Great Lakes Environmental Research Laboratory

Annual Report FY 1981

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

GREAT LAKES

ENVIRONMENTAL RESEARCH LABORATORY

ANNUAL REPORT FY 1981

December 1981

Eugene J. Aubert, Director

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
Office of Research and Development
Environmental Research Laboratories
Great Lakes Environmental Research Laboratory
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PREFACE

The Great Lakes Environmental Research Laboratory (GLERL) has completed its seventh year of operation in Ann Arbor. Our mission at GLERL is to conduct research directed toward understanding the environmental processes and solving problems in resource management and environmental services in the Great Lakes and their watersheds. The environmental information developed is made available to NOAA, other government agencies, universities, industries, and individual citizens to aid them in their environmental services, plans, and operations.

Understanding the complex lake-land-atmosphere system of the Great Lakes Region and the many interactions that influence our lives in this region requires a team of scientists with different backgrounds working together on field, laboratory, and analytic investigations on the limnological, hydrological, and meteorological properties of the lakes, their basins, and the overlying atmosphere. The ultimate goal of the GLERL program is to understand the lake-land-atmosphere system to the extent that environmental simulation and prediction models can be built to provide sufficiently precise information on Great Lakes processes and phenomena to support enlightened use of the region's resources.

This annual report is intended to inform the Great Lakes community of GLERL's capabilities, program, significant results, and plans for the future. It is also intended to encourage an exchange of information between laboratory staff and those in need of environmental information for operational, planning, or management activities.

Examples of some of the major problem areas that the GLERL program addresses are lake water levels and connecting channel flow prediction—critical to erosion control, transportation, recreation, and power generation; lake ice prediction—critical to lake transportation and shoreline structure design and protection; lake circulation—critical to ecosystems analysis and an understanding of the transport and dispersion of pollutants; surface waves and oscillations—critical to lake transportation, boating, and the control of shore erosion and flooding; and the dynamics of certain chemical and biological properties and systems—critical to understanding and prediction of the natural ecosystem and human alterations in the ecosystem and to water quality, water supply, and fisheries management.

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

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

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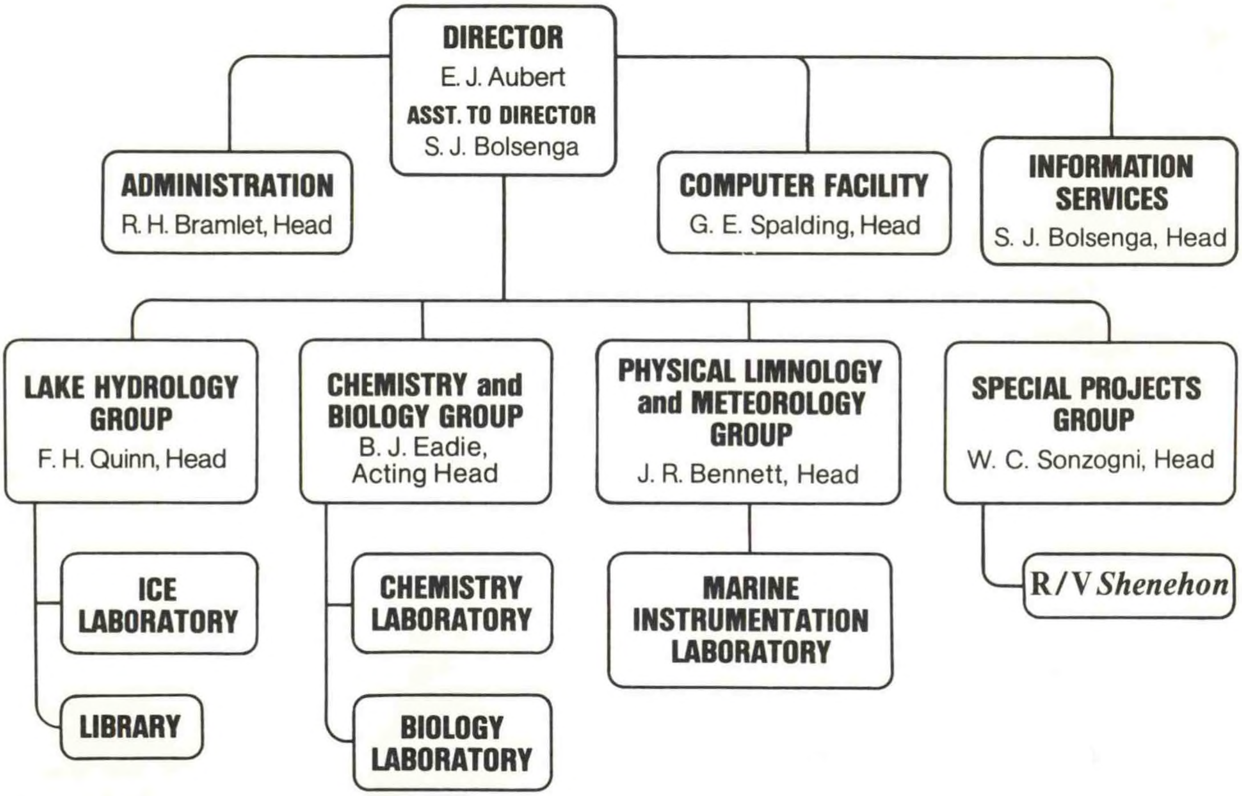
GLERL ORGANIZATION CHART



HIGHLIGHTS

For 7 years the Great Lakes Environmental Research Laboratory has conducted research on significant processes and problems in the Great Lakes Region. 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 1981, 62 papers authored by GLERL staff and 9 papers by contractors were published, and 41 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.

• A laboratory experiment has identified the presence of high concentration nutrient patches produced by zooplankton and the preferential growth of algae that encounter the patches. It is hypothesized that microscale nutrient patchiness caused by swimming zooplankton is important to the competition and coexistence among phytoplankton.

• A study is continuing to identify present-day species distributions of benthic animals and, by comparison with previous studies, will identify trends over the last half century in southern Lake Michigan. Benthos fill an important compartment in the food chain and are sensitive to water quality and sediment conditions.

• Scientists from GLERL, the University of Michigan, and the University of Wisconsin completed an assessment of the state of knowledge of nutrient cycling in the Great Lakes ecosystem. This resulted in a conceptual model of phosphorus cycling and provides focus for process research needs. Nutrient release by zooplankton was identified as a major recycling mechanism of nutrient supply to algae and is a major focus for future process studies.

• A directional wave and coastal boundary layer experiment was successfully implemented with the deployment of an instrument array to measure various water movements and meteorological components in Lake Erie along a transect from the shore out to some 6 kilometers. Data from this experiment will facilitate analysis and understanding of directional wave spectra under varying wind conditions, spectral transformation of surface waves from deep to shallow water, and the momentum balance due to waves and currents in the coastal boundary layer and surf zone.

• A free surface version of a variable grid, barotropic model was developed and tested on a storm surge analysis of Lake Erie. A rigid lid version of the prediction model will be tested against Lake Erie observed currents and circulations from the large data base collected by GLERL and the Canada Centre for Island Waters during 1980.

• A new hydrodynamic method was developed for inferring wind stress over a lake from readily measurable water level fluctuations, even during severe weather conditions. Calculations of wind stress magnitude can be used with overwater wind speeds to determine drag coefficients as a function of wind speed and atmospheric stability.

• A nonpoint source pollution model termed WATERSHED was developed to determine the most cost-effective pollution control strategy for use by the U.S. Soil Conservation Service and the U.S. Environmental Protection Agency. A users' handbook was developed to promote wide application of the technique, which includes trade-offs between cost and effectiveness of controlling point and nonpoint pollution sources.

• Recent contributions by GLERL staff to support the Great Lakes Environmental Planning Study include technical reports on (1) phosphorus bioavailability of pollutant inputs and its impact on management, (2) risk assessment as applied to Great Lakes water quality management, (3) ecological factors in Great Lakes water quality management, (4) hazardous spill modeling, (5) a Great Lakes environmental atlas, and (6) a chloride budget for the Great Lakes.

• Studies of risk assessment techniques were initiated to explore possible applications to water quality management. To date, a water quality risk assessment framework has been developed with the methodological components of risk identification, estimation, and evaluation.

• With the completion of the digitization of 3000 Great Lakes ice charts spanning the 20-year period 1960-79, the improved Great Lakes ice atlas is now targeted for publication in 1982. This ice atlas will facilitate planning by many users of the Great Lakes.

• A field study to determine the spectral reflectances of fresh and metamorphosed snow and of various types of freshwater ice was completed. The information is important to verify and improve existing snow reflectance models and to develop new models for energy-budget-based ice forecasts and for remote sensing applications.

• A simulation model of ice-cover growth and decay on the upper St. Lawrence River was developed and tested over two winter periods. Simulation results identified processes that exert the greatest control on growth and decay rates. Those processes are currently being incorporated into river ice-cover prediction models to be used by the St. Lawrence Seaway Development Corporation and the U.S. Army Corps of Engineers.

• A program to study the cycling, transport, and fate of toxic organic compounds, in cooperation with NOAA's Office of Marine Pollution Assessment (OMPA), continued. A model designed to estimate the equilibrium partitioning of synthetic organic compounds between the dissolved and solid phase within an aquatic ecosystem based on the solubility and vapor pressure of the compound, has been developed. This model estimates the concentration and mass distribution of synthetic organics among various compartments of an ecosystem and can be used as a screening tool for monitoring programs. Photodecomposition rates for several PCB isomers have been measured in lake water. This decomposition pathway is one of the major organic contaminant removal mechanisms within the Great Lakes System, and accurate rate measurements are necessary to predict concentrations at any future time.

Information Services

During the past year, as part of GLERL's Information Services, nearly 2100 research products were provided in response to nearly 1400 documented requests. Of these, 48 percent came from universities and State governments, 38 percent from private industry, and the remainder from private citizens and the Federal Government. 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 12 Draft Environmental Impact Statements evaluated during the year.

International and Interagency Activities

GLERL staff members were active in several International Joint Commission (IJC) boards and committees, including the Science Advisory Board, Levels and Flows Advisory Board, Technical Information Network Board, Aquatic Ecosystem Objectives Committee, International Great Lakes Diversions and Consumptive Use Reference Working Committee, and Phosphorus Management Strategies Task Force.

GLERL participated in the activities of the International Coordinating Committee on Great Lakes Hydraulic and Hydrologic Data, the Joint United States-Canadian Ice Information Working Group, the International Association for Great Lakes Research, the Great Lakes Experimental Team for the Coastal Zone Color Scanner, and the Regional Response Team for Spills of Hazardous Substances.

GLERL staff participated in Great Lakes Basin Commission activities as Alternate Department of Commerce Commissioners, and as members of the Great Lakes Basin Plan Committee, the Priorities Committee, the Coastal Zone Management Committee, the Standing Committee on Research and Development, the Long Range Planning Subcommittee, and the Great Lakes Environmental Planning Study.

Facilities

Primary field activities conducted by marine instrumentation laboratory personnel involved deployment of the Lake Erie coastal boundary layer measurement system and a current monitor and data acquisition system in the St. Clair River. Both systems will collect real-time data in fall 1981, with the current monitoring system continuing through the 1981-82 winter. A flow tank providing linear flow up to 4.5 feet per second was designed and built for current meter calibration and testing.

New approaches to fractionation and characterization of organic and inorganic dissolved phosphorus forms were developed in the chemistry laboratory. In the biology laboratory, nutrient release rates by individual zooplankton were measured with a flow-through incubation cell, high performance liquid chromatographic plumbing, and an AutoAnalyzer.

A particle dynamics laboratory was established this year. Part of the cooperative program with the University of Michigan, it will support expanded studies in this field. Since natural and artificially produced radionuclides serve as excellent process indicators, the laboratory provides the capability for measurement of very low levels of such substances in water, sediment, and biota.

The research vessel *Shenehon* successfully supported a variety of water-sediment, chemistry, and biology experiments in Lake Michigan.

STAFF AS OF SEPTEMBER 30, 1981

	Permanent Employees	
	Full Time	Part Time and Intermittent
Office of Director	11	2
Lake Hydrology Group	9	3
Chemistry and Biology Group	9	4
Physical Limnology and Meteorology Group	14	3
Special Projects Group	3	4
Total	46	16

Assel, R. A.	LH
Aubert, E. J.	OD
Bell, G. L.	CB
Bennett, J. R.	PLM
Bolsenga, S. J.	OD
Booker, H. L.	PLM
Bramlet, R. H.	OD
Burns, W. R.	SP
Carrick, B. J.	LH
Chapra, S. C.	SP
Croley, T. E., II	LH
Del Proposto, D. J.	OD
Derecki, J. A.	LH
Dungan, J. E.	PLM
Eadie, B. J.	CB
Faust, W. R.	CB
Field, L. P.	PLM
Gardner, W. S.	CB
Greene, G. M.	LH
Grimes, J. E.	SP
Grumblatt, J. L.	PLM
Hass, S. E.	OD
Herche, L. R.	OD
Kelley, J. M.	OD
Kelley, R. N.	LH
Kistler, R. D.	PLM
Landrum, P. F.	CB
Lawton, B. J.	LH
Lee, J. P.	OD
Leshkevich, G. A.	LH
Liebig, J. R.	CB
Liu, P. C.	PLM
Lojewski, N. L.	SP
Losey, D. A.	LH
Malczyk, J. M.	CB
McCormick, M. J.	PLM
Menoian, N. R.	OD
Miller, G. S.	PLM
Miller, T. C.	PLM
Morse, D. V.	SP
Muzzi, R. W.	PLM
Nalepa, T. F.	CB
Noble, P. E.	OD
Norton, D. C.	LH
Parker, R. K.	OD
Peters, J. R.	PLM
Pickett, R. L.	PLM
Pinsak, A. P.	SP
Quigley, M. A.	CB
Quinn, F. H.	LH
Robbins, J. A.	PLM
Saylor, J. H.	PLM
Scavia, D.	CB
Schwab, D. J.	PLM
Slavens, D. R.	CB
Sonzogni, W. C.	SP
Soo, H. K.	PLM
Spalding, G. E.	OD
Stubblefield, B.	LH
Tarapchak, S. J.	CB
Vanderploeg, H. A.	CB
Vreeland, S. A.	OD

LH—Lake Hydrology Group
OD—Office of Director
CB—Chemistry and Biology Group
PLM—Physical Limnology and Meteorology Group
SP—Special Projects Group

LAKE HYDROLOGY

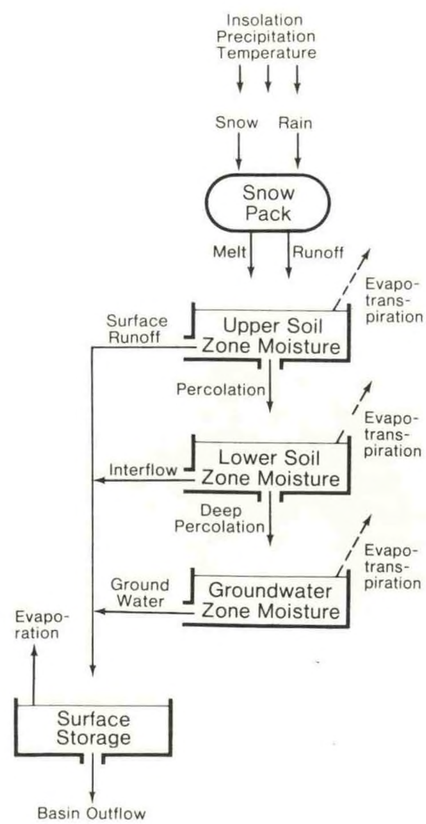
The emphases of the Lake Hydrology Group are on the hydrologic cycle, including channel hydraulics, and on ice research. The objectives of the hydrologic work are to develop improved methods of prediction and simulation of lake levels, connecting channel flows, and flow in tributary streams and to improve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

Prediction and simulation information on lake levels and flows is necessary for water resource planning and management and for the solution of problems in 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. Environmental Protection Agency, 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 winter navigation, shoreline engineering, 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 National Weather Service, the St. Lawrence Seaway Development Corporation, the Great Lakes shipping industry, and the general public, including shoreline property owners.

Hydrology

Beginning this year, a major project has begun to develop mathematical models to predict and simulate the runoff into each of the Great Lakes from their land basins. Great Lakes Basin runoff modeling is necessary for operational forecasting of lake levels and for understanding watershed response to natural forces. Experiments with existing comprehensive models indicate that they are impractical for representing many large watersheds. They require too many parameter estimates, clouding their physical relevance; they are expensive to fit and to use and they require more data than are available for large areas. Work this last year has centered on data acquisition for Lake Ontario and on the development of a simple physically-based conceptual model for use on the Great Lakes Basins, which will use only daily precipitation and temperature data to estimate weekly or monthly basin runoff. Data collection and reduction are complete for Lake Ontario, encompassing 30 years of daily precipitation and temperature at 24 locations and runoff at 20 locations for 17 watersheds bordering the lake. An interdependent "tank" model has been identified and tested on the Genesee River Basin in New York State. Snowmelt is treated via simple heat balance, and evapotranspiration is considered in a climatologic setting in which available soil moisture, as well as potential loss, are accounted for. Each tank storage is represented as a linear reservoir, and exact analytic solutions are employed throughout. Early test results indicate that the model compares favorably with the existing comprehensive models and with statistical models. Model fit requires about 2 man-days on the computer. Future work includes assessment of spatial/temporal resolution trade-offs, data acquisition and reduction on the remaining Great Lakes, model fits to watersheds about all Great Lakes, and integration of the models into lake-level determinations.

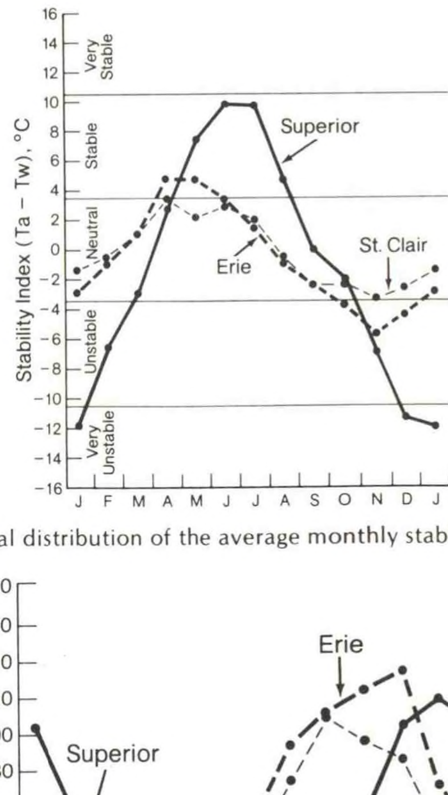


GLERL large-basin runoff model schematic.

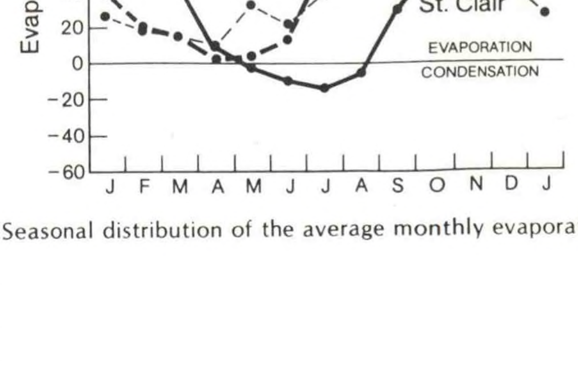
During the past year, lake evaporation studies were completed with the development of a generalized monthly evaporation model for Lakes Superior and Erie and Lake St. Clair, a much smaller lake within the chain of Great Lakes. The model is based on an improved aerodynamic procedure that includes full atmospheric stability effects, including reduction of lake evaporation by an ice cover during winter. This aerodynamic or mass transfer procedure is the most practical approach for operational evaporation estimates and permits determination of monthly evaporation rates from readily available land-based climatological data. The model was used to derive a long term evaporation data base for each lake, covering approximately the last 40 years (1940-79). Both monthly and annual evaporation from the individual lakes can vary substantially from year to year, but the normal annual water losses through evaporation are approximately 500, 700, and 600 mm from Lakes Superior, Erie, and St. Clair, respectively. The seasonal variation of evaporation from each lake is governed by atmospheric stability conditions, with high seasonal evaporation occurring during the fall-winter period and low evaporation occurring during the spring-summer period. Lake Superior also attains significant condensation during the low evaporation season when condensation on the other lakes is normally absent. On Lake Superior the use of atmospheric stability eliminated unreasonably high condensation and produced an increase in lake evaporation during summer, which was largely counter-balanced by ice-cover reduction of evaporation during winter, with only a slight overall change. On the other two lakes, with insignificant condensation, the use of atmospheric stability substantially reduced the high evaporation values, with corresponding reduction of the annual water losses (about 25 percent). The average ice-cover reduction of evaporation on the three lakes varied from about 10 to 15 percent of the annual values.

After considerable delay due to problems encountered with the current meters, the study of the winter flow regimes of the St. Clair and Detroit Rivers was reinitiated with the deployment of two meters in the St. Clair River at Port Huron. The dynamic flow models for the upper St. Clair River were modified to permit direct comparison on hourly and daily time scales between flows computed by the models and flows measured by the current meters. Standard river flow measurements will be used to calibrate the two-point current meter array for monitoring winter flows. These measurements were completed during October 5-9, 1981, with the Detroit District, U.S. Army Corps of Engineers, the U.S. Geological Survey (Michigan office), and the Water Survey of Canada participating in the project. Availability of the two-point flow index and derived mean river flows based on measurements will permit reevaluation of questionable winter flows and possible recalibration of the mathematical unsteady flow models for winter applications.

A precipitation data base for each of the Great Lakes has been developed for the period 1854-1979. The length of the time series enables a unique look at precipitation climatology in relation to lake level changes and water resources planning in the Great Lakes Basin. The climatology was used in conjunction with a mathematical response model of the system and simplified statistical rainfall-runoff models to qualitatively evaluate the proportion of a major lowering of water levels in Lakes Michigan and Huron (0.8 meters) in the late 1880's which could be explained by a change in the precipitation climatology. The study found that approximately 75 percent of the lowering was due to precipitation changes.



Seasonal distribution of the average monthly stability index.



Seasonal distribution of the average monthly evaporation.

Ice

A climatological analysis of nearly 3000 ice charts spanning the 20-year period 1960-1979 has been completed. The results of this analysis include the production of ice charts illustrating the maximum, minimum, and median ice-cover concentration for each of nine half-month periods for each Great Lake. The ice charts summarize ice concentration values for individual 5-by-5-kilometer cells that compose the surface area of each lake. In addition, the percent of ice-covered lake surface area has also been calculated for each lake each half month.

In 1982 this analysis will be published as a NOAA ice atlas. The atlas will contain three major sections dealing with winter severity, ice-cover climatology, and climatic aspects of ice thickness and ice stratigraphy in nearshore locations.

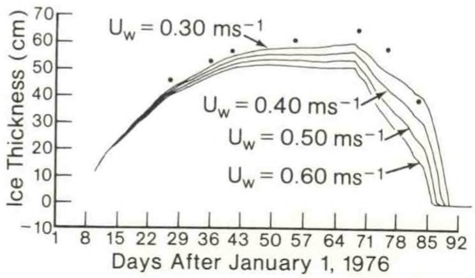
One of the highlights of the past year has been the development and testing of a mathematical model to simulate or predict ice-cover growth and decay on the upper St. Lawrence River. There are a number of reasons why the ability to predict ice decay rates is important for the St. Lawrence River. Despite its role as a major transportation corridor, the river is unusable for shipping for up to 4 months of the year. An accurate projection of the river's opening date is important because of the economic benefits of advance planning. For instance, ships from European ports must plan their departure so as to arrive at the St. Lawrence River as soon as possible after the river is open for passage. Another major economic function of the river is to generate electricity. Although maximum flow is desirable for power production at the Moses-Saunders Power Dam (located just upstream of Cornwall, Ontario), the river flow must be controlled during the decay period to help ensure an orderly breakup. A better prediction of breakup would lead to more accurate planning of power generation.

Deterministic models were developed to couple the components of surface energy flux, the turbulent heat flux from the river water, and the processes of heat transfer within the snow and ice layers. The models then simulate changes in ice-cover thickness and temperatures at fixed time intervals. An advantage of deterministic over statistical models is that one can test the model to discern those processes that have the most influence on the timing and magnitude of ice growth and decay.

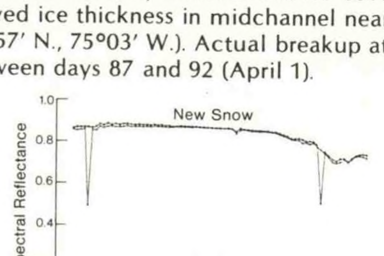
The model was initially tested over a winter that experienced mid-range temperature conditions and simulated breakup within the 6-day period of uncertainty, during which breakup actually took place. The model has also been tested at six different locations on the St. Lawrence River over the winter of 1980-81. Although this winter was characterized by extreme cold in December and January and extreme warmth in February, the model simulated breakup within the observed period.

A scanning, dual spectroradiometer system that simultaneously records incident and reflected flux in the 280-1100 nanometer range was developed to observe the spectral reflectance properties of snow and ice. Sun plus sky radiation were used to field calibrate the spectroradiometers. The arrangement of the spectroradiometers is suitable for field or laboratory applications where changing incident radiation necessitates simultaneous incident and reflected readings.

Measured spectral reflectances of new and moderately metamorphosed snow were generally greater than 80 percent from 340 to 950 nanometers. From 950 to 1100 nanometers, a characteristic dip and rise of spectral reflectances occurred. Spectral reflectances for clear ice contrasted sharply with those for snow. In general, values were less than 10 percent and the curves lacked distinctive shape. Secondary ice types revealed spectral reflectance curves similar in form to each other, but which varied significantly in the range of spectral reflectances for each ice type. The spectral reflectances will prove useful for energy budget modeling of ice formation, growth, and decay; for assessment of primary production and the status of freshwater plants and animals in winter; and for interpretation of certain types of remote sensing.



Sensitivity of the St. Lawrence River ice-cover model to changes in water velocity beneath the ice cover. Dots indicate observed ice thickness in midchannel near Wilson Hill Island (44°57′ N., 75°03′ W.). Actual breakup at this site occurred between days 87 and 92 (April 1).



Spectral reflectances of new snow (two scans) and of clear ice (three scans). These were obtained with a state-of-the-art scanning spectroradiometer system. Spikes are noise.

CHEMISTRY AND BIOLOGY

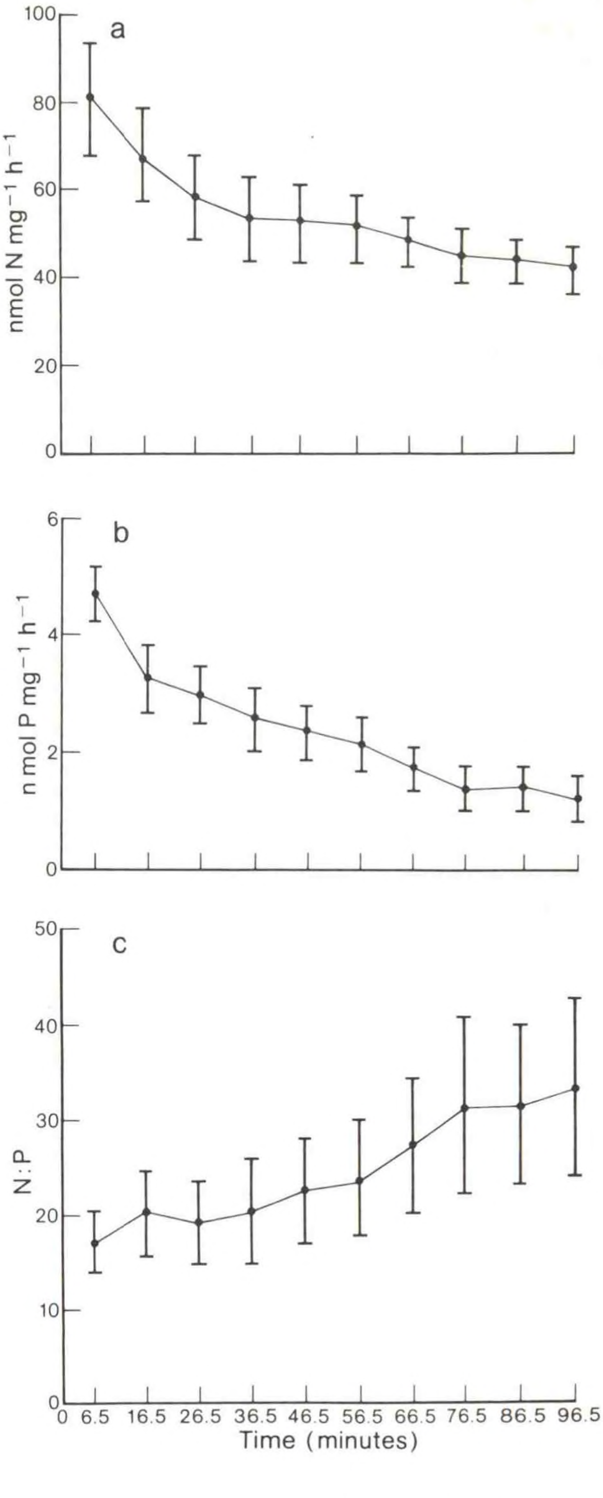
The work in chemistry and aquatic biology is aimed at understanding the existing lake conditions, recognizing the trends that have occurred, and developing the capability to predict the course of events given alternative approaches to the management of the lakes. In this respect, the program will provide information pertinent to a large number of problem areas relative to the development, use, protection, and conservation of the Great Lakes resource.

This information is of immense value to water resource managers in the Great Lakes Basin as they make decisions affecting water quality, power generation, commercial fisheries, and recreational uses of the lakes. Numerical models of the ecosystem can be used to forecast future conditions, to predict the results of implementation of various possible strategies, and to better understand the dynamics of lake biological and chemical phenomena. The variety and distribution of plankton types affect water supply taste and odor and play an important role in the entire ecosystem since plankters are a vital part of the lake food web. Water chemistry studies, by describing the constituents of the water at various sites and the changes with time and with variations in temperature, currents, and loading, are particularly important to water quality determinations. The current emphasis is on understanding the cycling of nutrients and toxic organic compounds within the ecosystem.

Eutrophication and Nutrient Cycling

The importance of internal cycling of nutrients in control of seasonal plankton dynamics was clearly documented in a state-of-the-art report prepared as part of the nutrient cycling program. Of the components in the internal cycle, nutrient release by zooplankton was identified as a major mechanism of supply to algae. Experimental and modeling studies of the mechanisms and controls of zooplankton nutrient regeneration have therefore been an important element of the nutrient cycling programs this past year.

A novel experimental apparatus was used to measure ammonia and phosphorus release from individual zooplankters under different feeding regimes. These experiments demonstrated differences in the way nitrogen and phosphorus are regenerated by zooplankton and in the way nutrient regeneration may be controlled by the quality of food present. Both results demonstrate potentially important errors present in existing models of nutrient regeneration. A second experimental program, where zooplankton nutrient ingestion rates are measured prior to measurement of nutrient release, is being carried out to test a process model relating nutrient release rates to ingestion rates and food



Mean ± standard error rates of release of ammonia (a) and soluble reactive phosphorus (b), and the molar ratio of nitrogen to phosphorus (c) versus time after *Daphnia magna* were removed from their food.

quality. Results from these experiments are expected to improve simulation of nutrient cycling under natural variations in environmental food quality and quantity.

Heterogeneity in supplies of limiting nutrients could theoretically lead to changes in the biotic fabric of plankton communities, and some laboratory studies have shown this in practice. A crucial question is whether or not the requisite patchiness occurs in nature. Large-scale (meters to kilometers) patchiness is a well-recognized result of physical processes. On a finer scale there is the possibility that biotic processes like decomposition or excretion could create localized zones rich in nutrients.

Autoradiographic methods have been used to identify the presence of nutrient patches produced by zooplankton. Algal cells that encounter patches of radiophosphorus released by swimming animals become differentially labeled with respect to cells that do not enter the patches. Nutrient patchiness at the scale of millimeters or less in nature probably influences the course of competition and coexistence among phytoplankton.

Toxic Organic Cycling

In August 1979, GLERL began a research program in cooperation with OMPA, the goal of which is development of a capability to predict the environmental consequences of persistent synthetic organic contaminants in aquatic ecosystems. The assurance of long term OMPA funding has allowed GLERL to develop a cooperative arrangement with the University of Michigan, and to pursue a comprehensive research program focused on certain questions regarding the flow of selected organics within the Great Lakes. Most of the results will be readily transferable to coastal marine systems.

A predictive capability is synonymous with modeling and, to accomplish this, a modeling team consisting of chemical, toxicological, ecological, and physical scientists has been established in-house. The modeling group is supported by researchers working on primary ecosystem processes. Most of the process research is conducted at the University of Michigan, an arrangement that allows for a maximum of flexibility. A schematic of the program is shown in the accompanying figure. The table shows a list of processes currently being studied.

A simple equilibrium model incorporating several first-order decomposition pathways has been calibrated for DDT and PCB mixtures in a horizontally homogeneous ecosystem with the characteristics of Lake Michigan. This model research has revealed the

TOXIC SYSTEM RESEARCH

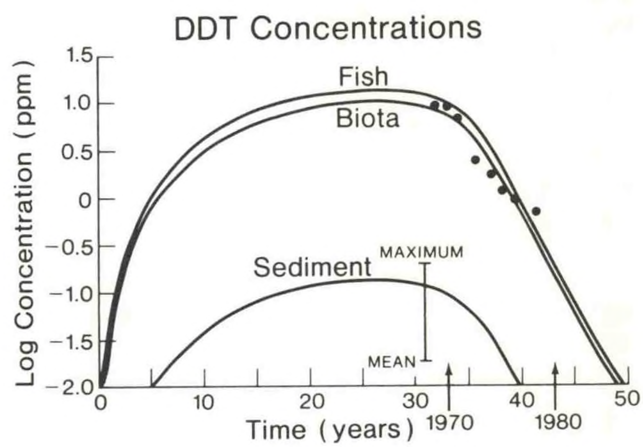
Number*	Description	Principal Investigator Affiliations
1	Photolysis (particulates)	University of Michigan
2	Sorption	University of Michigan
3	Air-water exchange	University of Michigan
4	Grazing, predation,	GLERL
5	Sorption, filtering, excretion	GLERL
6	Photolysis (dissolved)	University of Michigan
7	Biological decomposition	GLERL
8	Settling, resuspension	University of Michigan Argonne National Laboratory
9	Food web dynamics	GLERL
10	Pore water diffusion	University of Minnesota
11	Biological decomposition (sediment)	
12	Benthos-sediment interactions	GLERL
13	Benthos-water interactions	GLERL
14	Sorption (pore water)	University of Minnesota GLERL
15	Burial, fluxes, and bioturbation	GLERL University of Michigan
—	Process modeling (long term)	GLERL
—	Process modeling (short term)	GLERL
—	Transport modeling	GLERL

*See accompanying figure.

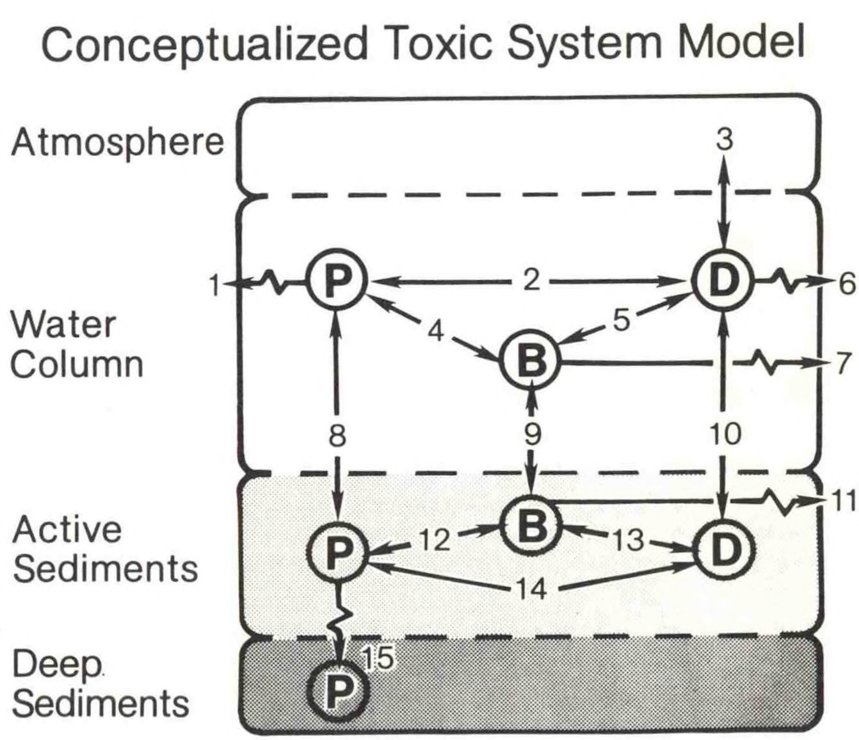
weakness in currently available process-rate information. The model, as constructed, yields some valuable insights into the environmental pathways of hydrophobic organic contaminants in aquatic ecosystems.

Ecosystem Modeling

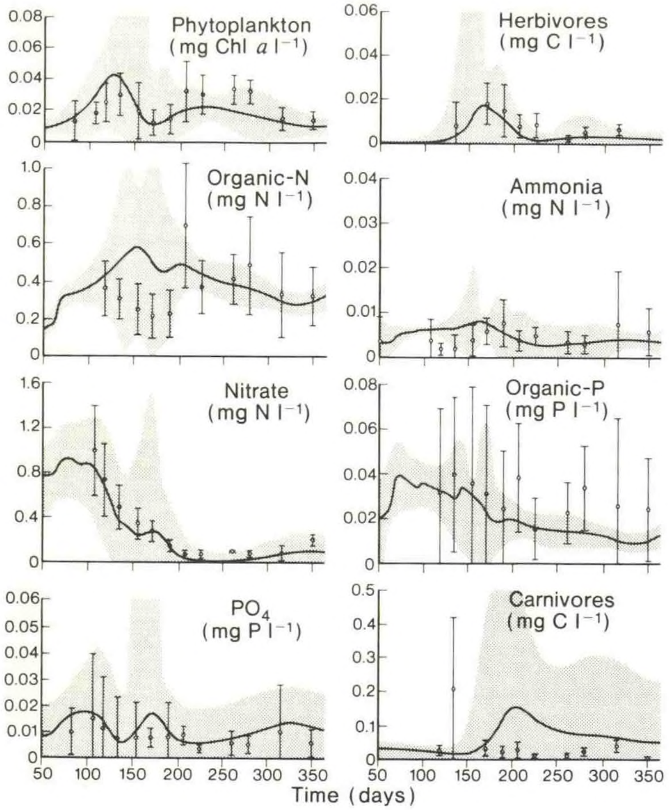
Simulation and prediction of the effects (both short term and long term) of human impact on the Great Lakes is a vital component of GLERL's research program. Models of gross variables, with large time and space scales, have aided in control of Great Lakes eutrophication as perceived on a whole-lake perspective. GLERL's present nutrient cycling and modeling programs are oriented toward current problems as perceived in coastal areas and embayments. As in the past, this modeling program is designed to synthesize existing information and to coordinate emerging data and theory in such a way as to improve our understanding of, and ability to simulate and predict, the lakes' dynamics. These improved models form the basis for resource management models of contaminant (nutrient and toxic) effects. As part of this program, a report documenting current information concerning phosphorus cycling was prepared. Two products resulted: (1) a conceptual model of the cycling of phosphorus and (2) a 5-10 year research plan designed to fill information gaps identified in the report and to build, test, and verify a detailed model of phosphorus dynamics in the nearshore region of the Great Lakes.



DDT model concentration in fish, plankton, and sediments (solid lines) and fish data (points) in an ecosystem resembling Lake Michigan.



Conceptualized toxic system model. *P* represents particle phase, *D* represents dissolved phase, and *B* represents an abbreviated food web. The 15 process arrows are described in the adjacent table.



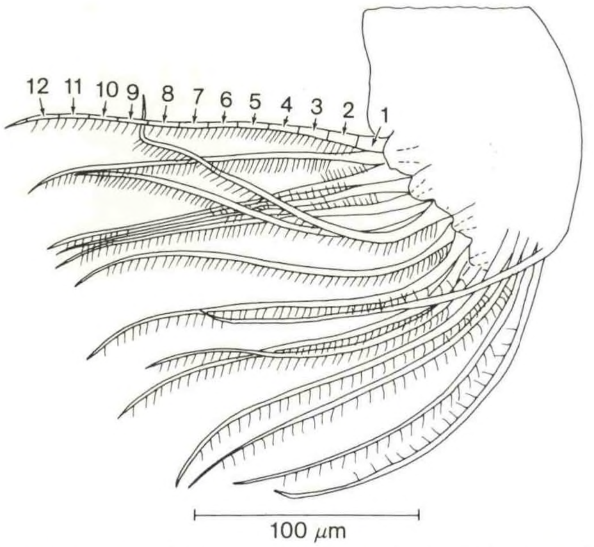
Plots of eight state variable trajectories (smooth curves) from the Saginaw Bay model. Model error estimates are represented as ± 1 standard deviation bands (shaded) from first-order analysis. Data (circles with error bars) are represented as bay-wide mean plus or minus standard deviation of all samples.

Present modeling efforts are centered on two themes: (1) detailed models of biological and chemical processes, with present emphasis on the phytoplankton-zooplankton interface, and (2) interactions (on various space scales) of the biological-chemical system with physical processes. Results from recently completed studies have demonstrated the importance of error analysis and stochastic effects on aquatic systems and their models. Present modeling efforts include analysis of those effects.

Plankton Succession

In 1981 phytoplankton studies have focused on evaluating relationships between the uptake kinetics of dissolved phosphorus and phytoplankton growth rates, as well as on carbon-14 autoradiographic analysis of species-specific assimilation rates of carbon by phytoplankton in Lake Michigan. Analysis of kinetic data has revealed the following: (1) biologic uptake, not abiotic fixation, of phosphorus is the primary mechanism of uptake, (2) specific growth rates of phytoplankton are closely coupled with the rate at which the dissolved phosphorus pool is being cycled, and (3) net plankton are more efficient than nannoplankton in assimilating dissolved phosphorus. The latter observation implicates nutrient factors in addition to zooplankton grazing as an important environmental determinant in regulating nannoplankton abundance. Analysis of autoradiographic preparations reveals that fluctuations in cell numbers do not reflect the rates at which phytoplankton are growing in lakes and that high photosynthetic rates of algae are associated with favorable surface-to-volume ratios.

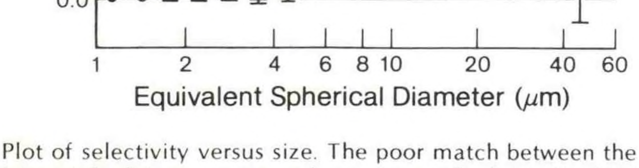
Zooplankton grazing studies have focused on the process by which copepods of the genus *Diaptomus*, the most important group of herbivores in the Great Lakes, select seston (phytoplankton and particulate material) of different sizes. Certain researchers have argued that the cumulative frequency distribution of distances between setules, that is, the fine hairs shown in the figure, can be used to predict the particle-retention efficiency of food gathering by copepods like *Diaptomus*. We have shown that this is not the case by direct comparison with retention efficiency determined from experiments with lake seston and from mixtures of different sized algae of the genus *Chlamydomonas*. One hypothesis for this finding argues that implicit hydrodynamic assumptions about water flow through the filter are false. This and other assumptions will be



Second maxilla of *Diaptomus*. The fine hairs on the finger-like extensions are setules.

tested by means of high-speed motion pictures of the feeding process through a microscope. High-speed cinematography is necessary because the mouth parts frequently move at about 100 Hertz. Laboratory studies on the feeding of *Diaptomus* are continuing. These studies were designed to develop a feeding model that predicts amounts of different kinds of food *Diaptomus* will eat under varying conditions of food supply.

The freshwater shrimp *Mysis relicta* is an important predator of zooplankton, and *Mysis*, in turn, is an important food for Great Lakes fish. Previous studies of *Mysis* predation have been limited to a few feeding experiments performed under artificial conditions in the laboratory. To evaluate and quantify the significance of *Mysis* predation on zooplankton, GLERL developed special field equipment and methods to examine their feeding *in situ*. During 1979, *in situ* feeding experiments were performed in Lake Michigan from spring through fall under varying conditions of species composition and abundance of zooplankton. Analyses of these data are now complete. In contrast to studies in other lakes, which used less sophisticated methods, we have shown that copepod nauplii are an important food for *Mysis* during all seasons. Moreover, we showed that feeding models developed at GLERL are useful for describing the feeding process of *Mysis*.



Plot of selectivity versus size. The poor match between the intersetule distance curve and experimentally determined W' (selectivity coefficient) curves for seston and *Chlamydomonas* implies that the intersetule distance curve is a poor predictor of particle-retention efficiency.

A major study is also underway to examine the role of the benthic community within the Great Lakes ecosystem. Although known to form an integral component of the benthic marine system, the meiobenthos (small benthic organisms) has not been quantified in the Great Lakes. All previous Great Lakes benthic studies have been concerned with the larger invertebrates or the "macrobenthos." After 4 years of sampling, we have gathered some much needed information on certain aspects of the meiobenthos: species composition, abundance, biomass, seasonal and annual fluctuations, vertical distribution in the sediments, and community response to nutrient enrichment. We found that, in the nearshore area, the biomass of the meiobenthos accounts for up to 16 percent of the total benthic invertebrate biomass on an annual basis. These smaller invertebrates have an estimated metabolic rate five times that of the larger ones; thus, energy flow (or materials movement) through the meiobenthos is up to 80 percent of that through the macrobenthos.

The program has recently expanded into determining the role of benthic invertebrates in the flux of nutrients from the sediments into the overlying waters. By combining laboratory and field experiments, we found that phosphorus is being regenerated from the nearshore sediments and that the amount of phosphorus being excreted by benthic invertebrates can account for all of the phosphorus being released.

One of the more important attributes of benthic invertebrates is their widespread use as environmental indicators. Communities integrate and reflect environmental changes over long periods of time. With increased eutrophication, the community evolves from species with low tolerances for imposed stress to species that are better adapted to the changing environment. Currently, we are comparing present-day distributions in southern Lake Michigan to distributions of some 17-50 years ago. Differences in the numbers and kinds of benthic invertebrates will provide information on the magnitude of trophic changes occurring in this portion of the lake.

PHYSICAL LIMNOLOGY AND METEOROLOGY

The Physical Limnology and Meteorology Group studies the physical variables describing the lake environment and the way in which these variables change as a result of external forces. The relevant physical characteristics of the lakes are currents, temperature, water level fluctuations, and the characteristics of the lake sediments and suspended matter. The primary driving forces are the wind stress acting on the lake surface and the heat exchange between the lake, the atmosphere, and the rivers. The primary emphasis of the program is on developing and testing models that will improve the capability of predicting these variables. These prediction models will, in turn, permit 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 other water level oscillations are potential hazards that may result in loss of lives and in damage to shoreline property, shipping, and recreational boating activities.

The phenomena that need to be modeled and predicted have time scales ranging from years to seconds and space scales from the length of the lake to a few meters. In view of this tremendous range in time and space scales, it is necessary to separate and group the various phenomena according to their scales in order to better understand and model them. Hence, the basic research program in the Physical Limnology and Meteorology Group has been arranged in three projects. Project (1), water movements and temperature, deals with lake circulation and thermal structure. This project encompasses studies dealing with lake-wide and nearshore circulation, seasonal changes in circulation, and upwelling and downwelling phenomena. Project (2), surface waves and oscillations, deals with wind-generated waves, storm surges, seiches, and problems of overlake winds. It is necessary for the phenomena grouped in Project (2) to be predicted on a real-time basis in view of their importance as hazards. Project (3), particle dynamics, was started recently, and is a cooperative effort with the Chemistry and Biology Group and scientists at the University of Michigan. The prime reason for initiating this project was that toxic organic substances and nutrients enter the lake attached to particulate matter. Hence, the pathways and ultimate fate of these pollutants in the lakes depend on the movement of various types of particulate matter through the lake environment.

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

Waves and Winds

Major achievements in the study of waves and winds this year consist of development of a new method for determining wind stress from water level fluctuations, development of a generalized representation of the Great Lakes wave spectrum, and the successful deployment and implementation of the directional wave and coastal boundary experiment in Lake Erie.

The transfer of momentum from atmosphere to water is a fundamental physical process that is still inadequately understood. The intricacy of the actual marine environment presents great difficulties in making direct and accurate measurements of the air flow structure over the water surface. Because of this, we have developed a new indirect method by which wind stresses over water are inferred from readily measured water level fluctuations. In this method the water surface fluctuation is expressed as the convolution integral of time- and space-dependent wind stress with a response function kernel. The method is based on the linearized, vertically-integrated, shallow water equations with rotation and friction terms. An application of the method to hourly measurements of Lake Erie water levels from 12 stations around the lake for the period of May to October 1979 shows that the calculated wind stress directions agree with wind directions observed from buoys on the lake for a wind speed greater than 7.5 meters per second. The agreement improves as wind speed increases. Calculated wind stress magnitudes can be used with observed wind speeds to determine overwater drag coefficients as a function of wind speed and atmospheric stability. Thus, this new method can be used to calculate drag coefficients even during severe weather conditions.

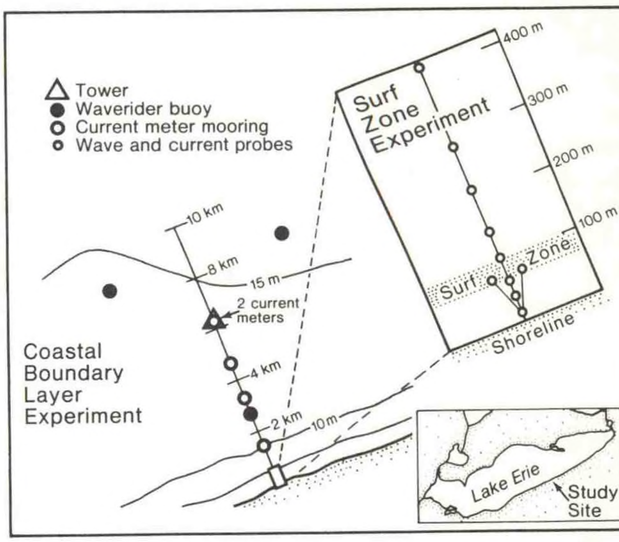
One of the most basic elements in the current state of numerical modeling of wind-generated waves is an accurate representation of the wave spectrum. Using the wind and wave data measured from NOAA's Data Buoy Office's NOMAD buoys in the Great Lakes, we examined the various parametric correlations of the currently available spectral representations and found them too scattered to be useful in attempting to improve the accuracy of results from model predictions. Consequently, we initiated an effort to develop a generalized spectral representation for Great Lakes waves. The effort has led to the proposal of a generalized expression that is characterized by a variable equilibrium range constant and a variable equilibrium range exponent, both with clear, tractable properties that distinguish the stages of wave growth and provide realistic spectral representation. The next task is to apply the representation to a numerical model for possible improvement in wave predictions, as well as operational adaptation. This effort is continuing and the results obtained so far are encouraging.

Our major field experiment this year, the Lake Erie directional wave and coastal boundary layer experiment, has been implemented with the successful installation of a wind-solar-powered research tower 6 kilometers off the Pennsylvania shore of Lake Erie near Conneaut, Ohio. The tower is instrumented to measure wind direction and speed, air and water temperatures, and lake currents. In addition, directional waves are measured at the tower with four Zwarts wave staffs configurated at the center and vertices of a 2-meter equilateral triangle. Three Waveriders have been deployed around the tower to measure the spatial variation of the deep water wave spectrum. Five vector averaging current meters are installed on the tower and on a transect between the tower and the shore. Wave and meteorological data are telemetered to shore and transmitted via telephone line to the Hewlett-Packard computer at GLERL. While the raw data are stored, the computer also performs real-time analysis of directional wave and statistical meteorological information. Close to shore, 10 rigid moorings spaced from shore to 400 meters offshore have been installed by the University of Michigan, Department of Atmospheric and Oceanic Sciences, under a GLERL research contract, to measure the nearshore spectral wave variation, mean water levels, and the longshore and offshore components of the currents through the surf zone.

With a large collection of high quality data from the Lake Erie experiment, our immediate task for next year will be implementing detailed analyses of these data. Specifically, we expect to examine (1) directional wave spectra under varying wind conditions, (2) spectral transformation from deep water to shallow water and the effects of shoaling, refraction, and bottom friction, and (3) momentum balance due to waves and currents in the coastal boundary layer and surf zone.

Water Movements and Temperature

The data collection phase of a study to improve our knowledge of the kinematics of Lake Erie circulation was completed in 1980. From an extensive array of moored current meters and thermistor chains, the temporal and spatial variations of the current velocity and water temperature have been recorded. This year the data have been translated, edited, and combined in a Lake Erie data base with similar data collected by the National Water Research Institute, Canada Centre for Inland Waters, as their contribution in the cooperative IJC study. Some early analyses have shown consistent and prevailing patterns of current flow closely matched with the force applied by wind stress. This Lake Erie data set is the first of sufficient quality and density to permit adequate verification of dynamical models.



Arrangement of coastal boundary layer experiment instrumentation.

Lake Erie, the shallowest of the Great Lakes, has revealed most vividly the effects of nutrient enrichment. Even though the condition of Lake Erie has improved in recent years, an annual problem called anoxia—oxygen depletion of the bottom waters—plagues the lake, especially in the central basin. Its investigation was one of the focal points of this study. Because Lake Erie is so shallow, during the stratified season the thermocline in the central basin penetrates almost to the bottom, leaving a very thin hypolimnion. Biological processes, such as respiration by fish and decay of organic material sifting down from above, rapidly use up the limited supply of oxygen in the hypolimnion, while the thermocline inhibits fresh infusions of oxygen-bearing surface waters. This results in the loss of oxygen—or anoxia. Since the development and persistence of anoxia depends on characteristics of circulation (and stratification), a prime objective was to measure the exchange of hypolimnion water between the central and eastern lake basins and the movement of this layer within the central basin itself.

Useful in examining the dynamical response of Lake Erie will be a variable grid barotrophic model that has been developed and requires the increased capability of the computing facility at the Environmental Research Laboratories Headquarters in Boulder, Colorado. A free surface version of the model has been tested on a storm surge analysis of Lake Erie. The rigid lid version will be compared with the observed currents and circulations of Lake Erie. Previous constraints on grid size that were limiting model improvements are to a large degree overcome with the present facility.

Applications of the Great Lakes spill model, originally designed to achieve hour-by-hour predictions of active spills for the National Weather Service and U.S. Coast Guard, have been extended. Long term prediction of four classes of compounds are now being attempted. These compounds, chlorinated hydrocarbons, oil, heavy metals, and radioactive wastes, all have two undesirable properties. First, they undergo biological concentrations in the food chain. Second, they are toxic. Hence it is vital to understand how these substances move once they are introduced into the Great Lakes.

In order to predict the motion and fate of such toxins, one must know the currents in the Great Lakes. The best way to hindcast or forecast these currents is by numerical modeling. Several existing numerical current models were tested during the development of the Great Lakes spill model.

Once these current models were operational, they were coupled to a water quality model. The water quality model uses the currents computed by the numerical model to keep track of advection, diffusion, decay, settling and resuspension of the toxic substance. Such coupled models have been used to study phosphorus and toxic pesticides. In addition to these compounds, there are many other toxic and radioactive compounds either in or accumulating in Great Lakes sediments (e.g., PCB's, lead, mercury, beryllium, plutonium, etc.). The patterns of these compounds in the sediments can be matched, and their future distributions forecast. Improved hydrodynamical modeling capabilities are incorporated into the applications version as the techniques are developed and verified.

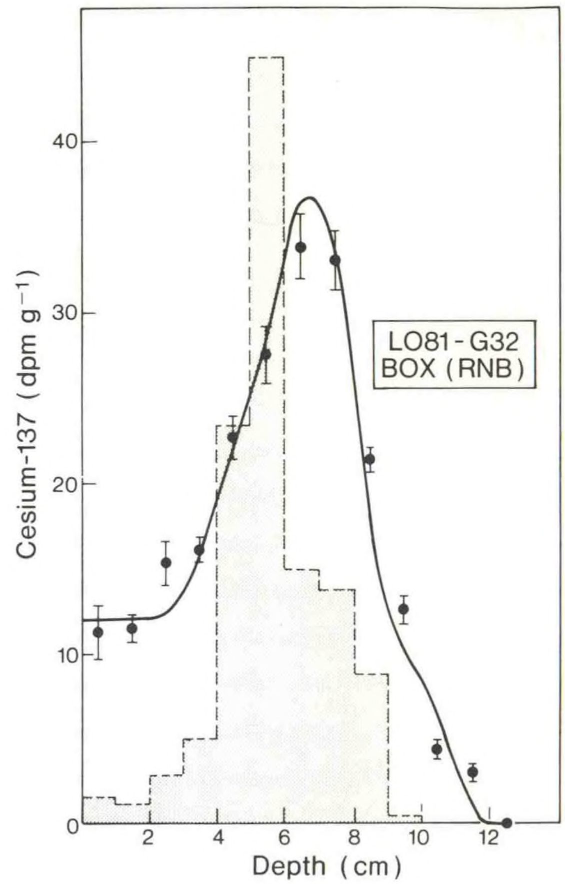
Particle Dynamics

The establishment of particle dynamics research as a specific project is an outgrowth of the recognition that the behavior of nutrients and contaminants is strongly influenced, if not controlled, by the sorptive characteristics and hydrodynamic behavior of particulate matter in the Great Lakes. This project, as initially implemented, focused on the characteristics of the nepheloid layer and suspended material, the phenomenon of lake whiting (calcium carbonate precipitation), and on theoretical and experimental investigations of particle aggregation and disaggregation processes. This last year, the scope of the project was broadened in two major ways: (1) inclusion of sedimentation processes and post-depositional movements of particles and (2) use of radiometric methods to identify and quantify particle transport processes in both water and sediments. New initiatives in these areas include (1) development of radiotracer methods for particle dynamics studies, (2) determination of present and historical records of contaminant deposition in the high sedimentation areas of each of the Great Lakes, (3) investigation of the role of zoobenthos in vertical sediment transport, (4) interactions between sedimentation and diffusive transfer processes for conservative tracers, and (5) development of a field study of the distributions of particulate matter aimed at verification of hydrodynamic models.

Initial studies have emphasized accumulation of lead-210 (natural) and cesium-137 (nuclear fallout) in Great Lakes sediments. By determining the distribution of these isotopes in many sediment cores, it has been shown that lead-210 can be used to date sediments and intersedimentation rates with precision and, in combination with measurements of sediment contaminant distributions, has provided contaminant deposition rates. Such information is important both for development of mass balances and for models describing the fate of contaminants in lakes. Cesium-137 measurements have revealed strong sediment focusing effects in the lakes. Materials deposited uniformly on the lake surface eventually end up concentrated in selected areas on the bottom. The radionuclide has also demonstrated the importance of the effect of sediment mixing by bottom-dwelling organisms on contaminant distributions. The rapid mixing of sediments from the surface down to as far as 15 centimeters prevents contaminated materials from undergoing complete burial.

Cesium-137 has been especially valuable in estimating the extent to which mixing prolongs the contact of contaminants with overlying water. The vertical distribution of cesium-137 is shown for a sediment core obtained from Lake Ontario as part of the high sedimentation study. The shaded histogram shows the profile expected if the cesium-137 (which has a 30-year half-life) deposited on the lake surface were instantly transferred to sediments and there were no sediment mixing. Because the residence time of cesium-137 in the lakes is known to be short (approximately 1 year), the discrepancy is probably due to mixing. The solid continuous line

Vertical distribution of cesium-137. The shaded histogram shows distribution with no mixing. The solid continuous line shows distribution from model calculations assuming steady-state mixing.



shown is the result of a model calculation that assumes steady-state mixing to a depth of several centimeters. Additional studies have confirmed that the radiometrically determined mixing depth corresponds to the zone occupied by most zoobenthic organisms. As a result of this mixing process, contaminant levels in surface sediments are nearly an order of magnitude higher at the present time than if sediment mixing were absent. Radiometric studies have thus shown the importance of this process and the necessity of its inclusion as a submodel in any ecosystems nutrient or contaminant model.

SPECIAL PROJECTS

The work of the Special Projects Group is centered on environmental systems studies and applied modeling. The objectives of this work are (1) to predict the effects on the Great Lakes ecosystem of management alternatives and man-induced changes, (2) to develop and apply systems analysis methods, such as optimization analysis and risk assessment, to help solve water resource problems, (3) to develop predictive models for practical application in assessing management alternatives, and (4) to develop information to minimize costs and risks in pollution management.

The environmental systems studies and applied modeling research are holistic in scope; i.e., they attempt to take the big picture approach. As such, the focus is on long term rather than short term ecological effects. It is also integrative or synthesis oriented; research from a variety of disciplines (GLERL as well as other agency and academic research) is interpreted for practical considerations. A by-product of the work is additional coordination between GLERL staff and scientists and engineers from other organizations.

The work in the Special Projects Group has evolved from previous years. Research emphasis is switching from the study of nutrient pollution to toxic substance pollution. In particular, long term water quality models used in real decision-making situations to calculate average conditions in the lakes as a function of management strategies are being applied to the toxic substances problem. Such models have led to more cost-effective phosphorus management, and promise to be effective in helping to derive cost-effective toxic substance management policies. This is not to say that nutrient enrichment problems, such as pollution from land runoff, will no longer be considered, but rather that some of the technology developed to deal with eutrophication is now being used in dealing with toxics.

Additional emphasis is also being placed on water quantity studies. The Great Lakes are an immense and unique freshwater resource, the value of which is increasing as water shortages in other parts of the nation (and the world in general) become more acute. However, the worth of this water is directly related to its quality. Therefore, attention is being focused on the relationship between water quantity and quality, and how the value of the Great Lakes system can be maximized.

Nonpoint Source Pollution

While remarkable progress has been made during the last decade in cleaning up discharges from point sources, such as industries and municipal sewage treatment plants, more than half of the pollutants entering our nation's waters are from diffuse or nonpoint sources. Runoff from land, both agricultural and urban, is an important nonpoint pollution source. Alleviating nonpoint pollution inputs will be a major challenge of the future.

Land runoff. Runoff from certain agricultural land areas constitutes an important source of nonpoint pollution.

GLERL scientists contributed to nonpoint pollution control in a number of ways. Working with the Great Lakes Basin Commission, they developed a nonpoint source pollution model for use by the U.S. Environmental Protection Agency and the U.S Soil Conservation Service. The model, termed WATERSHED, is a technique for determining the most cost-effective pollution control strategy within a river basin. Trade-offs between cost and effectiveness of both point and nonpoint pollution sources are considered in the model. A user's handbook was developed to promote wide application of the technique, which should help reduce costs while cleaning up coastal and inland waters. GLERL scientists are also working on other predictive models that refine hydrologic and water chemistry components. Such models promise to provide further resolution of nonpoint source pollution and should lead to even better strategies to help protect our invaluable water resources.

Water Management Cost-Effectiveness

As part of an ongoing program to simulate and evaluate long term phosphorus dynamics in the Great Lakes, the cost-effectiveness of phosphorus control strategies was evaluated. The primary objective of the evaluation was to calculate the least costly phosphorus control program capable of achieving water quality objectives in the Great Lakes. This entailed identifying the most economical mix of point and nonpoint source controls to meet objectives and ranking of the various control options according to their cost-effectiveness.

The major conclusion of the study was that 80 percent of the objectives could be achieved for 20 percent of the total cost.

Toxic Substance Budget Modeling

Preliminary work on simulating long term toxic substance dynamics in the Great Lakes has focused on radionuclides. These contaminants entered the Great Lakes system in large quantities during the late 1950's and early 1970's as a result of nuclear weapons testing in the atmosphere. Because a substantial data base exists on the levels of several radionuclides in the water, the sediments, and the food chain, they are in an ideal analog for the study of other contaminants. To date, general models to simulate dynamics of cesium-137, plutonium-239, and strontium-90 have been developed. In the future, these models will be applied to other toxic substances, such as PCB and DDT.

Water Quantity

Among GLERL's water quantity research, a study of consumptive uses, done in cooperation with Canadian scientists as part of a major international IJC study, was especially important. Estimates were made of the amount of Great Lakes water now consumed (withdrawn but not returned to the lakes) and the amount likely to be consumed in the future. The results indicated that consumptive uses should increase from the current rate of 4900 cubic feet per second to anywhere from three to seven and one-half times higher by the year 2035 and depend upon the industrial processes assumed. Such future consumptive use could have a significant effect on lake levels. Lower lake levels economically benefit some coastal zone interests, but negatively affect power interests. The major consumers of the water are expected to be electric power generation facilities, manufacturers, and municipalities. Further research will refine water withdrawal estimates and consider additional growth alternatives that affect use rates. In addition, the overall effect on the ecosystem of water withdrawal will be considered.

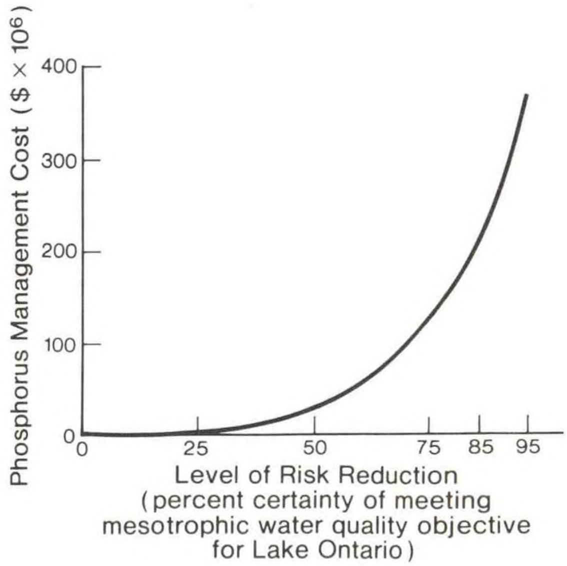
Great Lakes Environmental Planning Study

Scientific information was developed and applied by GLERL staff to support the Great Lakes Environmental Planning Study, part of a systems planning process of the Great Lakes Basin Commission. The study established alternatives for using and protecting the lakes, the costs and expected effects of the alternatives, and the need to balance these costs and effects. Recent contributions include technical reports on (1) phosphorus bioavailability of pollutant inputs and its impact on management, (2) risk assessment as applied to Great Lakes water quality management, (3) ecological factors in Great Lakes water quality management, (4) hazardous spill modeling, (5) a Great Lakes environmental atlas, and (6) a chloride budget for the Great Lakes. These and previous Great Lakes Environmental Planning Study contributions have had an important effect on the planning and policy throughout the Great Lakes Region.

Risk Assessment/Assimilative Capacity

Risk assessment techniques have been under investigation to explore possible applications to water quality management. The term risk assessment represents diverse analyses of hazard and probability aspects of various public risks. As a result of this effort, a water quality risk assessment framework was developed with the methodological components of risk identification, estimation, and evaluation. Risk estimation involves quantifying, to the extent possible, the key uncertainties of water quality management: the predicted water quality response to pollutant loading and the "best" water quality standard.

Risk evaluation is the final step in ascertaining an acceptable level of risk. This involves designating management strategies and the associated costs of a program to achieve the water quality objective with specific levels of certainty. A plot of water quality risk reduction versus cost for phosphorus management in Lake Ontario indicates the increasing cost of meeting the phosphorus water quality objective with greater certainty. The



Cost versus level of risk reduction.

cost of risk reduction must then be evaluated against the severity of the water quality hazard to human health and/or the environment.

Assimilative capacity refers to the ability of lakes and marine waters to absorb wastes without suffering unacceptable environmental degradation. For example, recent GLERL research indicates that Great Lakes sediments serve as a burial ground for many pollutants, particularly in the deep basins where much of the lakes' particulate material eventually ends up. The long term significance of pollutant accumulations in these deep depositional basins is a subject for further research. Thus, the goal here is to balance acceptable risks with acceptable costs. As discussed above, there is a level of pollution management beyond which adverse economic and political effects become overriding.

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 principle GLERL activity is maintenance of an advisory service as a means of providing scientific information in a form compatible with user needs.

This past year, as part of that service, GLERL provided 2100 research products in response to nearly 1400 documented requests. Of these, 48 percent came from institutions of higher learning and State governments, 38 percent from non-government institutions, and the remainder from Federal Government agencies and private citizens. 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.

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, 12 draft environmental impact statements were reviewed by GLERL.

Not all potential users know of GLERL and the range of services and products available, so 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. In one of the more unusual ways of informing the public of GLERL activities, 275 visitors received information on GLERL operations from the crew of the GLERL research vessel *Shenehon* at its ports-of-call during the past year.

Publications Unit

Publications are a major GLERL product and a critical part of our efforts 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, proofing, and procurement of graphics. Editing, typing, and proofing of manuscripts are provided on an inhouse basis, 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 inhouse reports. During the last fiscal year, 45 manuscripts were processed in the GLERL publications section.

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.

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 our research product is used; in addition, we obtain information on requirements for environmental information to support planning and management activities. This user need information is helpful in shaping future GLERL research programs.

International Joint Commission

GLERL staff members actively participate in a wide variety of the activities of the IJC. Both committee and subcommittee work is involved, including participation in activities of the Aquatic Ecosystem Objectives Committee of the Science Advisory Board. Specific ecological objectives, including one regarding microbiology, were developed this year. Also included is participation in the International Great Lakes Diversions and Consumptive Use Reference Working Committee. This committee has provided information to the IJC relevant to water supply and the Great Lakes Regulation Plan. In related areas, GLERL holds membership on the Levels and Flows Advisory Board and the Technical Information Network Board. GLERL staff members have provided considerable input to studies leading to the formation of the International Great Lakes Technical Information Data Board. In order to support the task of developing phosphorus waste load allocations for the Great Lakes, senior GLERL scientists have supplied information to the Phosphorus Management Strategies Task Force. Mathematical models were used to determine the amount of United States and Canadian phosphorus loadings to Lake Erie transported to, and affecting, Lake Ontario.

International Association for Great Lakes Research

Members of GLERL actively participate in activities of the International Association for Great Lakes Research. This past year, a senior GLERL scientist was appointed Editor of the Journal of Great Lakes Research. Another serves as an Associate Editor. GLERL scientists also hold positions on the Board of Directors and the Awards Committee.

Great Lakes Basin Commission

Due to a lack of funding, the Great Lakes Basin Commission closed on September 30, 1981. During FY81, GLERL staff were involved in the Great Lakes Basin Commission as Alternate Department of Commerce Commissioners and as members of the Great Lakes Basin Plan Committee, the Priorities Committee, the Coastal Zone Management Committee, the Standing Committee on Research and Development, the Long Range Planning Committee, and the Great Lakes Environmental Planning Study.

The Great Lakes Basin Plan Committee had responsibility for developing an approach to identify and coordinate water and related structural and non-structural near and midterm programs designed to enhance the economic, environmental, and societal aspects of the Great Lakes Basin. The Priorities Committee developed guidelines and criteria for establishing priorities of the Federal or federally-supported Great Lakes Basin water resource initiatives for consideration by the National Water Resources Council. The Coastal Zone Management Committee coordinated, exchanged, and developed information pertinent to the Coastal Zone Management activities of the Great Lakes States. The Standing Committee on Research and Development assisted the Priorities Committee and Great Lakes Basin Plan Committee activities and developed improved research coordination. The Great Lakes Environmental Planning Study analyzed the cumulative system effects of state pollution control plans on the water quality of the Great Lakes. Owing to the closing of the Great Lakes Basin Commission, GLERL will distribute the many Great Lakes Environmental Planning Study reports. GLERL staff are also serving in the decommissioning of the Great Lakes Basin Commission to insure that the information developed by that agency over the years is maintained.

Regional Response Team for Spills of Oil and Hazardous Substances

GLERL provides the Department of Commerce members to the Great Lakes Regional Response Team, chaired by the U.S. Coast Guard. The purpose of the team is to facilitate cleanup of oil spills and other hazardous substances in the Great Lakes and their connecting channels. In addition to participating in committee activities, GLERL continues to develop and refine tools, such as the oil spill model, that are used by members of this group.

Great Lakes Experiment Team—Coastal Zone Color Scanner

GLERL staff members, including the crew of the *Shenehon*, cooperated with scientists from the National Aeronautics and Space Administration to conduct a region-wide evaluation of a coastal zone color scanner for remote sensing of a variety of water quality variables. The data were analyzed under contract with the University of Michigan and the results of that analysis were reported to NOAA. A handbook for collecting and analyzing samples from this program was also produced.

Joint United States-Canadian Ice Information Working Group

A GLERL staff member 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.

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 with a charge to coordinate tributary stream inflow to the Great Lakes system, to coordinate studies of flow in the connecting channels and the St. Lawrence River, and to establish procedures for updating and disseminating river flow data.

Winter Navigation Program

In the past, GLERL has worked in support of the U.S. Army Corps of Engineers in a multiagency program to examine the feasibility of extending the navigation season in the Great Lakes. Because a large portion of the demonstration program has been completed, much of GLERL's involvement has ended; however, GLERL staff continue to participate in an ad hoc capacity to advise the Corps on environmental studies that should be conducted prior to operational implementation of winter navigation extension.

International Field Year for the Great Lakes (IFYGL)

The technical work of this multiagency, joint United States-Canadian program is complete. The book *IFYGL — The International Field Year for the Great Lakes* is currently being prepared for printing. The publication summarizes and synthesizes the major scientific achievements resulting from analytical and numerical simulations of the dynamical events recorded in the IFYGL data bases and published separately in 454 United States and Canadian articles and reports. Thirteen chapters (plus appendices), dealing with subjects covering the meteorology, hydrology, limnology, and biology-chemistry of Lake Ontario, are included.

Lake Erie Wastewater Management Study

The Lake Erie Wastewater Management Study is a multiyear U.S. Army Corps of Engineers program to design and develop a demonstration wastewater management program for the rehabilitation and environmental repair of Lake Erie. GLERL staff participated on the Advisory Group that reviewed study programs and recommendations. The final report is currently being written, with GLERL staff acting in an ad hoc advisory capacity.

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, with a total space of about 23,900 square feet including offices and support facilities, and in a 14,000-square-foot warehouse and dock facility in 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.

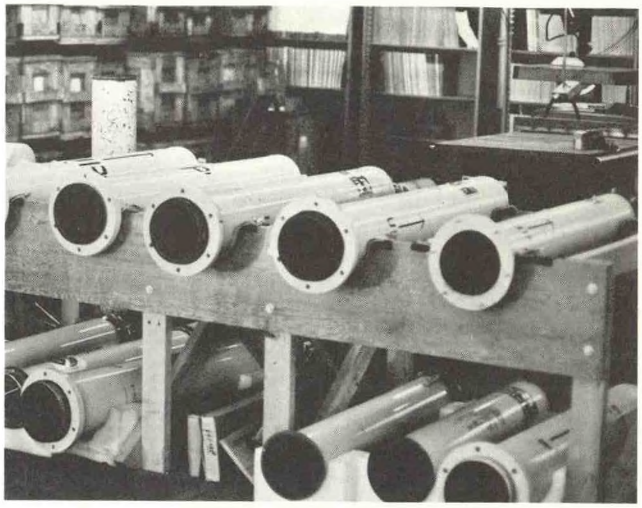
This past year the primary field activity of marine instrumentation laboratory personnel has been deployment of the Lake Erie coastal boundary layer system and the current monitor and data acquisition system in the St. Clair River. Both of these are now successfully collecting meaningful data monitored in real time. The Lake Erie coastal boundary layer system provides wind, temperature, and wave data from a tower and six buoys 4-5 miles offshore of North Springfield, Pennsylvania. A data summary is produced each half hour from the Hewlett-Packard computer at GLERL.

Deployment of the two electromagnetic current meters in the St. Clair River has been completed, and the instruments continually transmit data to recorders onshore. Interrogation by telephone from a remote terminal at GLERL is also possible. Communication with both the recorder and the current meter is thus available, allowing changes in the data gathering mode and entry of remarks from the remote terminal.

Completion of the construction of a flow tank was crucial for the successful testing and debugging of the Marsh McBirney ARC 585 current meters used in the St. Clair River study. The tank, designed and built by marine instrumentation laboratory personnel and an outside contractor, met all expectations and provided linear flow up to 4.5 feet per second.

Other activities completed this past year include the design and construction of a triple sediment corer, a hydraulic core extractor, and a variety of instrumentation for the chemistry and biology laboratories.

Technicians at the laboratory are continuing to maintain our inventory of vector-averaging current meters and acoustical releases. Vector-averaging current meters have been loaned to the Pacific Marine Environmental Laboratory and North Carolina State University. Engineers at the marine instrumentation laboratory have cooperated with the University of Michigan and Woods Hole Oceanographic Institution on research pertaining to mooring and current meter servicing.



.Current meter casings on servicing rack at the marine instrumentation laboratory.

Chemistry Laboratory

There are two major types of compounds analyzed by GLERL's chemistry laboratory: trace synthetic organic materials and nutrients. The synthetic organics, primarily polynuclear aromatic hydrocarbons, are extracted from various ecological matrices by Soxhlet extraction and cleaned on Sephadex and silica. Separation and analysis are performed on a glass capillary Hewlett-Packard gas chromatograph and on our recently acquired Waters liquid chromatograph equipped with ultraviolet and fluorescent detectors. Yields are calculated by recovery of carbon-14-labeled spikes introduced into the original sample matrix.

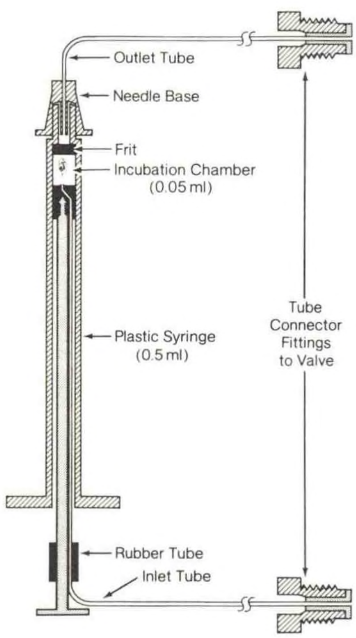
The uptake and release rates of selected polynuclear aromatic hydrocarbons by benthic organisms is being followed through carbon-14-labeled-compound metabolism. Compounds are extracted, cleaned on thin layer or high performance liquid chromatography, and counted by liquid scintillation.

The nutrient program has concentrated on the measurement of recycling rates and on the characterization of forms of phosphorus in lake waters. Speciation of phosphorus forms is needed to understand and predict chemical and biological cycling mechanisms in the lakes. We have developed new approaches to the fractionation and characterization of organic and inorganic dissolved phosphorus forms in lake and river water. Liquid chromatographic methods have been designed to fractionate dissolved compounds directly into chemically distinct groups. This fractionation scheme is being interfaced with specific detection systems for phosphorus (organic and inorganic), ultraviolet-absorbing organic material, and major metals to examine the incorporation or association of phosphorus with other dissolved components in the water.

Biology Laboratory

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

Continuous nutrient release rates by individual zooplankton are measured with a flow-through incubation cell in conjunction with high performance liquid chromatographic plumbing and a modified Technicon AutoAnalyzer.



Schematic of incubation flow cell. This is interfaced with high performance liquid chromatographic components to measure the magnitude and kinetics of nutrient regeneration by individual zooplankton.

Ice Laboratory

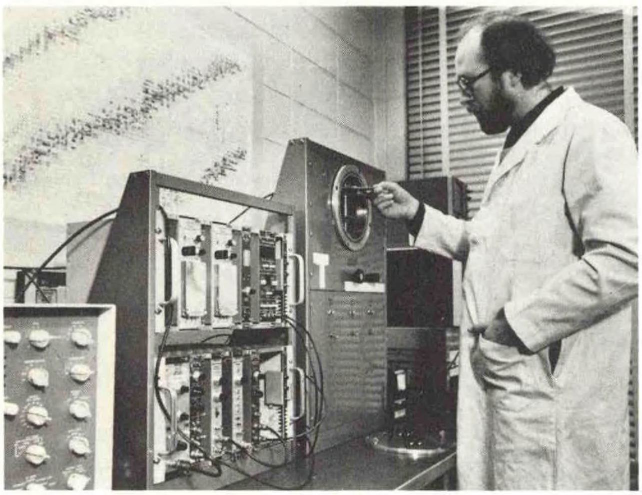
The ice laboratory makes it possible to extend the winter measurement season and to expand opportunities for measurements of ice characteristics. The facility is composed of a work room and an ice storage room. The work room, held at -7.0°C, can be used to calibrate instrumentation for the ice research program in an environment similar to that encountered in the field, as well as to conduct experiments on natural ice harvested in previous field seasons. 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 for the storage of natural ice samples. The facility also provides low temperature storage for a limited number of field samples from the chemistry-biology program and serves as a calibration room for testing a variety of instruments for the marine instrumentation laboratory, including current meters.

Particle Dynamics Laboratory

Natural and artificially produced radionuclides introduced into the Great Lakes serve as excellent model contaminants and process indicators. The particle dynamics laboratory provides the capability for detection and measurement of very low levels of many such radioactive substances present in water, sediment, and biota. The laboratory was established this past year 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 semtocuries), 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. An extensive capability now exists 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. The laboratory has recently obtained a major new system: a high volume, high resolution, well-shielded lithium-drifted germanium detector coupled to a state-of-the-art multichannel analyzer with computer interface capability. The system is designed for simultaneous determination of many radioisotopes, including beryllium-7, potassium-40, cesium-137, and other fallout radionuclides. The system is also used for quantitative determination of stable element concentrations via neutron activation analysis.



Scientist inserting sediment sample into alpha spectrometer at the particle dynamics laboratory.

R/V *Shenehon*

The primary platform used in support of open lake field investigations is the *Shenehon*. 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 1630-pound lifting capacity at 21-foot extension can be used for deployment and retrieval of heavy instrument moorings. Winches handle hydrographic wire and multiconductor cable (200 meters) 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 and an autopilot provide the capability and precision for the ship to return to an exact site in the lakes for equipment retrieval. Extensive work was accomplished during the winter lay-up to improve accommodations aboard the boat. Principal improvements were installation of a modern galley and a new shower and head.

During FY 1981 the *Shenehon* was based at the U.S. Army Corps of Engineers' boat yard at Grand Haven, Michigan. Warehouse facilities and space for a mobile shore based laboratory were also provided at that location. The range of ship operations in FY 1981 included Lakes Michigan and Erie.

Biology experiments supported by the *Shenehon* during the past year included benthic, planktonic, and bacterial studies aimed at nutrient cycling in the aquatic environment and long term effects of pollutant inputs. Benthic organisms were collected from 40 stations in southern Lake Michigan during three cruises to determine long term changes in abundance and composition of the organism populations. The history of such collections at the same sites dates back 50 years. Benthic organisms were also collected at the mouth of the Grand River to support an experiment to determine if benthic invertebrates release significant quantities of phosphorus to the water. The amount of metabolic phosphorus release as compared to release through mechanical mixing of sediments will be quantified in this study. In another nutrient investigation, zooplankton collected from Lake Michigan off Grand Haven are being used to determine release patterns of phosphorus and nitrogen by zooplankters and to estimate the significance of zooplankton in nutrient regeneration within the Great Lakes. 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 objective is to be able to predict selection and ingestion of algae in mixed assemblages of *Diaptomus* and to fit this into the broader nutrient cycling simulations. In an ongoing cooperative program with the University of Michigan, the vessel was used to sample an area offshore from Grand Haven during different seasons to support a study of bacterial distribution and microbial transformations of nutrients.

In one of the lake chemistry investigations, colloids were extracted from Lake Michigan water and analyzed immediately after being collected from the *Shenehon* to determine the amounts of inorganic and organic phosphorus associated with colloidal material in the water. Lack of information about composition and stability of dissolved phosphorus compounds is a major impediment to understanding phosphorus cycling in aquatic systems.

Investigation of the dynamics of materials movement and characteristics of the nepheloid layer continued in Lake Michigan. Five sets of sediment trap moorings that had remained in the open lake during winter were recovered by the *Shenehon* in spring; one was redeployed. Bottom sediment samples were also taken to aid in this determination of amount and type of suspended material settling through the water column to the lake bottom.

As a part of physical characteristics studies, measurements were made and southern Lake Michigan water samples collected from the *Shenehon* for use in evaluating a mathematical model that is being developed in a cooperative GLERL-University of Michigan project. This model will simulate aggregation and disaggregation of particulate material when the material is subjected to varying shear stresses. Effect of varying shear stresses related to water depth on particle aggregation can have a significant effect on forecasts of sediment transport, erosion, and deposition.

PUBLICATIONS

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

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

Bolsenga, S. J. 1981. Radiation transmittance through lake ice in the 400-700 nm range. *J. Glaciol.* 27:57-66.

Bolsenga, S. J. 1981. Spectral reflectances of freshwater ice and snow from 340 through 1100 nm. Ph.D. dissertation, the University of Michigan, Ann Arbor. University Microfilms.

Chambers, R. L.*, and Eadie, B. J. 1981. Nepheloid and suspended particulate matter in southeastern Lake Michigan. *Sedimentology* 28:439-447.

Chapra, S. C. 1980. Application of phosphorus loading models to river-run lakes and other incompletely mixed systems. In *Restoration of lakes and inland waters*, Report No. EPA 440/5-81-010, pp. 329-334. Washington, D.C.: U.S. Environmental Protection Agency.

Chapra, S. C., and Dobson, H. F. H.† 1981. Quantification of the lake trophic typologies of Naumann (surface quality) and Thienemann (oxygen) with special reference to the Great Lakes. *J. Great Lakes Res.* 7:182-193.

Croley, T. E., II. 1980. *Hydrologic and hydraulic calculation in BASIC for small computers.* Iowa City, Iowa: The University of Iowa, Iowa Institute of Hydraulic Research.

Croley, T. E., II. 1980. *Synthetic-hydrograph computations on small programmable calculators.* Iowa City, Iowa: The University of Iowa, Iowa Institute of Hydraulic Research.

Croley, T. E., II, and Hunt, B.† 1981. Multiple-valued and non-convergent solutions in kinematic cascade models. *J. Hydrol.* 49:121-138.

Croley, T. E., II, Giaquinta, A. R.†, and Woodhouse, R. A.† 1981. River thermal standard costs in the upper midwest. *J. Energy Div.*, ASCE 107:65-77.

*No longer affiliated with this laboratory.
†Not affiliated with this laboratory.

Derecki, J. A., and Kelley, R. N. 1981. *Improved St. Clair River dynamic flow models and comparison analysis.* NOAA Technical Memorandum ERL GLERL-34.

Donovan, M.†, Job, C. A.†, and Sonzogni, W. C. 1981. The Milwaukee pollution case—Implications for water resources planning. *Water Resour. Bull.* 17:23-28.

Eadie, B. J. 1981. *An equilibrium model for the partitioning of synthetic organic compounds: Formulation and calibration.* NOAA Technical Memorandum ERL GLERL-35.

Gardner, W. S., and Eadie, B. J. 1980. Chemical factors controlling phosphorus cycling in lakes. In *Nutrient cycling in the Great Lakes: A summarization of factors regulating the cycling of phosphorus*, ed. D. Scavia and R. A. Moll, pp. 13-34. Great Lakes Research Division Special Report No. 83.

Gardner, W. S., Eadie, B. J., and Miller, W. H.† 1980. Microtechnique to remove particles from high performance liquid chromatographic samples. *J. Liq. Chromatogr.* 3:1585-1592.

Gardner, W. S., and Miller, W. H.† 1980. Reverse-phase liquid chromatographic analysis of amino acids after reaction with o-phthalaldehyde. *Anal. Biochem.* 101:61-65.

Gardner, W. S., Miller, W. H.†, and Imlay, M. J.† 1981. Free amino acids in mantle tissues of the bivalve *Amblema plecata:* Possible relation to environmental stress. *Bull. Environ. Contam. Toxicol.* 26:157-162.

Gardner, W. S., and Miller, W. H.† 1981. Intracellular composition and net release rates of free amino acids in *Daphnia magna. Can. J. Fish. Aquat. Sci.* 38:157-162.

Gardner, W. S., and Scavia, D. 1981. Kinetic examination of nitrogen release by zooplankters. *Limnol. Oceanogr.* 26:801-810.

Gardner, W. S., Nalepa, T. F., Quigley, M. A., and Malczyk, J. M. 1981. Release of phosphorus by certain benthic invertebrates. *Can. J. Fish. Aquat. Sci.* 38:978-981.

Gaskill, D. W.* 1981. *Homogeneity analysis of seasonal mean temperature series at 25 stations around the Great Lakes.* NOAA Data Report ERL GLERL-18.

Giaquinta, A. R.†, and Croley, T. E., II. 1981. Impact of thermal standards on power plant water consumption. *Water Resour. Bull.* 17:423-430.

†Not affiliated with this laboratory.
*No longer affiliated with this laboratory.

Great Lakes Environmental Research Laboratory. 1980. *Annual report for the Great Lakes Environmental Research Laboratory*. Ann Arbor: Great Lakes Environmental Research Laboratory.

Great Lakes Environmental Research Laboratory. 1981. *Technical plan for the Great Lakes Environmental Research Laboratory*. Ann Arbor: Great Lakes Environmental Research Laboratory.

Great Lakes Environmental Research Laboratory and the University of Michigan. 1981. *First annual progress report to the Office of Marine Pollution Assessment: The cycling of toxic organic substances in the Great Lakes ecosystem*. Ann Arbor: Great Lakes Environmental Research Laboratory.

Greene, G. M. 1981. *Simulation of ice-cover growth and decay in one dimension on the upper St. Lawrence River*. NOAA Technical Memorandum ERL GLERL-36.

Greene, G. M. 1981. Simulation of ice-cover growth and thermal decay on the upper St. Lawrence River. Ph.D. dissertation, the University of Michigan, Ann Arbor. University Microfilms.

Heidtke, T. M.†, Sonzogni, W. C., and Botts, L.† 1981. *Great lakes environmental planning study: Summary report*. Great Lakes Environmental Planning Study Report.

Landrum, P. F., and Giesy, J. P.† 1981. Anomalous breakthrough of benzo(a)pyrene during concentration with XAD-4 resin from aqueous solutions. In *Advances in the identification and analysis of organic pollutants in water*, ed. L. H. Keith, pp. 345-355. Ann Arbor: Ann Arbor Science.

Landrum, P. F., and Crosby, D. G.† 1981. Comparison of the disposition of several nitrogen-containing compounds in the sea urchin and other marine invertebrates. *Xenobiotica* 11:351-361.

Landrum, P. F., and Crosby, D. G.† 1981. The disposition of *p*-nitroanisole by the sea urchin, *Strongylocentrotus purpuratus*. I. Kinetics. *Ecotoxicol. Environ. Safety* 5:225-239.

Landrum, P. F., and Crosby, D. G.† 1981. The disposition of *p*-nitroanisole by the sea urchin, *Strongylocentrotus purpuratus*. II. Biotransformation and bioconcentration. *Ecotoxicol. Environ. Safety* 5:240-254.

Leshkevich, G. A. 1981. *Categorization of northern Green Bay ice cover using LANDSAT-1 digital data—A case study*. NOAA Technical Memorandum ERL GLERL-33.

Liu, P. C., and Ross, D. B.† 1980. Airborne measurements of wave growth for stable and unstable atmospheres in Lake Michigan. *J. Phys. Oceanogr.* 10:1842-1853.

McCormick, M. J., and Scavia, D. 1981. Calculation of vertical profiles of lake-averaged temperature and diffusivity in Lakes Ontario and Washington. *Water Resour. Res.* 17:305-310.

Monteith, T. J.†, and Sonzogni, W. C. 1981. *Variations in U.S. Great Lakes tributary flows and loadings*. Great Lakes Environmental Planning Study Report.

Nalepa, T. F., White, D. S.†, Pringle, C. M.†, and Quigley, M. A. 1980. The biological component of phosphorus exchange and cycling in lake sediments. In *Nutrient cycling in the Great Lakes: A summarization of factors regulating the cycling of phosphorus*, ed. D. Scavia and R. A. Moll, pp. 93-109. Great Lakes Research Division Special Report No. 83.

Nalepa, T. F., and Quigley, M. A. 1981. *The macro- and meiobenthos of southeastern Lake Michigan near the mouth of the Grand River, 1978-79*. NOAA Data Report ERL GLERL-19.

Nalepa, T. F., and Robertson, A.* 1981. Screen mesh size affects estimates of macro- and meiobenthos abundance and biomass in the Great Lakes. *Can. J. Fish. Aquat. Sci.* 38:1027-1034.

Nalepa, T. F., and Robertson, A.* 1981. Vertical distribution of the zoobenthos in southeastern Lake Michigan with evidence of seasonal variation. *Freshwater Biol.* 11:87-96.

Pinsak, A. P., Hore, R. C.†, and Vallery, D. J.† 1981. Consumptive water use. In *Great Lakes diversions and consumptive uses: Report to the International Joint Commission by the International Great Lakes Diversions and Consumptive Uses Study Board*, Sec. 6, pp. 1-56. Detroit: U.S. Department of the Army, Corps of Engineers.

Preston, C. N.* 1981. *Great Lakes precipitation*, 1854-74. GLERL Open File Report.

Quigley, M. A. 1981. Freshwater macroinvertebrates. *J. Water Pollut. Control Fed.* 53:1015-1027.

Quinn, F. H. 1981. *Equilibrium effects of present Great Lakes Basin consumptive use on lake levels*. GLERL Open File Report.

†Not affiliated with this laboratory.

*No longer affiliated with this laboratory.
†Not affiliated with this laboratory.

Rao, D. B.*, and Schwab, D. J. 1981. A method of objective analysis for currents in a lake with application to Lake Ontario. *J. Phys. Oceanogr.* 11:739-750.

Saylor, J. H., Huang, J. C. K.*, and Reid, R. O.† 1980. Vortex modes in southern Lake Michigan. *J. Phys. Oceanogr.* 10:1814-1823.

Scavia, D. 1980. Conceptual model of phosphorus cycling. In *Nutrient cycling in the Great Lakes: A summarization of factors regulating the cycling of phosphorus*, ed. D. Scavia and R. A. Moll, pp. 119-140. Great Lakes Research Division Special Report No. 83.

Scavia, D., Powers, W. F.†, Canale, R. P.†, and Moody, J. F.* 1981. Comparison of first-order error analysis and Monte Carlo simulation in time-dependent lake eutrophication models. *Water Resour. Res.* 17:1051-1059.

Scavia, D., Canale, R. P.†, Powers, W. F.†, and Moody, J. F.* 1981. Variance estimates for a dynamic eutrophication model of Saginaw Bay, Lake Huron. *Water Resour. Res.* 17:1115-1124.

Scavia, D., and Moll, R. A.†, ed. 1980. *Nutrient cycling in the Great Lakes: A summarization of factors regulating the cycling of phosphorus.* Great Lakes Research Division Special Report No. 83.

Schwab, D. J. 1981. Determination of wind stress from water level fluctuations. Ph.D. dissertation, the University of Michigan, Ann Arbor. University Microfilms.

Schwab, D. J., Shuchman, R. A.†, and Liu, P. C. 1981. Wind wave directions determined from synthetic aperture radar imagery and from a tower in Lake Michigan. *J. Geophys. Res.* 86:2059-2064.

Sonzogni, W. C. 1981. The slow painting of a 'big picture.' *Great Lakes Basin Comm. Commun.* 11:3.

Sonzogni, W. C., and Swain, W. R.† 1980. Perspectives on U.S. Great Lakes chemical toxic substances research. *J. Great Lakes Res.* 6:265-274.

Sonzogni, W. C., Chapra, S. C., Armstrong, D. E.†, and Logan, T. J.† 1981. *Bioavailability of phosphorus inputs to lakes: Significance to management.* Great Lakes Environmental Planning Study Report.

Sonzogni, W. C., Richardson, W.†, Rogers, P. †, and Monteith, T. J.† 1981. *Chloride budget for the Great Lakes: A current assessment.* Great Lakes Environmental Planning Study Report.

Sonzogni, W. C., Robertson, A.*, and Beeton, A. M.† 1981. *The importance of ecological factors in Great Lakes management.* Great Lakes Environmental Planning Study Report.

Sullivan, R. A.†, Boise, M.†, and Sonzogni, W. C. 1981. *Environmental quality maps for the U.S. Great Lakes Basin.* Great Lakes Environmental Planning Study Report.

Sullivan, R. A.†, Heidtke, T. M.†, Hall, J. R.†, and Sonzogni, W. C. 1981. *Potential impact of changes in Great Lakes water quality on fisheries.* Great Lakes Environmental Planning Study Report.

Tarapchak, S. J. 1980. Measurements of phosphate-phosphorus in lake water. In *Nutrient cycling in the Great Lakes: A summarization of factors regulating the cycling of phosphorus,* ed. D. Scavia and R. A. Moll, pp. 1-11. Great Lakes Research Division Special Report No. 83.

Tarapchak, S. J., Slavens, D. R., and Maloney, L. M.* 1981. Abiotic versus biotic uptake of radiophosphorus in lake water. *Can. J. Fish. Aquat. Sci.* 38: 889-895.

Vanderploeg, H. A. 1981. Effect of the algal length/aperture length ratio on Coulter analysis of lake seston. *Can. J. Fish. Aquat. Sci.* 38:912-916.

Vanderploeg, H. A. 1981. Seasonal particle-size selection by *Diaptomus sicilis* in offshore Lake Michigan. *Can. J. Fish. Aquat. Sci.* 38:504-517.

*No longer affiliated with this laboratory.
†Not affiliated with this laboratory.

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*No longer affiliated with this laboratory.

PRESENTATIONS

Bowers, J. A.†, and Vanderploeg, H. A. 1981. Predatory behavior of *Mysis relicta* in Lake Michigan. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Croley, T. E., II. 1981. Ordering distributed parameter computations. Chapman Conference on Spatial Variability in Hydrologic Modeling, July 21-23, 1981, at Colorado State University, Fort Collins, Colorado.

Croley, T. E., II, Carvey, D. G.†, and Robb, J. G.† 1981. Watershed evaluation and research system application. International Symposium on Rainfall-Runoff Modeling, May 18-21, 1981, at Mississippi State University, Mississippi State, Mississippi.

Derecki, J. A. 1980. Operational estimates of Lake Superior evaporation based on IFYGL findings. Fall Meeting of the American Geophysical Union, December 8-12, 1981, San Francisco, California.

Eadie, B. J. 1981. Chemical fluxes in the benthic boundary layer. American Chemical Society Meeting, May 20-22, 1981, Dayton, Ohio.

Gardner, W. S., and Malczyk, J. M. 1980. Micromethod to examine phosphorus composition of lake water and benthic invertebrate release products. Third Midwest Water Chemistry Workshop, December 4-5, 1980, at the University of Michigan, Ann Arbor, Michigan.

Gardner, W. S., and Corbin, A. M. 1981. Chemical characterization and TSK size exclusion fractionation of Lake Michigan dissolved organic matter by liquid chromatography. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Gardner, W. S., and Scavia, D. 1981. Kinetics of nitrogen excretion by Cladocera. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Krezoski, J. R.†, and Robbins, J. A. 1981. Dual radiotracer measurement of zoobenthos-mediated particle and solute transport in lake sediments. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Krezoski, J. R.†, Robbins, J. A., and White, D. S.† 1981. Radiometric determination of the vertical distribution of sediment feeding by *Stylodrilus heringianus*. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Leshkevich, G. A. 1981. Comparison of visual and machine interpretation of northern Green Bay ice cover using LANDSAT-1 data—A case study. Seventh International Symposium on Machine Processing of Remotely Sensed Data, June 23-26, 1981, at Purdue University, West Lafayette, Indiana.

Leshkevich, G. A. 1981. Lake Superior ice cycle, 1978-79. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Leshkevich, G. A. 1981. Lake Superior ice cycle, 1979. Seminar, May 19, 1981, at the National Weather Service Forecast Office, Ann Arbor, Michigan.

Liu, P. C. 1981. On a generalization of the equilibrium range in the spectrum of wind-generated waves. Symposium on Wave Dynamics and Radio Probing of the Ocean, May 13-20, 1981, Miami, Florida.

Meyers, P. A.†, Leenheer, M. J.†, Edwards, S. J.†, and Eadie, B. J. 1981. Organic character of settling sediments in Lake Michigan. American Chemical Society Meeting, May 20-22, 1981, Dayton, Ohio.

Monteith, T. J.†, and Sonzogni, W. C. 1981. Variations in U.S. Great Lakes tributary flow: A 40-year perspective. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Nalepa, T. F., Gardner, W. S., and Quigley, M. A. 1981. Biological release of nutrients by benthic invertebrates. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Pickett, R. L. 1981. A Lake Ontario winter storm. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Pickett, R. L. 1981. Mean circulation of the Great Lakes. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Pinsak, A. P. 1981. Great Lakes system implications in resource management. Ann Arbor Exchange Club Meeting, March 9, 1981, Ann Arbor, Michigan.

Quigley, M. A. 1981. Silica regeneration processes in nearshore southern Lake Michigan. 24th Confer-

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ence on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Quigley, M. A. 1981. Soluble reactive phosphorus-pore water concentrations and release rates from nearshore Lake Michigan sediments. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Quinn, F. H., and Croley, T. E., II. 1981. The role of precipitation climatology in hydrologic design and planning on the Laurentian Great Lakes. Fourth Conference on Hydrometeorology, October 7-9, 1981, Reno, Nevada.

Reckhow, K. H.†, and Chapra, S. C. 1981. Empirical and mechanistic modeling of lake eutrophication. International Water Supply Association Specialized Conference on Eutrophication and Water Supply, October 8, 1981, Vienna, Austria.

Rice, C. P.†, Erstfell, K. M.†, and Eadie, B. J. 1981. The role of surface films in the transfer of organic pollutants at the air-water interface. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Robbins, J. A. 1981. Stratigraphic and kinetic effects of sediment reworking by Great Lakes zoobenthos. Second International Symposium on the Interactions Between Sediments and Fresh Water, June 14-18, 1981, at Queen's University, Kingston, Ontario.

Robertson, A.* 1981. Plenary session on Great Lakes limnology—Lake Ontario. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Saylor, J. H. 1981. Vortex mode oscillations in Great Lakes Basins. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Scavia, D. 1981. Control of nitrogen release by *Daphnia magna* are shown and discussed in relation to food supply. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, Milwaukee, Wisconsin.

Scavia, D. 1981. Factors governing biological dynamics and production in Lake Ontario. Division of Biological Sciences Seminar, September 18, 1981, at the University of Michigan, Ann Arbor, Michigan.

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*No longer affiliated with this laboratory.

Scavia, D. 1981. Uncertainty analysis of a eutrophication model of Saginaw Bay. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Scavia, D., and Gardner, W. S. 1981. Control of nitrogen release rates by food in *D. Magna*. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Schwab, D. J. 1981. Determining wind stress from water levels. Seminar, February 19, 1981, at the University of Michigan, Ann Arbor, Michigan.

Schwab, D. J., and Rao, D. B.* 1981. Free oscillations of the Mediterranean and Adriatic Seas. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Sonzogni, W. C. 1981. Evaluating the importance of nonpoint sources—Advances in the last decade. American Chemical Society Meeting, May 20-22, 1981, Dayton, Ohio.

Sonzogni, W. C. 1981. Meeting water quality goals for the Great Lakes. Second Post-PLUARG Conference, June 10-11, 1981, Racine, Wisconsin.

Sonzogni, W. C., Heidtke, T. M.†, and Monteith, T. J.† 1981. Potential effect of water conservation on wastewater inputs to the Great Lakes. 24th Conference on Great Lakes Research, April 28-30, 1981, at Ohio State University, Columbus, Ohio.

Tarapchak, S. J. 1980. The effects of acid and ammonium molybdate on soluble reactive phosphorus determinations. Third Midwest Water Chemistry Workshop, December 4-5, 1980, at the University of Michigan, Ann Arbor, Michigan.

Tarapchak, S. J. 1981. Comparison of rate constants for phosphorus uptake by Lake Michigan phytoplankton. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Vanderploeg, H. A., and Eadie, B. J. 1981. The significance of calcium carbonate whitings to zooplankton in Lake Michigan. 44th Annual Meeting of the American Society of Limnology and Oceanography, June 15-18, 1981, at the University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

*No longer affiliated with this laboratory.

†Not affiliated with this laboratory.

CONTRACTOR PUBLICATIONS

Brater, E. F. 1981. *Estimating runoff from ungaged drainage basins.* Final report prepared for GLERL by the University of Michigan under Contract No. 03-78-B01-108.

Churchill, J. H. 1981. *Tracking near surface drogues using an acoustic travel time technique in shallow, highly stratified water—Problems and observations.* Woods Hole Oceanographic Institution Report No. WHOI-81-37. Technical report prepared for GLERL by Woods Hole Oceanographic Institution under Contract No. 03-5-022-26.

Lo, T. Y. 1981. A dynamic settling column for measurement of sedimentation of flocculent material under the influence of turbulence. Ph.D. dissertation, the University of Michigan, Ann Arbor. University Microfilms.

Mortimer, C. H. 1980. *Inertial motion and related internal waves in Lake Michigan and Lake Ontario as responses to impulsive wind stress: I. Introduction, descriptive, narrative, and graphical archive of IFYGL data.* Special Report No. 37 prepared for GLERL by the University of Wisconsin-Milwaukee, Center for Great Lakes Studies, under Contract No. NOAA-03-78-B01-21.

Reckhow, K. H. 1980. Techniques for exploring and presenting data applied to lake phosphorus concentration. *Can. J. Fish. Aquat. Sci.* 37:290-294.

Reckhow, K. H. 1981. Modeling lake trophic quality under uncertainty. In *Proceedings, symposium on surface water impoundments*, pp. 393-403. New York: American Society of Civil Engineers.

Rice, C. P., and Frez, W. A. 1981. *Application of capillary chromatography to the study of the cycling of PCB's on suspended particles.* Final report prepared for GLERL by the Great Lakes Research Division, the University of Michigan, under Grant No. NA79RAD00006.

Rumer, R. R., Wake, A., and Chieh, S. H. 1981. *Development of an ice dynamics forecasting model for Lake Erie.* Report prepared for GLERL by the State University of New York at Buffalo, Department of Civil Engineering and Center for Cold Regions Engineering, Science, and Technology, under Contract No. NA80RAC00148.

Rumer, R. R., Jr., Wake, A., Chieh, S. H., and Crissman, R. D. 1981. Development of an ice transport model for Great Lakes application. In *Proceedings, sixth conference on port and ocean engineering under Arctic conditions*, ed. B. Michel, vol. II, pp. 892-900. Quebec: International Association for Hydraulic Research.

CONTRACTS AND GRANTS DURING FY 1981

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. A. Bowers	University of Michigan	Nutrient Cycling
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. F. Kitchell	University of Wisconsin (Madison)	Predator-Prey Models for Great Lakes Fishes
J. T. Lehman	University of Michigan	Formulation of Zooplankton in Lake Ecosystem Models
B. M. Lesht	Argonne National Laboratory	Field Study of Sediment Resuspension
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)	Inertial Motion and Related Internal Waves
C. H. Mortimer	University of Wisconsin (Milwaukee)	Coupling of Physical and Biological Dynamics in Large Lakes
K. H. Reckhow	Duke University	Uncertainty and Risk Management of Toxic Substances in Aquatic Systems
R. R. Rumer	State University of New York (Buffalo)	Ice Transport Forecast Model for Lake Erie
H. T. Shen	Clarkston College	Ice-Cover Effects on Hydraulic Transient Analysis
M. S. Simmons	University of Michigan	Assimilation Rates of Carbon in Great Lakes Phytoplankton