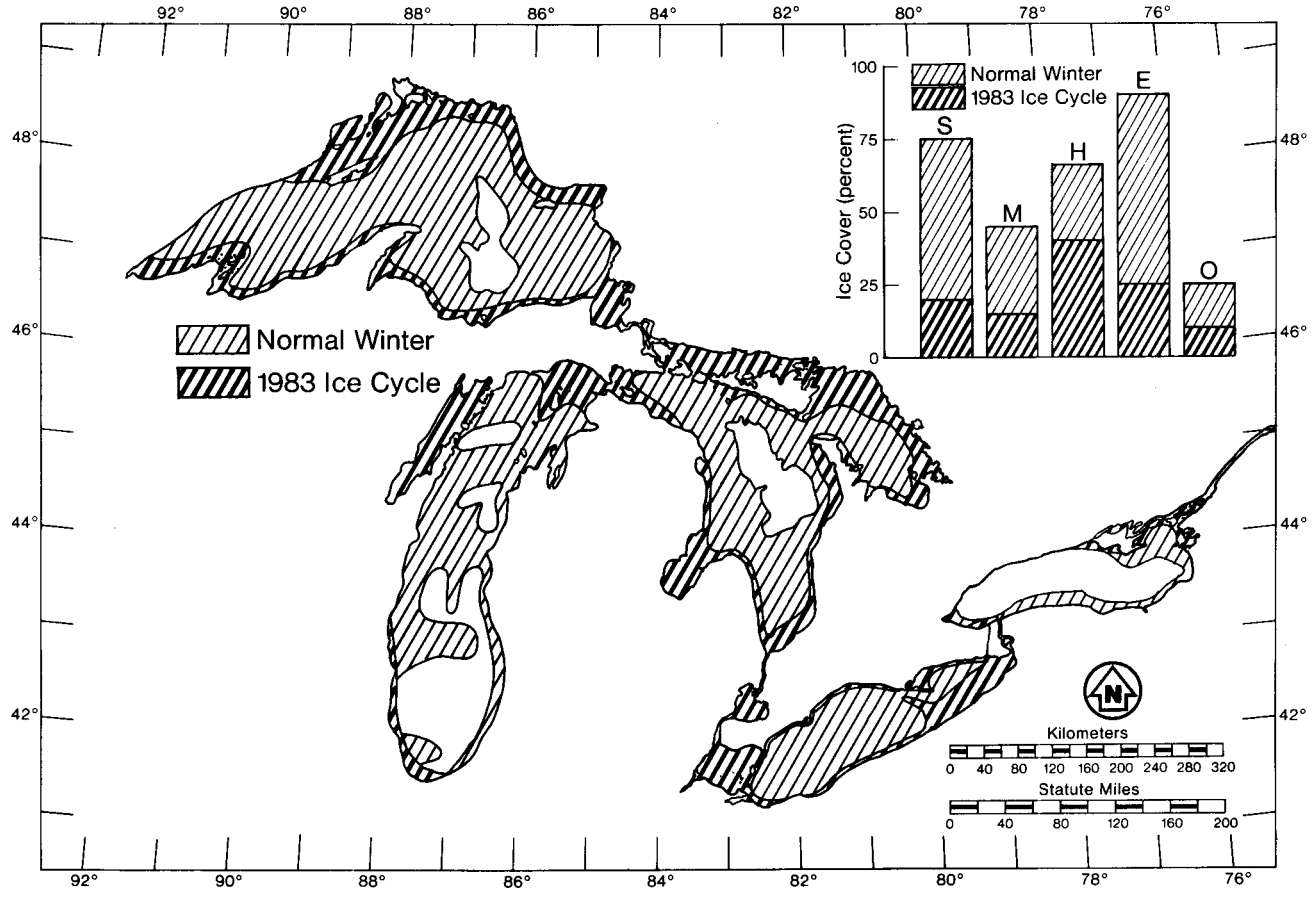
A related study of ice-cover effects on river flow was conducted on the St. Lawrence River under contract by the Clarkson College of Technology, with H. T. Shen as principal investigator. This 30-month ice research study entitled "Ice-Cover Effects on Hydraulic Transient Analysis" was completed and the final report submitted in March 1983. The study produced six technical reports, eight papers, and five graduate theses. The final result of the study is a hydraulic transient model for the upper St. Lawrence River (international section) that can be used to simulate the flow conditions throughout an ice-cover season. The hydraulic transient model combines the computational algorithm developed in the GLERL upper St. Lawrence River model and a new formulation for the ice-cover effects developed in this study. Effects of ice cover are determined by using the ice roughness and

ice thickness simulation models, along with the position of the leading edge of the ice cover in each channel branch. The results at the power dam, representing the downstream boundary of the model, produced a standard error for the simulation of 0.37 feet or about 3 percent.

Ice

A revised Great Lakes Ice Atlas is in press. This NOAA atlas contains three major sections: (1) maps for half-month time periods, illustrating the areal distribution characteristics of the Great Lakes ice cover, (2) graphs and tables of ice thickness and ice stratigraphy characteristics of ice cover in the nearshore zone of the Great Lakes, and (3) graphs and tables of winter severity during the 20-year period of the ice-cover climatology (1960-79) and the 60-year period prior to that climatology (1898-1959), based on accumulated freezing degree-days. The atlas and ice-cover concentration data base provide a significant improvement over current Great Lakes ice-cover distribution information and have already proven useful to managers of the Great Lakes water resource, as well as to scientists and engineers in need of ice-cover information for the Great Lakes. Examples of the usefulness of the ice-cover climatology and ice concentration data sets are provided by recent studies and data requests.

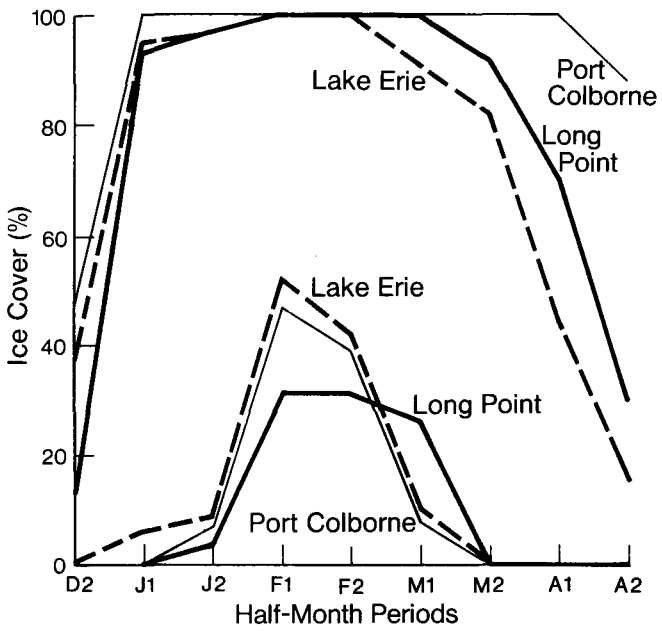
The 1983 winter was one of the 20 mildest winters on the Great lakes during the past 200 years. One result of the unusual winter weather was the mildest overall ice season on the Great Lakes since systematic observations of ice-cover extent on the lakes were initiated some 20-odd years ago. The long-term ice-cover distribution characteristics defined in the revised Great Lakes ice atlas were used to compare the ice-cover extent during 1983 with normal ice-cover extent on the Great Lakes. Estimated seasonal maximum ice extent for 1983 and normal maximum are as follows: Lake Superior—20 percent (normal is 75 percent), Lake Michigan—17 percent (normal is 45 percent), Lake Huron—36 percent (normal is 68 percent), Lake Erie—25 percent (normal is 90 percent), and Lake Ontario—less than 10 percent (normal is 24



Ice-cover distribution near the time of seasonal maximum ice cover for winter 1983 compared to normal. The 1983 ice season was the mildest on the Great Lakes since systematic observations of ice cover were started in 1962.

percent). The effect of this light ice season on the flora and fauna of the Great Lakes has yet to be evaluated, but the ice atlas provides a frame of reference for use in such evaluations.

The detailed ice-cover information contained in the atlas was analyzed in support of the continuing international study of the possible climatic impact of the Niagara River ice boom on the eastern end of Lake Erie. The 20-year digital ice concentration data set for Lake Erie was partitioned into three overlapping lake regions: the entire lake, the lake east of Long Point, and the lake east of Port Colborne, Ontario. Semi-monthly average regional percentage ice cover and percentage probability of exceedance of percentage ice cover from a given average regional ice cover were calculated for each lake region. The three lake regions had distinct ice coverage and ice coverage probability characteristics that appear to be related to lake bathymetry and lee or windward shore location. In particular, the Port Colborne region, because of its small area, shallow depth, and lee shore location, has greater ice coverage and greater probability of greater ice coverage in March and April, relative to the lake (region 1) or the lake east of Long Point (region 2).



Lake Erie regional maximum (upper curves) and minimum (lower curves) average percentage ice cover for the entire lake, the lake east of Long Point, and the lake east of Port Colborne for nine half-month periods from the last half of December (D2) through the last half of April (A2). These data are for a 20-year period from 1960 to 1979. The lake east of Long Point represents 22 percent, and the lake east of Port Colborne 2 percent of the entire Lake Erie surface area.

A copy of the digital ice concentration climatology and ice concentration data base, as well as computer software to access these data, has been provided to the National Snow and Ice Data Center, National Environmental Satellite and Information Service, located in Boulder, Colorado, for archiving and to make the data more readily available to the public at large. In addition, the entire digital ice concentration data set remains as an on-line GLERL data set, primarily for internal use but also available for outside studies and/or funded special product studies done by GLERL. Further analysis of these data may include spatial and temporal analysis of the ice-cover charactristics of the Great Lakes on sublake space scales in an effort to link seasonal trends in ice cover with seasonal trends in hydrometeorological parameters for use in ice-cover simulation and perhaps ice forecasting.

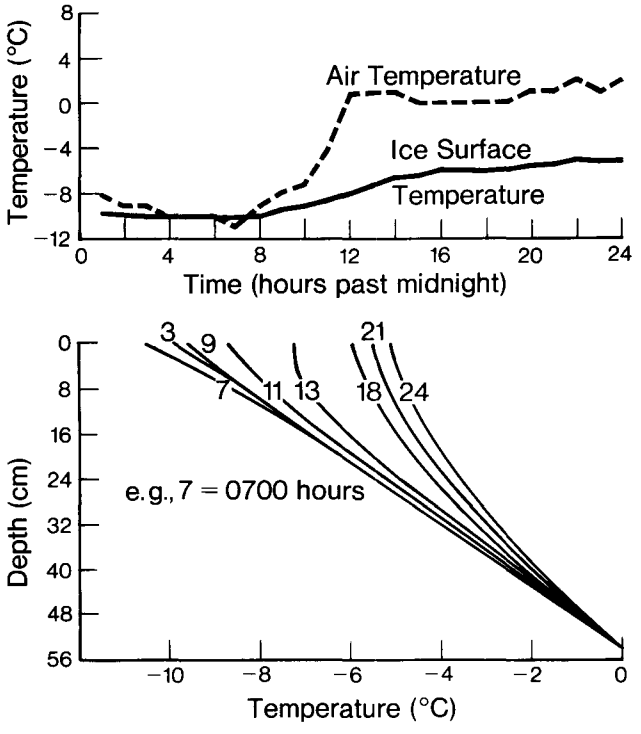
Temperature data collected across Lake Superior during the winters of 1973, 1974, 1975, and 1976 and during the falls of 1976, 1977, 1978, and 1979 were analyzed to identify the general characteristics of the seasonal decline in temperature during fall and winter. In late summer, August 15 to September 15, heating of the surface water produces a well-developed thermocline. Heat storage in the epilimnion is near its maximum value during this time. From the last half of September to approximately mid-November, surface cooling produces an unsteady density gradient in the upper portion of the water mass that results in mixing to increasingly greater depths. The water column eventually becomes virtually isothermal at a temperature above the temperature of maximum density. The entire water column then cools to the temperature of maximum density, approximately 4°C, marking the end of the fall overturn. This is usually completed in shallow areas by or before mid-December. In deeper areas of Lake Superior, fall overturn may not be complete until late December or early January some years. Further cooling of the surface layers then allows ice to form over portions of the lake. During winter, a weak reverse temperature gradient is observed owing to the further cooling of the surface water layer. Minimum water temperatures occur in late winter and early spring. Future research using these data will include an analysis of the fall and winter temperature decline characteristics of discrete areas of the lake. The results of this study will provide information for modeling temperature decline and time of initial ice formation for specific areas of Lake Superior.

Work continued this past year in interpreting the large collection of nearshore ice thickness data for 30 stations around the Great Lakes. Year-by-year variations in maximum ice thickness for a given site were shown to be closely correlated with variations in the

regional air temperature regime. Conversely, variations in the percentage of the ice cover composed of snow ice were only weakly related to regional variations in air temperatures or precipitation. Results from the study suggest the significance of very localized processes in producing a given ice-cover stratigraphy. Given the relative success possible in simulating lake ice thicknesses from air temperatures, the results also suggest that some of these localized processes are self-canceling in their effect on ice thickness.

Field work on the spectral reflectance of ice and snow was revived this last winter to expand our understanding of the relative properties of the Great Lakes ice cover. Despite the extremely mild conditions, sufficient ice cover was available to test a method of measuring spectral reflectance under clear skies. Measurements of incident and reflected shortwave and near-infrared radiation were taken by mounting a 3-inch integrating sphere on each of the two spectral radiometers. Laboratory tests with a point source of light and field tests with both direct beam radiation and diffuse radiation confirmed a reasonable cosine response to radiation in the spheres. This capacity to measure reflectance under clear skies is particularly significant during the spring breakup period. Once the snow cover is gone, radiation that is not reflected is absorbed within the ice cover rather than at the immediate surface. This internal adsorption can rapidly weaken the ice cover as cohesion between crystals decreases.

Ice thermodynamic modeling was advanced during the past year by comparing two methods of simulating heat transfer through the ice sheet. If the model time interval is 24 hours or greater, a linear temperature gradient through the ice and snow can be assumed, leading to a relatively simple algorithm for computing heat flux. Tests of the model at five sites along the St. Lawrence River show that this model configuration accurately simulates rates of growth and the influence of snow cover. If the model time interval is much smaller than 24 hours, the model then must simulate heat transfer along a nonlinear temperature gradient. This model configuration was also successfully tested against data from the St. Lawrence River, but showed no real improvement over the linear gradient model in simulating ice growth. The hourly model should prove very useful, however, in studying the diurnal influence of shortwave radiation on the ice thermal profile during the melt period. In addition, the nonlinear temperature gradient model allows engineers to estimate thermal expansion forces that can lead to shoreline and marina damage.



Simulated temperatures at the surface of (top graph) and within (bottom graph) a 54-centimeter-thick ice sheet over the course of a day. The upper curve in the top graph is the measured warming of the air on February 1, 1981, at a station adjacent to the St. Lawrence River at Ogdensburg, New York. The lower curve in the top graph is the simulated temperature response of the snow-free surface of the ice sheet. The bottom graph shows the simulated internal temperature profiles over the same period. The temperature gradient is strongest at 7:00 a.m. At that time, it is also approximately linear. Over the course of the day, the upper portion of the ice sheet warms quickly, creating a nonlinear temperature gradient. Models like the one that produced these profiles are valuable in the study of the growth and decay of river ice covers.

PHYSICAL LIMNOLOGY AND METEOROLOGY

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

The scales of the variables that need to be modeled and predicted range from years to seconds and from the size of the lake down to a few meters. In view of this tremendous range in time and space, the various phenomena must be separated according to their scales to understand and model them better. Hence, research in the Physical Limnology and Meteorology Group has been arranged in two areas. The first is water movements and temperature, which encompasses studies of lakewide and nearshore circulation, seasonal changes in circulation, and upwelling. The second area is winds and waves, which deals with wind-generated waves, storm surges, seiches, and overlake winds. The latter area involves prediction on a real-time basis. The group also contributes to studies of particle dynamics conducted by the Synthetic Organics and Particle Dynamics Group and scientists at the University of Michigan. This program was initiated because many toxic organic substances and nutrients enter the lake attached to particles. Hence the pathways and ultimate fate of these pollutants in the lakes depend on the movement of various types of particles through the lake environment.

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

Water Movements and Temperature

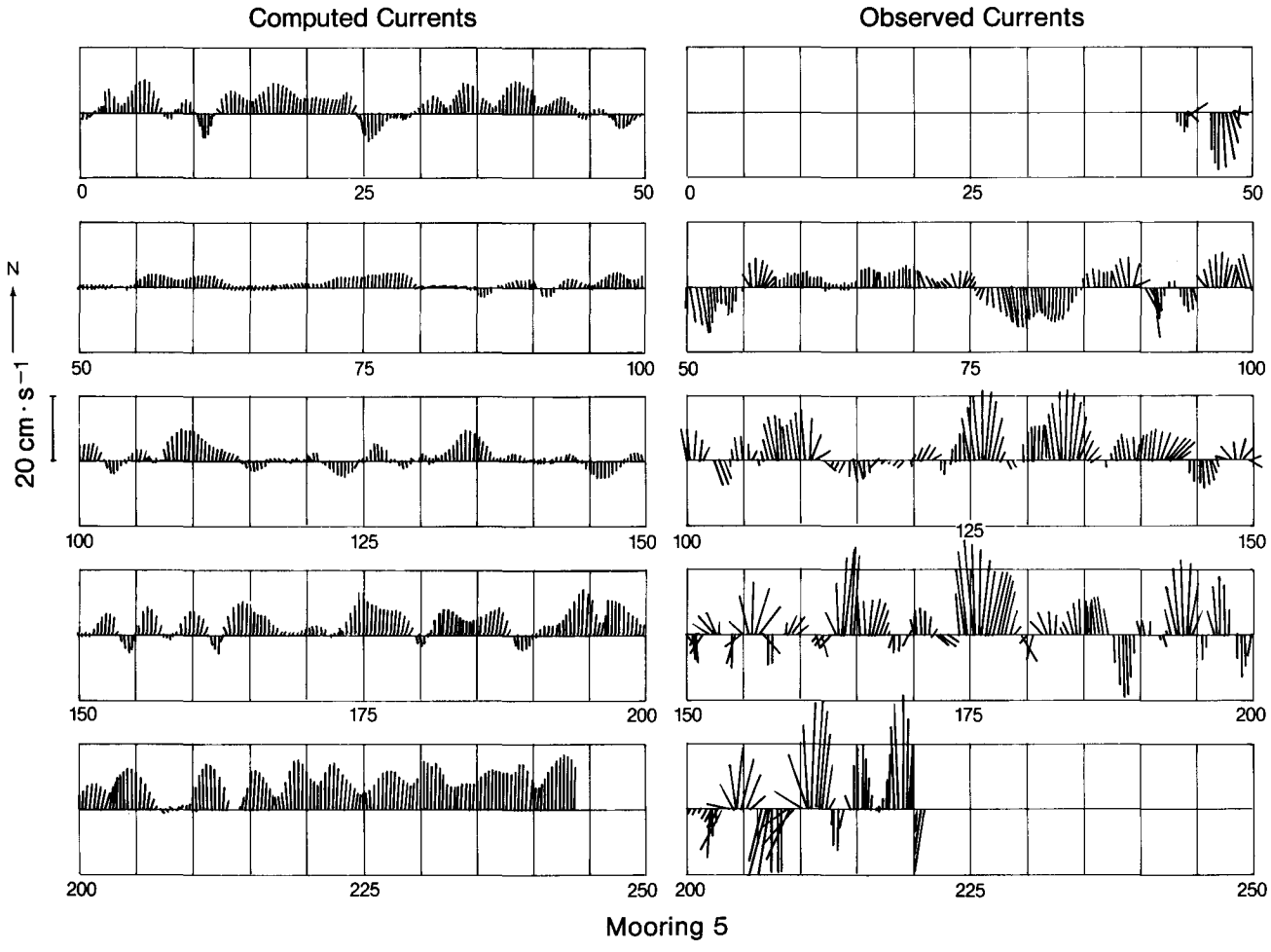
Rotational mode structures were examined by numerical simulation and compared with observations of these waves. Two numerical techniques have been used. First, a barotropic rigid lid model was run with 3-hourly winds from six meteorological stations around Lake Michigan for the period April-November 1976. Results were compared to current meter records from the southern basin. Modeled and observed currents agreed only in the frequency range corresponding to the maximum energy in the meteorological forcing, approximately 0.125-0.3 cycles per day. In this range, spectral peaks occur at identical frequencies for the wind, observed currents, and modeled currents. At lower and higher frequencies, the model underestimates kinetic energy observed in the currents.

To determine whether the above spectral peaks were due to resonance with the rotational normal modes of the lake, a second model was developed. This model calculates the periodic response of the circulation to purely oscillatory winds. Results indicate that (1) lake response is nonresonant over the main wind forcing frequency and that (2) the spatial structure of the response is insensitive to changes in the forcing frequency from 0.125-0.3 cycles per day. In addition, the response to a north-south oscillatory wind resembled a free topographic wave, with two counterrotating gyres in the southern part of the lake and a complicated pattern in the northern part.

A field experiment was implemented in 1982 in Lake Michigan to explore further the spatial structure and intensity of these important oscillations. Based on observations of southern Lake Michigan in 1976 and the results of numerical simulation, an array of current meters (with temperature recorders) was deployed at 15 locations in the lake in July 1982. All of the moorings were fitted with current meters at 15 and 50 meters below the water surface and with suspended sediment collection traps. Circulation patterns and intensities will be related to the observed sediment concentrations.

All of the current meters were recovered in summer 1983 after a recording interval of nearly 12 months. Initial translation and editing of the data reveal that a high percentage of the current meters worked well. Database building will be completed in December 1983 and analysis of the records will start then.

After a year of charting the progress of satellite-tracked current drifters in Lake Michigan, a track data



Vector time series of computed (left panel) and observed (right panel) currents at a current meter mooring in Lake Michigan. The computed current vectors started on April 1, 1976, and continued til November 30, 1976. Observed currents, from May 14, 1976, to November 8, 1976, are from the 25-meter depth and have been low-pass filtered to remove energy at frequencies greater than 0.5 cycles per day. These time series show that the numerical model simulates the important features of the current structure.

base totaling over 5,000 kilometers in length has been compiled. Data analysis has already begun and will continue into 1984. Preliminary examination of the track data has resulted in several adjustments to the GLERL oil spill model, which is used by the U.S. Coast Guard in case of a spill or a search and rescue operation. Work is continuing on an improved version of this spill model.

Statistical analysis of the drifter track data revealed a median current speed of 17 centimeters per second, with 99 percent of the speeds found to be less than 55 centimeters per second. Static tests showed that the satellite positioning was accurate to within 0.5 kilometers. The long-term drifter movement suggests strong northward currents off the eastern shore of Lake Michigan, southward currents off the western shore, and meandering currents toward the middle. On an intermediate (3-5 day) time scale, the tracks show changes that result from shifting overlake wind patterns. On a still shorter time scale (17-18 hours), the tracks reveal clockwise inertial circles, a few kilometers in diameter, caused by the Earth's rotation.

Analysis of the drifter tracks will continue when data tapes from the recently retrieved vector-averaging current meters have been processed. A systematic comparison of these two data bases is planned for 1984.

Meanwhile, several experiments are planned for fall 1983 using recycled GLERL current drifters. The Canada Centre for Inland Waters will borrow several drifters to track the Niagara River plume in western Lake Ontario. A winter study of water currents and ice dynamics in the western and central basins of Lake Erie is also planned.

An improved spill model was completed and is now being tested. Improvements over the old version

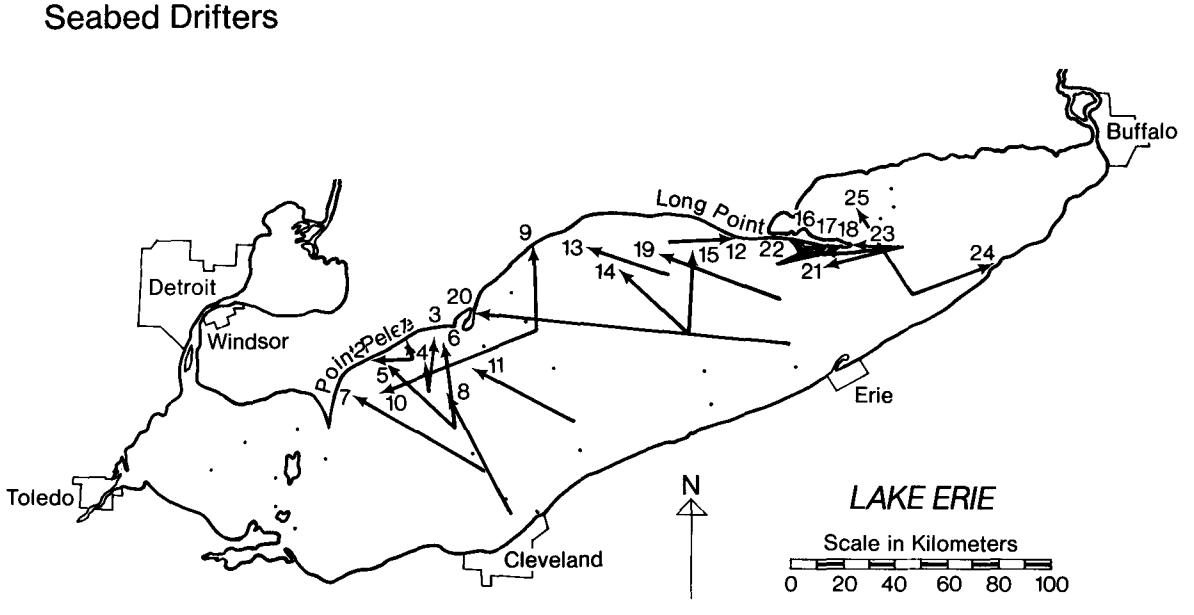
include increased resolution, multiple spill capability, zoom, and conformance to the GLERL modeling system standards. In addition, the accuracy of the currents used in the above model to predict particle trajectories was tested against exact solutions. First, solutions for a 100-kilometer-diameter circular lake with a parabolic depth profile were computed with mesh sizes of 10, 5, and 2.5 kilometers. The vertically-averaged flow was calculated for a 5-day simulation and a uniform wind stress. These solutions were compared to an accurate solution generated by separation of variables in the radial and azimuthal directions and numerical integration in time and radius. The 10-kilometer result was inaccurate, the 5-kilometer solution was acceptable, and the 2.5-kilometer solution was nearly perfect.

Next the numerical method for calculating trajectories was tested. The method was second-order in time and used a spatial interpolation method that allows particles to move along a jagged finite difference coast without running into the shore or becoming trapped in corners. The accuracy of this technique was evaluated by computing trajectories with a solid rotation current pattern and with the wind-driven currents. The solid rotation cases established that the technique gives acceptable accuracy for any grid size. The wind-driven cases served to evaluate the errors from both sources—the calculation of Eulerian currents and trajectories. The first of these sources is the most critical, but advanced computers can compute sufficiently accurate one-layer models for the Great Lakes.

A two-dimensional, vertically integrated model and a three-dimensional, thermally stratified model are being used to simulate Lake Michigan currents. These currents then drive a water quality model that advects, diffuses, settles, and resuspends particles and dissolved toxic materials. To achieve this objective, a general computer program has been developed to calculate advective motion, settling, and resuspension.

The model has been tested for pure advection using an idealized lake. Numerical accuracy has been found to be adequate for testing the effects of settling and resuspension in idealized cases. Eventually, the model will be verified by comparison with data from sediment traps moored in Lake Michigan. Radionuclides will be used as particle tracers to help scientists infer suspended sediment transport paths. When verification of this vertically integrated model is complete, a three-dimensional version will be tested. Effects of Ekman layer sediment transport on sedimentation patterns have been found to be important. A method for parameterizing this three-dimensional effect into a one-layer model has been developed.

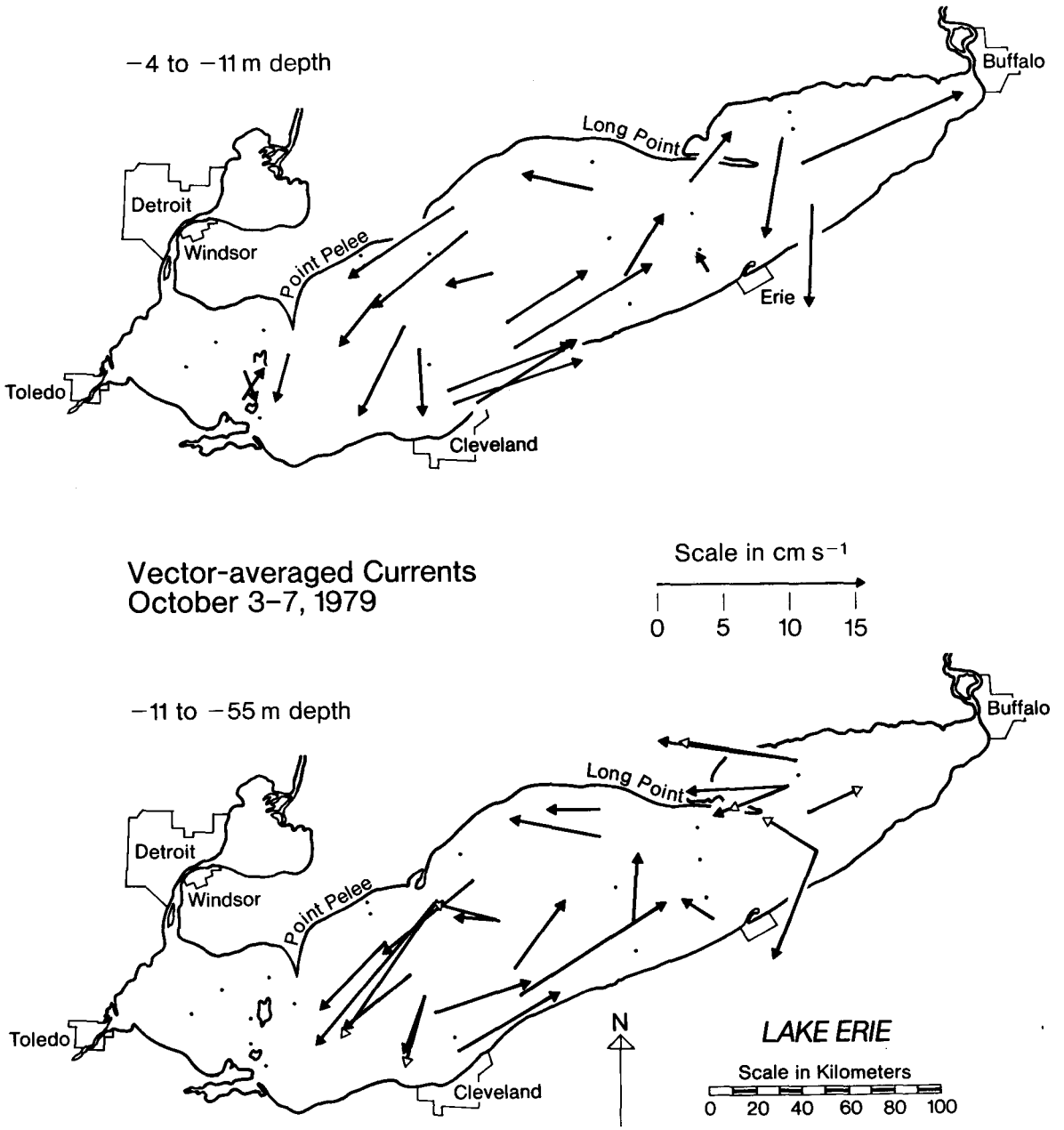
Analyses of water temperature and current data collected in Lake Erie during 1979-80 were completed. These new data document the process of central basin stratification and provide current flows during the existence of a thin hypolimnion layer. An



Movements of Woodhead seabed drifters released in Lake Erie in 1979 and subsequently recovered. As is indicated here, bottom currents move from United States waters toward the Canadian coast. The movement of pollutants across international boundaries has been the subject of considerable discussion and research and is a topic of particular interest to the International Joint Commission.

episode of hypolimnion volume entrainment was recorded. Eastern basin outflow to the central basin of Lake Erie was seen to travel northwestward after moving westward in the deep channel through the Pennsylvania Ridge that separates them. The data also showed persistent flow out of the western basin through the Pelee and South Passages to the central basin. Strong and continuous seiche-driven currents through these channels add a tidal-like current regime to the otherwise steady outflow.

Current and water temperature data recorded in Green Bay have been analyzed. Data from meters moored in the bay mouth showed persistent high speed flow out of the bay in the upper levels while cold hypolimnetic water flowed far into the bay. This persistent flow accelerates bay flushing rates. In the past, these have been computed using only precipitation runoff and exchanges with Lake Michigan driven by tidal-like water level fluctuations. Circulation throughout the bay is generally counterclockwise.



Lake Erie vector-averaged current vectors for October 3-7, 1979. Open arrowheads show currents closest to the bottom on moorings that had three current meters. Counterclockwise circulation prevails throughout the central basin and in the northern half of the eastern basin.

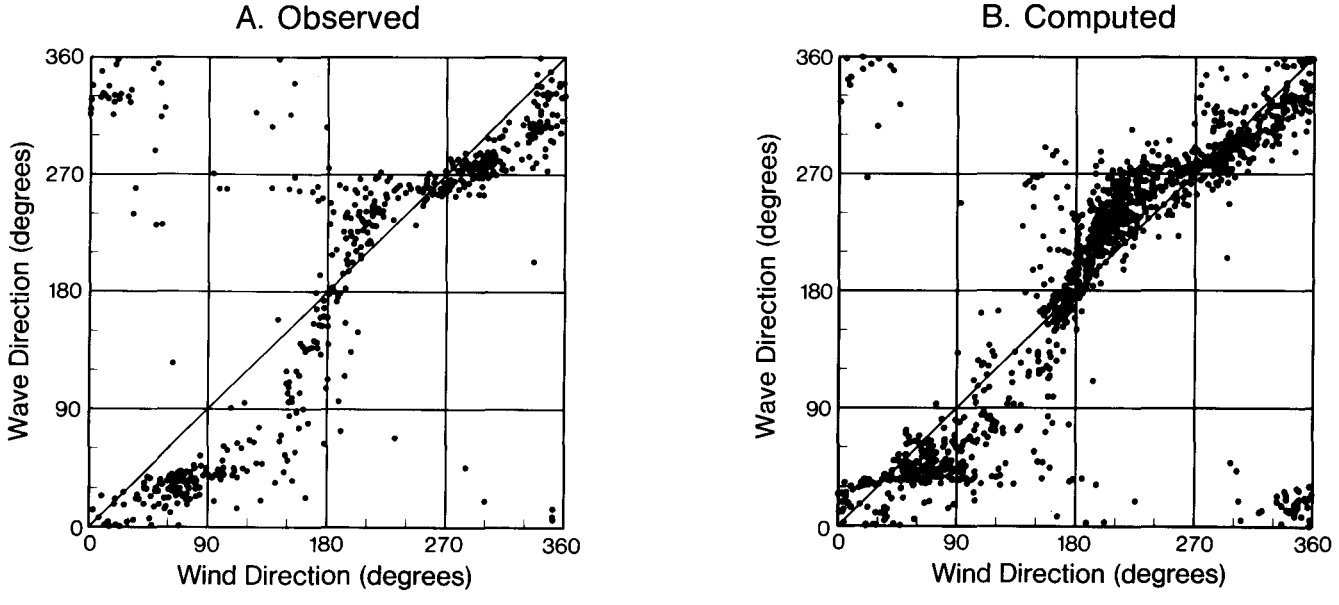
Winds and Waves

Three published methods for predicting overlake wind speed from overland wind speed were compared to each other with an extensive set of paired overland/overlake wind measurements from Lake Erie. The results of the comparison were that the three methods were not significantly different, all of the methods were not very accurate (2 meters per second root mean square error), and this was about all the accuracy that could be achieved with simple statistical methods for predicting overlake wind. The accurate prediction of overlake meteorological conditions from overland observations remains as one of the principal impediments to improvement of wind-wave, circulation, and storm surge models.

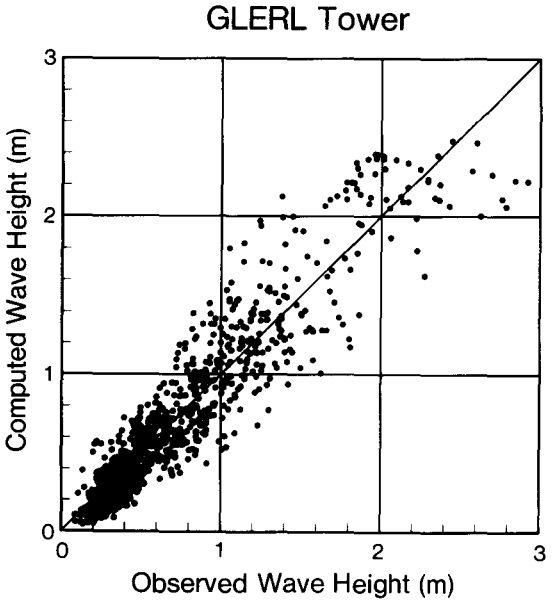
The longshore momentum balance in the inner and outer regions of the coastal boundary layer has been determined for four storm episodes. Careful analysis of wind, wave, and current measurements made during the 1981 field season has revealed the relative importance of acceleration, pressure gradient, bottom stress, wave radiation stress, and wind stress terms in the two regions. In the outer region, the wave radiation stress is smaller than the others, but the radiation stress is passed through to the inner boundary region. In this area, where refraction is occurring and the waves have not yet broken, all of the terms in the momentum balance are important. Inside the breaker zone, the momentum balance is basically between radiation stress and bottom friction. These results are important in the development of conceptual and numerical models of transport and diffusion in the coastal boundary layer.

Continuous transmissometer measurements made at the GLERL tower during a 1981 Lake Erie field experiment have been analyzed in terms of simple sediment resuspension models based on wave orbital velocity and grain-size distribution typical of the Lake Erie site. Results from two storm episodes indicate that advective processes most likely are responsible for the differences between the model and the measured transmissivity.

Considerable progress has been made in adapting and improving a dynamical Great Lakes wave forecasting model developed by M. Donelan at the National Water Research Institute, Burlington, Ontario, for use at GLERL. The model was first tested in ideal geometry against theoretical and empirical results for wave growth and for steady conditions. It was found that the numerical scheme did not exhibit the directional spreading of wave momentum vectors under a uniform wind that had been predicted analytically by Donelan for fetch-limited waves. The numerical method was modified to take account of the influence of cross-wind gradients of wave height on wave direction. The results were found to corre-



Comparison of hourly measurements of wind direction at the GLERL wave research tower in Lake Erie for September and October 1981 with (A) observed wave direction (note the systematic deviation of wave direction from wind direction) and (B) wave directions predicted by a numerical wave forecast model. The computed values show the same systematic deviation of wave direction from wind direction.



Comparison of hourly measurements of significant wave height at the GLERL wave research tower in Lake Erie for September and October 1981 with values predicted by a numerical wave forecast model developed at GLERL and Canada Centre for Inland Waters. There is very good agreement between computed and observed wave height.

spond closely to the analytical solutions for both wave direction and wave height.

The true test of the model came in comparing the results to the Lake Erie directional wave measurements. Measured wave directions at the tower exhibit a systematic deviation from the wind direction. Wind measured at the tower was used as the forcing function to run the model for September and October 1981. The results for wave direction and wave height at the GLERL tower were excellent (correlation coefficient between observed and computed wave height—0.95; standard error—18 centimeters). Comparison of the model results to measurements made by the NDBC buoy in western Lake Erie during the same time period indicate that the reported NDBC wave heights are about 50 percent higher than the computed wave heights, but the correlation is still high (0.90). Currently under investigation is the possibility (already suggested by other studies) that the strapped down accelerometers used on NDBC buoys systematically overestimate wave height.

The eight NDBC Nomad buoys deployed in four of the Great Lakes in 1981 provided over 33,000 hours of simultaneously recorded wind, wave, water, and air temperature data. These data have been catalogued and analyzed in terms of long-term statistics, parametric correlations, wave growth characteristics, and comparison with model outputs. The NDBC buoy data base will continue to provide a basis for additional theoretical and empirical studies in the future, such as the development of a generalized spectral representation for Great Lakes waves.

A study was completed on the effect of mean wind stress on water level gage elevations with respect to chart datum. It was found that mean setup can have a significant influence on the gage-transfer method, particularly on Lake Erie. Correction factors for gage elevations on Lake Erie were determined and submitted for consideration to the IJC committee on the new Great Lakes water level datum. The results of the mean momentum balance calculations from the Lake Erie coastal boundary layer experiment described above corroborated the elevation adjustments for Fairport and Erie.

INFORMATION SERVICES

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

This past year, as part of that service, GLERL provided over 3,000 research products in response to almost 2,000 documented requests. Of these, 37 percent came from institutions of higher learning, 34 percent from private citizens, 12 percent from foreign government agencies, 7 percent from industry and private organizations, 6 percent from U.S. Federal Government agencies, and 4 percent from State Governments. This is in addition to regular mailings to those who have indicated interest in a 6-month listing of available publications and one or more of the five types of GLERL publications: chemistry and biology, environmental systems engineering, ice, lake hydrology, and physical limnology and meteorology. But publications are but one form of environmental information. Also included are predictions and simulations produced from environmental models, forecasts and forecast techniques, descriptive or analytical information on the present or past status of one or more limnological characteristics of a lake or of the system, and data bases. Many of these involve what might be termed "technology transfers." A partial list of GLERL technology transfers effected this year and users is given below.

Technology Transfers

Measurement Technique—Phosphorus and Phytolankton Growth.
User: Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, U.S. Department of the Interior

Design of Water Chemistry Filters.
User: Gilman Instrument Company

Measurement Technique—Ammonia Excretion by Marine Zooplankton.
User: Skidaway Institute of Oceanography

Measurement Technique—High-Performance Liquid Chromatographic Analysis of Amino Acids.
User: Michigan State University

Technique Modification—Inorganic Phosphorus in Lake Water.
User: Michigan Technological University

Electivity Indices for Quantifying Feeding Processes.
User: Bedford Institute of Oceanography

Satellite-Tracked Drogue for Ecosystem Experiment.
User: University of Michigan

Extraction and Cleanup Procedures for PAH in Lake Sediments and Biota.
User: Clemson University

Intracalibration for Cesium-137 and Other Radionuclides in Great Lakes Waters.
Users: CCIW, Argonne National Laboratory

Reverse Phase Technique for Measurement of Partition Coefficients.
Users: Drexel University, University of Michigan

Large Basin Runoff Models.
Users: IJC, U.S. Army Corps of Engineers, Consulting Engineers

Unsteady Overland Sedimentation Models.
User: U.S. Geological Survey, U.S. Department of Agriculture

St. Marys River Ice Forecast Techniques.
User: U.S. Army Corps of Engineers

Oil Spill/Search and Rescue Computer Model.
Users: U.S. Coast Guard, NWS, Hazardous Materials Response Branch—NOAA Corps

Great Lakes Applications of Satellite-Tracked Current Drifters, Including Data Handling and Physical Improvements to Drifters.
Users: CCIW, U.S. Coast Guard, Polar Research Laboratories

Radio-Direction Finders for Locating Satellite-Tracked Drifters.
Users: Polar Research Laboratories, Canadian Weather Service, CCIW, NDBC

In Situ Sea Surface Temperatures for Calibration of Advanced Very High Resolution Radiometer (AVHRR) Satellites.
User: NWS

Accuracy of Tiros Satellite Positioning.
User: Service Argos

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

environment. This past year, five draft environmental impact statements were reviewed by GLERL.

Other responsibilities carried out under this activity include identification of, and communication with, potential users; determination of user interests and needs; and liaison between the laboratory and users. Committee and board memberships and attendance at workshops, conferences, and other scientific gatherings are some means of informing people about GLERL; certain special publications, such as the technical plan and this annual report, are others. Advice was provided in such widely diverse areas as the IJC's Lake Michigan Task Force for Surveillance, a delegation of Chinese scientists and engineers seeking help to solve their water quality problems, provision of working drawings to various users for a GLERL designed radio-direction finder, and advice to the National Research Council on disposition of the Niagara River Ice Boom.

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

Publications Unit

Publications are a major GLERL product and a critical part of the effort to make research findings available to a broad spectrum of users for application to environmental problems and decisions. The publications unit has responsibility for the preparation of manuscripts, including editing, typing, proofreading, and procurement of graphics. Manuscripts are edited, typed, and proofread in-house, while graphics and photographic services are procured under contract. Manuscripts are formatted according to the requirements of the publication form: articles and notes in professional journals, NOAA technical reports and memoranda and data reports, or in-house reports. During the last fiscal year, 45 manuscripts were processed in the GLERL publications unit.

This past year, the publications unit moved to larger offices and further upgraded their word processing equipment. Advances in software and hardware are constantly being evaluated to produce GLERL output more effectively.

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

INTERNATIONAL AND INTERAGENCY ACTIVITIES

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

International Coordinating Committee on Hydraulic and Hydrologic Data

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

Interagency Great Lakes Hydromet Steering Committee

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

NOAA Sea Grant

This past year a joint project between GLERL and the Ohio State Sea Grant Office was initiated to develop an environmental and recreational guide for Lakes Erie and St. Clair. Future efforts will involve the other Great Lakes and the other Sea Grant colleges. In addition, a number of senior GLERL scientists were involved in reviewing the various Great Lakes Sea Grant programs, as well as Sea Grant proposals.

International Joint Commission

GLERL staff members actively participate in a wide variety of IJC activities. Examples are the Science Issue Panel for the Great Lakes; the Aquatic Ecosystem Objective Committee Work Group; the Task Force on Modeling; the Lake Michigan Task Force for the Surveillance Work Group; the Detroit, St. Clair, and St. Marys Rivers and Lake St. Clair Task Force for the Surveillance Work Group; and the International Great Lakes Diversions Working Committee. In related areas, GLERL staff hold membership on the Levels and Flows Advisory Board and the Information Network Board.

Great Lakes Commission

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

International Association for Great Lakes Research

Scientists at GLERL actively participate in activities of the International Association for Great Lakes Research. Senior GLERL scientists serve as Vice President, Board Member, Secretary, Associate Editors, and members of the Awards Committee.

Regional Response Team for Spills of Oil and Hazardous Substances

GLERL continues to play a role in spill response in the Great Lakes by providing the Department of Commerce representative to the Regional Response Team (RRT) and supports the NOAA National Ocean Service regional Scientific Support Coordinator (SSC). The RRT is a standing committee that evaluates and revises the regional contingency plan for response to spills of oil and hazardous materials. The RRT may be called upon to provide specialized resources in re-

sponse to a spill. A full-time SSC is assigned to work at GLERL. The SSC establishes and maintains contacts with the regional scientific community, identifies vulnerable resources in conjunction with State and Federal agencies, and assists in the preparation of regional and local contingency plans. In this regard, a Great Lakes-wide environmental sensitivity mapping project has been initiated. Work is underway on the St. Lawrence River, Lake Erie, and the Detroit-St. Clair River System. When a spill has occurred, the SSC provides liaison between the on-scene coordinator and the scientific community. GLERL scientists have provided assistance to the U.S. Coast Guard and the U.S. EPA in regional spills and have participated in drills conducted by the U.S. Coast Guard and NOAA's Office of Marine Pollution Assessment (now OAD).

National Research Council Panel on Niagara River Ice Boom Investigations

A senior GLERL staff member was appointed to this group, the purpose of which was to examine possible climatic changes due to the alteration of ice cover by an ice boom installed at the eastern end of Lake Erie. A final report was produced by the panel in 1983.

National Weather Service

GLERL staff participated in an NWS meeting on marine forecasting in the Great Lakes held in Cleveland, Ohio. Plans were made for increased communication and cooperation between NWS and GLERL in marine observations, possibly even GLERL assistance in developing a field program with NWS satellite-transmitting Waverider buoys. These data would be received real-time at GLERL over the NWS marine circuit now available on the Hewlett-Packard computer. They would possibly be used to check the calibration of the NOMAD buoys.

Joint United States-Canadian Ice Information Working Group

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

Versuchsanstalt für Wasserbau, Hydrologie, und Glaziologie

A collaborative research effort with scientists at Versuchsanstalt für Wasserbau, Hydrologie, und Glaziologie, ETH (Laboratory of Hydraulics, Hydrology, and Glaciology, Federal Institute of Technology), Zurich, Switzerland, on internal oscillations in Lakes Lugano and Zurich was completed. The analysis techniques and models developed in this study will be useful in determining the importance of baroclinicity on circulation in the Great Lakes.

Other Activities

GLERL scientists participated in a number of other international and interagency activities, including the International Society for the Study of the Sea-Water Interface, the Governor's Problem Solving Institute, the U.S. EPA-U.S. Army Corps of Engineers' Proposed Rasin River Dredging Study, the U.S. Department of Agriculture's Science Education Administration's Unsteady Overland Sedimentation Project, and the NOAA-U.S. Geological Survey Coordinating Committee for Hydrologic Research.

FACILITIES

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

Marine Instrumentation Laboratory

The marine instrumentation laboratory staff selects, calibrates, repairs, and, when necessary, adapts or designs instruments to collect data in the lakes and their environs. Engineers and technicians in this unit work closely with GLERL researchers to ensure that instruments are compatible with the purpose of the experiment.

The marine instrumentation laboratory has retrieved 22 moorings this year. Twenty of these had current meters and sediment traps with acoustical releases. The Marsh McBirney, Inc., electromagnetic current meters operated without interruption this past winter in the St. Clair River, giving the first glimpse of the winter flow. Extensive testing was done on three new model 527 and three model 585 current meters (all six manufactured by Marsh McBirney, Inc.), and numerous production control problems were rectified. The current meters are now ready for another winter measurement program, this time in the St. Clair and Detroit Rivers. A Neil Brown Instrument System (NBIS) direct-reading current meter (DRCM-2) has now been completely evaluated and marine instrumentation laboratory engineers are quite impressed by the signal to noise ratio of the output of this acoustical current meter. Budget limitations forced development of our own readout system for monitoring the NBIS-DRCM-2; it uses a Hewlett-Packard-75 calculator with a Hewlett-Packard current loop (HPIL) interface. Marine instrumentation laboratory staff improved the accuracy of this meter by using their own calculation and reduction equation rather than the manufacturer's value, which assumes error contributed actively in every channel by the meter's analog to digital conversion.

Five Tiros satellite-tracked drifter buoys were used in Lake Michigan this past winter and summer. These mini-Tiros ocean drifter buoys, built by Polar Research Laboratory, were intended for ocean use and designed to be expendable. Marine instrumentation laboratory technicians and engineers improved the buoy to allow recycling and to extend usage. These improvements, which have now been adopted by the manufacturer, involved development of a radio-direction finder to pinpoint the locations of the buoys. Directions for fabricating the radio-direction finders have been supplied to the manufacturer and various government agencies for their use.

Various sampling, extraction, and incubation devices were built or modified for the Ecosystem and Nutrient Dynamics Group and the Synthetic Organics and Particle Dynamics Group at GLERL. A Beckman L5150 liquid scintillation counter was interfaced with a Commodore VIC-20 microcomputer unit, allowing calculations of calibration standards to be applied to data analysis. It also made possible the addition of data communication to a host computer for data filing; yet the parts for the interface cost less than $200. A Hewlett-Packard 41C calculator with a HPIL was used in a system to acquire samples for a diffusion study being conducted by the Synthetic Organics and Particle Dynamics Group. A VHF radio-link system was developed for a cooperative study with the Office of Marine Pollution Assessment (now OAD). It will be used to monitor hazardous environments. The marine instrumentation laboratory was also actively involved in selection and integration of the new Digital Equipment Corporation VAX computer system currently being installed at GLERL.

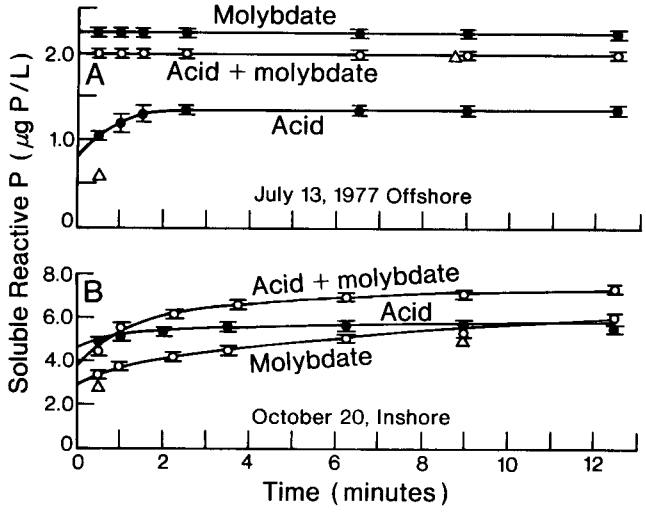
Chemistry Laboratories

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

The uptake and release rates of selected PAH by benthic organisms are being followed through carbon-14- and tritium-labeled-compound metabolism. Compounds are extracted, cleaned on thin layer or high-performance liquid chromatography, and counted by liquid scintillation.

The nutrient program has concentrated on evaluating chemical phenomena affecting phosphorus measurements, measuring biological nutrient recycling rates, and characterizing forms of phosphorus in lake waters.

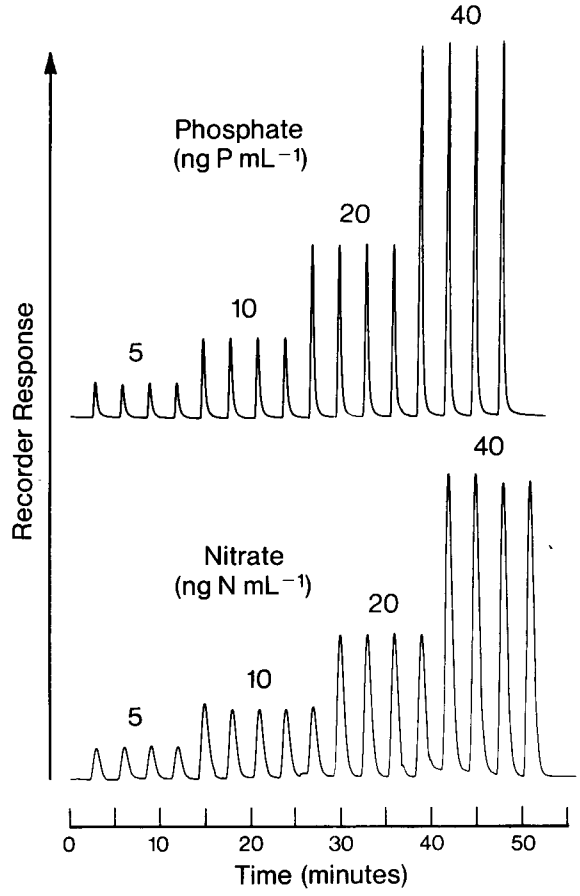
Soluble reactive phosphorus is often measured and used as an index of the biologically available phosphate concentration in natural waters. GLERL research indicates that caution is needed in selecting among the various methods to measure this fraction



Results of phosphate progressive hydrolysis tests done by the Chamberlain-Shapiro method on (A) offshore Lake Michigan water collected on July 13, 1977, and (B) nearshore Lake Michigan water collected on October 20, 1977. Open triangles are 30-second and 9-minute estimates; precision is shown as the standard error of the mean (vertical bars). These tests demonstrate that acid, acid plus molybdate, and molybdate reagent additions result in overestimation of phosphate because molybdate and, to a lesser extent, acid accelerate the release of phosphate from bound sources into solution.

because two phenomena can result in overestimation of phosphate levels. First, acid hydrolysis of phosphate from bound sources in solution can be accelerated in the presence of molybdate (the substance used to complex phosphate) as shown by higher phosphate values in acid plus molybdate than in acid exposures. Second, molybdate can either accelerate hydrolysis under basic conditions or form a complex with organically bound phosphorus, as shown by higher phosphate values in molybdate than in acid plus molybdate exposures.

New chemical approaches have been developed and applied to measuring low levels of nutrients in small experimental systems for nutrient regeneration experiments. Flow injection analyses (FIA) and segmented flow analyses (SFA) (both performed on the AutoAnalyzer) are two independently developed analytical approaches used previously to automatically measure nutrients in aquatic samples. A combination of the desirable features of both FIA and SFA can be achieved by introducing samples for SFA by flow injection. This discrete injection-SFA technique was used to measure nitrate and phosphate in 0.2 milliliters of water at concentrations down to 1 nanogram phosphorus (or nitrogen) per milliliter. This methodology was evaluated and is currently being routinely used for field and experimental samples.



Recorder response for replicate injections of various concentrations of phosphate and nitrate from a 0.2-milliliter sample loop. This is an example of measurements of low levels of nitrogen and phosphorus in small volumes of water. This technique is used to measure nutrient regeneration from lake sediment samples in small laboratory experimental systems.

Using the above technology, new approaches were developed and a study done to demonstrate the quantitative importance of metabolic excretion, relative to microbial degradation, in aerobic sediment mineralization processes.

Biology Laboratories

The biology laboratories' equipment and instrumentation include a multichannel Coulter Counter used to measure particle size selection and zooplankton grazing on natural lake algae and seston. An array of instruments, including a liquid scintillation spectrometer, is used to investigate nutrient uptake, growth rates, competition for nutrients by algae, and cycling rates of selected algal nutrients. Facilities also include a full complement of sampling gear and instrumentation, growth chambers, stereo and inverted microscopes, and cultured populations of phy-

toplankton and zooplankton species for model studies. A mobile trailer has been fitted for lakeside investigations of the physiology and feeding rates of planktonic and benthic organisms.

Ice Laboratory

The ice laboratory makes it possible to extend the winter measurement season and to expand opportunities for measurements of ice characteristics. The facility is composed of a work room and an ice storage room. The work room, held at -7.0°C, can be used to conduct experiments on natural ice harvested in previous field seasons, as well as to calibrate instrumentation for the ice research program in an environment similar to that encountered in the field. For example, scientists are investigating new optical diffusers for the dual spectroradiometers used in measuring ice reflectance. These new diffusers will allow the instrument to be used under clear sky conditions without mathematical correction factors. The cold room is also being used to test the sensitivity of a variety of instruments, such as spectroradiometers and current meters, under low temperature conditions. The interior walls are painted flat black to facilitate optical experiments. Ancillary equipment includes a high intensity light source, a mercury line source, and an optical bench.

Adjacent to the work room is a smaller room held at -29.0°C. In addition to providing low temperature storage for ice samples and a limited number of field samples from the chemistry and biology programs, the facility serves as an additional calibration room.

Particle Dynamics Laboratory

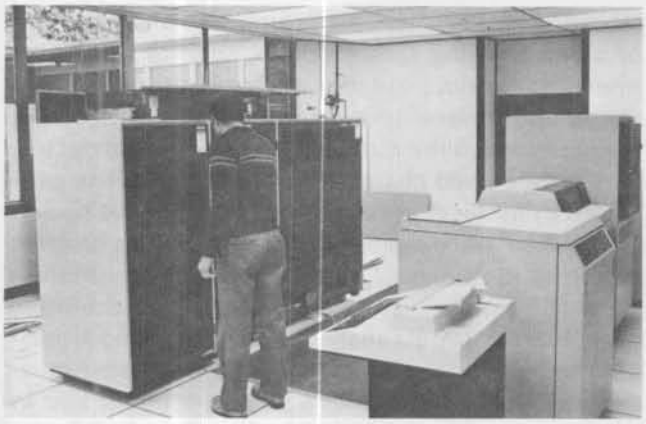
Natural and artifically produced radionuclides introduced into the Great Lakes serve as excellent model contaminant and process indicators. The particle dynamics laboratory can be used to detect and measure very low levels of many such radioactive substances present in water, sediment, and biota. The laboratory was established recently as part of the cooperative program with the University of Michigan, Great Lakes and Marine Waters Center.

Facilities include several gas flow proportional counters with automatic sample changers for total alpha and beta counting. These systems are used both for low-level counting of environmental samples and for laboratory radiotracer studies. The laboratory has one absolute geometry alpha spectroscopy system and has recently added two additional alpha spectroscopy modules. This addition is a significant improvement in capability for extremely low-level (about 10 femtocuries), high resolution measurement of alpha emitting radionuclides, such as the plutonium and thorium isotopes and polonium-210. Currently under development is a radon gas counting system in which the radioactive gas is transferred to a zinc sulfide lined chamber, where scintillations produced by its decay are detected by a photomultiplier. This system, once operational, will provide a basis for radiometric studies of vertical diffusivity within the benthic boundary layer. There is now an extensive capability for gamma analysis. A well-shielded 3-by-5-inch sodium iodide detector is used for routine measurement of fallout cesium-137 in sediment and in trap samples. Several 2-by-2-inch sodium iodide detectors are presently used in gamma scan systems. In these systems the detectors are housed in extremely well-collimated lead shields (shields that direct light waves) mounted on hydraulically operated platforms. The gamma scan systems are used to determine the vertical distribution of gamma emitting tracers added to laboratory microcosms containing sediments, water, and zoobenthos. In addition, the laboratory includes a major gamma detection system—a high volume, high resolution, well-shielded lithium-drifted germanium detector coupled to a state-of-the-art multichannel analyzer. The system is interwired with the University of Michigan computer facility, allowing for on-line data processing. The system is designed for simultaneous determination of many radioisotopes, including beryllium-7, potassium-40, cesium-137, and other fallout radionuclides. The system may also be used for quantitative determination of stable element concentrations via neutron activation analysis.

Computer Facility

The computer systems group supports the work of GLERL scientists by designing, coding, debugging, and testing systems and applications programs. They also counsel and train scientist-technician programmers to increase the effectiveness and efficiency of their use of computing resources.

General scientific computing is presently being done on ERL's Control Data Corporation Cyber 170/750 located in Boulder. This computer is accessed by means of a remote-job-entry station and about 25 interactive terminals located throughout the laboratory. A statistical multiplexer is used to control data traffic on a 9,600-baud telephone link to Boulder; it supports the remote-job-entry station, two 1,200-baud and five 2,400-baud hard-wired terminals, and nine 300-baud dial-up lines. Four of the interactive terminals have screen graphics capabilities; one of these also has a hard-copy graphics capability.



Scientist inspecting installation of the new VAX 11/780 computer. This new equipment will greatly enhance computing support for GLERL scientists.

The GLERL computing facility was greatly enhanced this year by the acquisition of a Digital Equipment Corporation VAX 11/780 computer system. This system is expected to satisfy the small-to-moderate computing needs of GLERL scientists. The VAX, to be installed early in FY 1984, will initially communicate with the NOAA CDC 170/750 computer. Applications now running on the 170/750 will, where appropriate, migrate to the VAX over the next several months.

Research Vessel *Shenehon*

The *Shenehon* is the primary platform used in support of open lake field investigations. The vessel is a converted T-boat 65.6 feet long, with a 6.5-foot mean draft, a 600-nautical-mile cruising range, and a 10-knot cruising speed. A hydraulic articulated crane with a 1,630-pound lifting capacity at 21-foot extension is used for deployment and retrieval of heavy instrument moorings. Winches handle hydrographic wire and multiconductor cable for sample casts and *in situ* measurements of water variables. An on-board laboratory facilitates onsite physical, chemical, and biological experiments. A LORAN C navigation system provides the capability and precision for the boat to return to an exact site in the lakes for equipment retrieval.

During FY 1983, the *Shenehon* was based at the U.S. Army Corps of Engineers' boat yard at Grand Haven. The Corps also provided warehouse facilities and space for a mobile shore-based laboratory at that location. Boat operations were confined to Lake Michigan.

In a study to quantify the vertical mass and chemical flux during thermal stratified and nonstratified periods, sediment trap moorings were deployed at five locations in Lake Michigan during November and December 1982 for collections during winter 1982-83. These traps were serviced in early summer and redeployed.

Periodic cruises were made to the vicinity of a NDBC NOMAD buoy in support of a study to determine the vertical distribution and transport of radionuclides. A sediment trap mooring was serviced, cores taken, and large volume water samples were pumped and filtered during each cruise. Large diameter (30-centimeter) traps were used to ensure the collection of sufficient sediment.

Biological work supported by the *Shenehon* during the past year included benthic, planktonic, and bacterial experiments studying nutrient cycling in the aquatic environment and the long-term effects of toxic material inputs. As part of a toxics materials study, specimens of the organism *Pontoporeia hoyi* were collected in Lakes Huron and Michigan to measure uptake of PAH.

In a nutrient cycling study, benthic invertebrates were collected from the Grand River and adjacent Lake Michigan to determine whether they release significant quantities of phosphorus by metabolic and digestive processes and to examine mechanisms of nutrient release. In another nutrient investigation, dissolved phosphorus was collected from the Grand River and adjacent lake and fractionated into its various forms as a prerequisite to determining its bioavailability. Water and zooplankton samples were also collected in Lake Michigan for a laboratory study of selection and volume of food ingested by the copepod *Diaptomus*.

The *Shenehon* supported a Lagrangian Pilot Study that used a satellite-tracked surface drogue to follow and ensure sampling in the same water mass. Sediment traps were suspended below the satellite drifter. Other operations included the deployment and retrieval of moorings, light and temperature studies, plankton net tows, and collection of water samples by hydrographic casts and pumping.

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

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

Crew of the research vessel *Shenehon* recovering a sediment trap mooring from Lake Michigan. Deployment and retrieval of the instruments used to collect basic data are important functions requiring a well-equipped boat.

retrieve satellite-tracked drogues that tracked water current trajectories in Lake Michigan.

In the data collection phase of an investigation of the rotational mode currents induced in Lake Michigan by suddenly imposed wind stresses, the vessel was used in June and July to retrieve 16 current meter moorings that were deployed throughout the lake in 1982. The bulk of these were along the junction of the northern and southern basins. These current meters remained in Lake Michigan through winter 1982-83. Sediment traps were also deployed on the current meter moorings to take advantage of the water current data to provide greater insight into the mass movement of settling and resuspended particles in Lake Michigan.

A "wire line" sweep technique designed by GLERL personnel was used successfully three times during FY 1983 to recover submerged sediment traps and one current meter mooring. These recoveries resulted in little or no loss of data and a considerable savings due to limited use of divers.

Shipboard improvements included the installation of a hydraulic hydrographic winch on the articulating crane and a variable speed hydraulic winch for temperature and light transmission studies. Both improvements resulted in more usable deck space, greater flexibility in operations, and greater detailing of temperature and light transmission profiles.

Library and Information Services

GLERL library staff supplies necessary library and information services support for laboratory activities by maintaining a tailored research collection and offering special retrieval services when the collection cannot meet the documentation or information needs of the researchers. The current GLERL library collection consists of research materials in the areas of climatology, hydrology, hydraulics, ice, limnology, mathematical modeling, meteorology, oceanography, sedimentation, and wave motion with emphasis on the Great Lakes Basin. Toxic organics and nutrients are now being included as major subject areas. Holdings include 2,811 books, 3,102 unbound periodical volumes, and 2,602 reports (excluding an estimated 200 books, 2,300 reports, and 1,220 unbound periodical volumes kept in a remote storage location). Space limitations have necessitated both local and distant area storage facilities. A large number of materials obtained at the closing of the Lake Survey Center library continue to be recataloged and incorporated into the GLERL Library collection as time and shelf space permit.

Library staff perform reference, interlibrary loan, photocopying, acquisition, circulation, and bibliographic services, including on-line information retrieval, for laboratory affiliated personnel. In addition, the library staff expedite on-demand document retrieval and increase reference capability on behalf of GLERL scientists through on-site access arrangements with the University of Michigan library system. Limited services to others are provided upon special request.

In June 1983, the library was moved to an adjacent building. The new location provides slightly larger space. During FY 1983, library staff cataloged 260

books and 793 technical reports, retrieved 389 interlibrary loans, and performed 113 on-line literature searches. On-line bibliographic literature searching capabilities were expanded through the addition of two ISI Search Network data bases. GLERL Library serial holdings were submitted for inclusion in the Washtenaw-Livingston Library Network (WLLN) Union List of Serials and the Online Computer Library Center (OCLC) Union Listing Component. Serial holdings were updated in JOURNALINK, a national union list of serials.

FY 1984 GLERL Library plans include the input of current book records into the OCLC Online Union Catalog, a national union catalog, and a rewrite of the GLERL Library Automated Retrieval System (GLARES), an in-house technical report catalog. Participation in the former catalog will permit inclusion of GLERL book holdings in the NOAA Library Information Network (COM) Catalog, thereby enhancing resource sharing with all NOAA libraries, as well as with other automated libraries. A planned rewrite of GLARES will broaden interactive access to the report catalog at the local level while substantially reducing costs. These automated innovations are expected to expand the current level of library and information services without increasing staff demands.

PUBLICATIONS

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

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

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† Not affiliated with this laboratory.

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CONTRACTS AND GRANTS DURING FY 1983

Principal Investigator	Institution	Title
A. M. Beeton	University of Michigan	A Cooperative Program in Great Lakes Long-Term Effects Research
A. M. Beeton	University of Michigan	The Cycling of Toxic Organic Substances in the Great Lakes Ecosystem
J. E. Breck	Oak Ridge National Laboratory	Models for Behavior and Fate of Long-Lived Contaminants
D. M. Di Toro	Manhattan College	Long Time Scale Investigation of Organic Particle Transport and Fate in Lake Erie
S. J. Eisenreich	University of Minnesota	Toxic Organic-Sediment Dynamics in the Great Lakes
J. P. Giesy	Michigan State University	Lysosomal Enzyme Release Assay as a Measure of Stress in Freshwater Clams
C. E. Herdendorf	Ohio State University	Lake Erie Environmental and Recreational Atlas
G. A. Meadows	University of Michigan	The Growth and Decay of the Coastal Boundary Layer
R. A. Moll	University of Michigan	Bacterial Dynamics
C. H. Mortimer	University of Wisconsin (Milwaukee)	Coupling of Physical and Biological Dynamics in Large Lakes
C. H. Mortimer	University of Wisconsin (Milwaukee)	Inertial Motion and Related Internal Waves
D. Nelson	Argonne National Laboratory	Removal of Radionuclides From Watersheds of the Great Lakes
K. H. Reckhow	Duke University	Uncertainty and Risk Management of Toxic Substances in Aquatic Systems
H. T. Shen	Clarkson College	Ice-Cover Effects on Hydraulic Transient Analysis

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