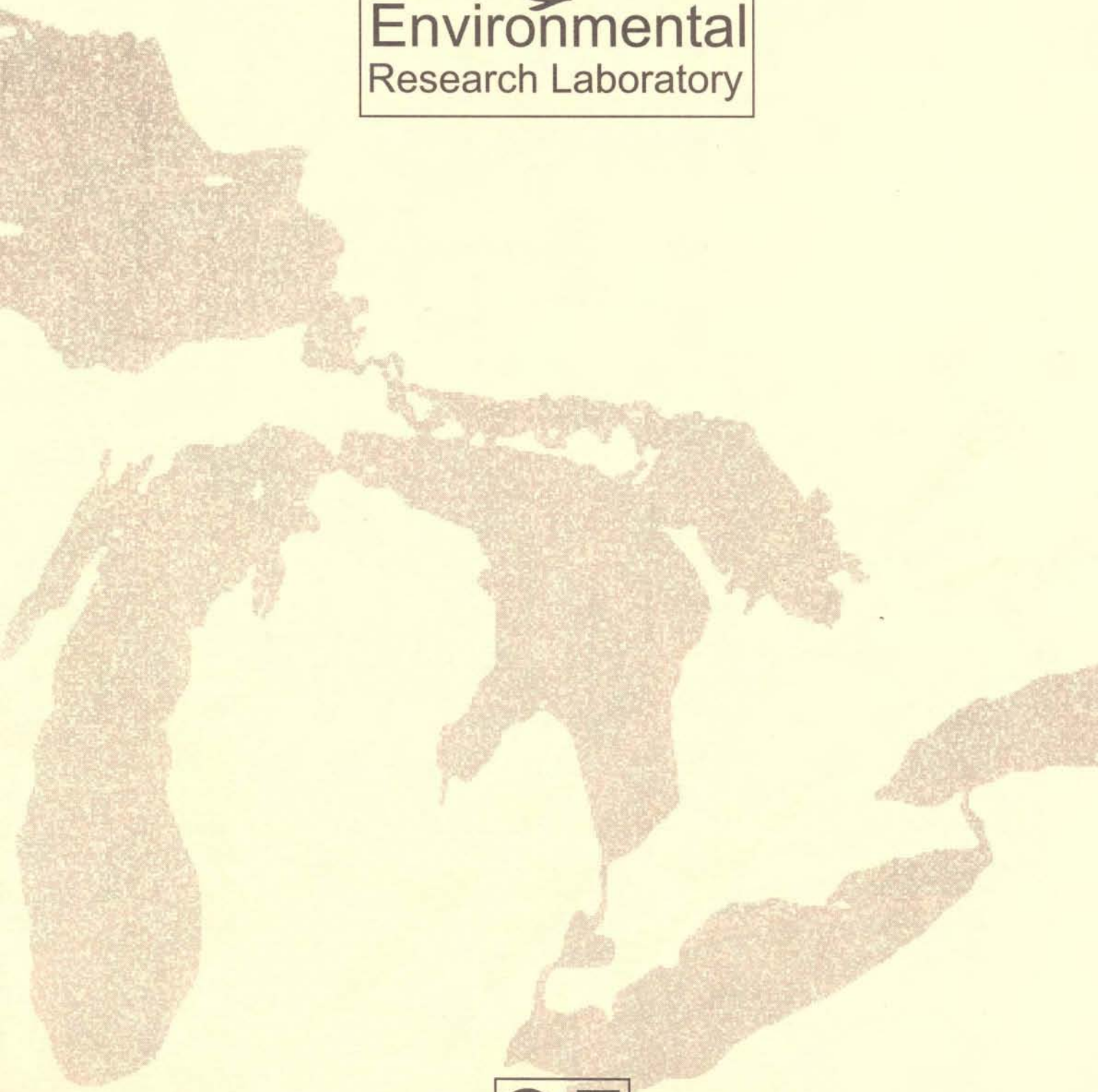
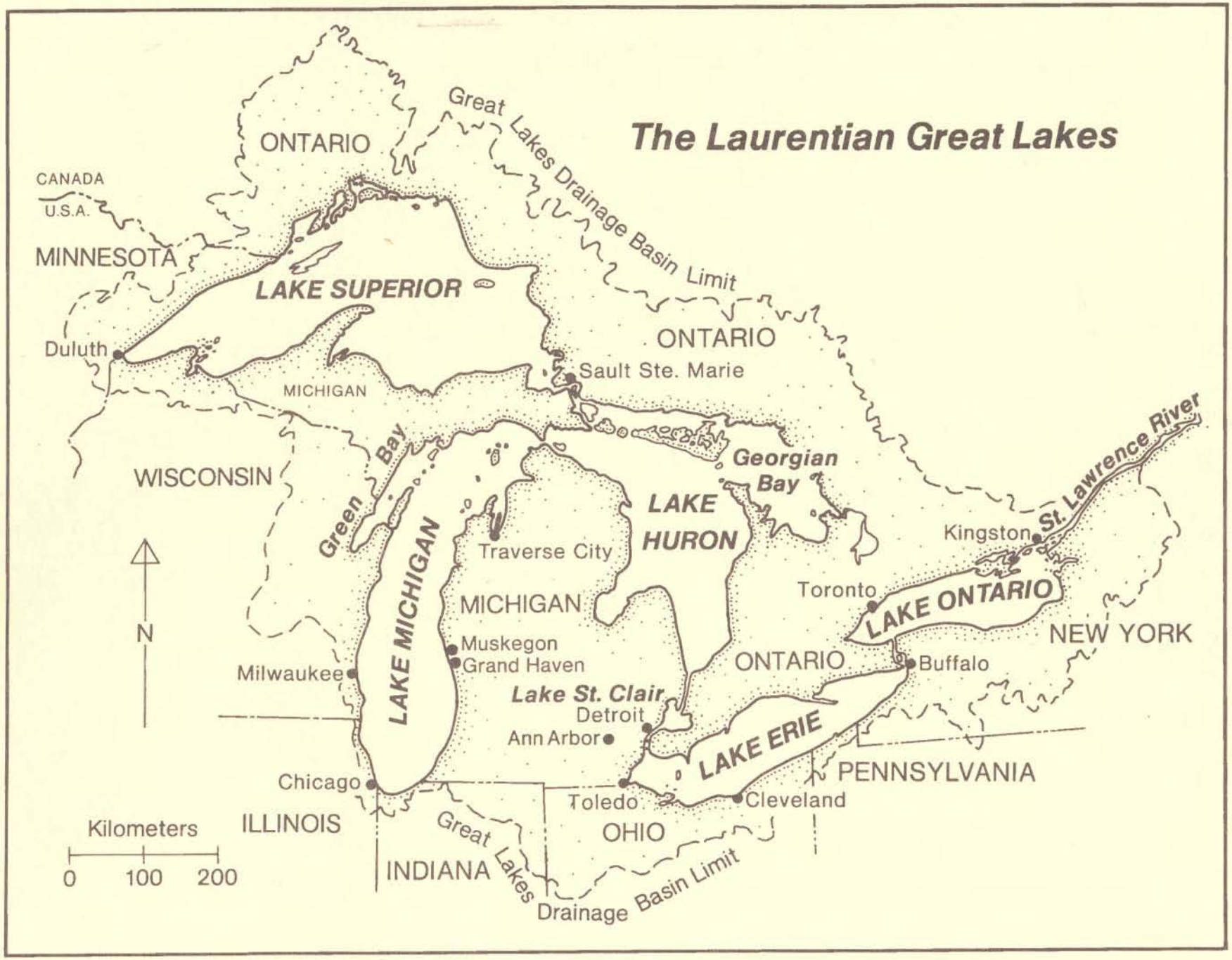
GREAT LAKES Environmental Research Laboratory



95 Yearly Report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Green Bay
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Georgian Bay
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GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY (GLERL)

YEARLY REPORT FY 1995

Director

Alfred M. Beeton

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ACKNOWLEDGEMENTS

Design and electronic production by C.M. Darnell.
This is GLERL Contribution No. 1016

Contents

INTRODUCTION

This report describes GLERL's most significant research accomplishments during fiscal year (FY) 1995. Most projects had many more accomplishments, but because of their routine or interim nature, such as the successful collection of field samples, or completion of sample analyses, they are not listed here.

Projects descriptions, accomplishments, and plans are listed under their primary GLERL research program area and then by their Environmental Research Laboratory (ERL) established Research Task.

GLERL is a center of expertise for the hydrology, physics, ecology, biology, and geochemistry of the Great Lakes and nearshore marine ecosystems, and it provides scientific information, environmental models, and tools used by resource management agencies, the scientific community, the private industrial sector, and private citizens. It is unique from other laboratories and the academic community in its capabilities, both in staff expertise and instrumentation for the study of the physics (circulation) and hydrology (water levels) of the Great Lakes basin. Its staff in geochemistry, ecology, and biology are leading experts on large lake and nearshore marine ecosystems and are leaders in the scientific community.

GLERL scientists conduct research on critical environmental issues affecting the health and function of the aquatic ecosystem, human safety, the shipping and power industries, coastal municipalities, and shoreline property of the Great Lakes and nearshore marine areas. GLERL's research programs support NOAA's mission under the Environmental Assessment and Prediction and the Environmental Stewardship portfolios of the NOAA Strategic Plan.

Research activities are enhanced through the Cooperative Institute for Limnology and Ecosystems Research (CILER). CILER, which is a joint research enterprise of the University of Michigan, Michigan State University, and GLERL, promotes collaborative research between scientists from throughout the Great Lakes basin, addressing a wide variety of research topics. Many of the projects described here involve participation between GLERL staff and CILER Fellows, Visiting Fellows, and other scientific staff.

RESEARCH PROGRAM ORGANIZATION

Aquatic Contaminants
- ERL Research Task GLERL 06 - Aquatic Contaminants

Water Resources Research
- ERL Research Task GLERL 04 - Hydrologic Processes
- ERL Research Task GLERL 05 - Water Resources Forecasting

Circulation Modeling
- ERL Research Task GLERL 01 - Great Lakes Coastal Forecast System
- ERL Research Task GLERL 03 - CoastWatch

Ecosystem Dynamics
- ERL Research Task GLERL 09 - Ecosystem Dynamics Research
- ERL Research Task GLERL 10 - Nonindigenous Species Research
- ERL Research Task GLERL 12 - Episodic Events

Climate Change and Variability
- ERL Research Task GLERL 11 - Climate Variability

Nearshore Processes
- ERL Research Task GLERL 02 - Nearshore Hydrodynamics

Biogeochemistry Research
- ERL Research Task GLERL 07 - NECOP
- ERL Research Task GLERL 08 - Biogeochemistry of Lakes and Coastal Ecosystems

AQUATIC CONTAMINANTS

This research program combines process studies and mathematical modeling focused on toxic organic contaminants to increase our understanding of the dynamics and effects of pollutants in the ecosystem. Contaminants introduced into the ecosystem bind to particles and either remain suspended in the water column (particle-associated contaminants) or settle into the sediment (sediment-associated contaminants). Aquatic bottom-dwelling organisms (benthos) are exposed to certain critical pollutants through their contact with the sediment. These pollutants may then be introduced into the food chain where they ultimately threaten human health as well as the health of the ecosystem. This research program is focused on sediment-associated contaminants and their effects on benthos. This program incorporates one major ERL Research Task Category: GLERL 06– Aquatic Contaminants.

ERL Research Task Category: GLERL 06 - Aquatic Contaminants

Bioaccumulation of Organic Contaminants by *Diporeia* spp.: Kinetics and Factors Affecting Bioavailability

Accumulation of contaminants by benthic organisms may occur several ways: (1) by ingestion of sediment particles, (2) by respiration of the interstitial water, (3) by respiration of the overlying water, (4) by ingestion of freshly deposited food particles, and/or (5) through physical contact with any of the above. Resolving the factors and routes of accumulation are necessary to develop accurate predictions of bioaccumulation (amount of contaminant that accumulates in an organism). Recent attempts to include the benthic food web in bioaccumulation models indicate that benthos contribute significantly to the food web transfer of organic contaminants. Attempts to model the bioaccumulation of polycyclic aromatic hydrocarbons (PAH) by *Diporeia* spp., a major benthic food web component in the Great Lakes, suggest that there are substantial seasonal changes in the concentration of contaminants in the organism, but these seasonal changes have not yet been incorporated into more complex food chain models. This work focuses on how temperature, sediment composition, and feeding on fresh detritus affect bioaccumulation in benthic organisms.

In FY 95, a review of toxicokinetics results and data for *Diporeia* spp. over the last 13 years was completed. *Diporeia spp.* represent the major benthic invertebrate in the Great Lakes based on its biomass. Because of their high lipid content and importance in energy cycling within the Great Lakes, they contribute to the transfer of contaminants from the sedimentary environment to the pelagic food chain. This review is a necessary precursor to development of an improved model of the seasonal

concentration of organic contaminants in this major Great Lakes food base organism, which in turn will provide the basis for a better model and predictive capability for contaminant transfer through the food web. The review indicates that for proper modeling of *Diporeia spp.* in contaminant cycling in the Great Lakes, further investigation into the basic biology, e.g., feeding behavior, lipid dynamics, and respiration dynamics, along with the routes, kinetics, and sensitivity to toxins will be important.

An existing model to estimate the toxicokinetics of *Diporeia spp.* over the course of a year was reworked for use on a PC and updated with data obtained from a review of the literature. This new model was compared to the previous model and was forwarded to the US EPA for use in their mass balance projects.

Measurement of Select Toxic Organic Contaminants in Surficial Sediments of Lake Michigan: Estimation of Lakewide Inventories and Seasonal Settling Fluxes

A mass balance of input and output of select contaminants for Lake Michigan is the goal of an EPA-sponsored program titled Lake Michigan Mass Balance Program (LMMB). This study is designed to answer questions posed in the amended Clean Air Act, and to assist environmental managers in developing and implementing the Lake Michigan Lakewide Management Plan (Lake Michigan LAMP).

The purpose of this project is to provide an inventory of critical contaminants (PCBs and trans nonachlor) in Lake Michigan surface sediments. Contaminant deposition zones, hot spots, and local sources will be identified using trace organic contaminant concentration maps and sediment inventories. In addition, the seasonal transport of contaminants between regions of the water column, and between the water column and surface sediment will be estimated from automated sediment trap collections.

In FY 95, Field Sampling and Analytical Quality Assurance Project Plans (QAPjP) were created through a series of conference calls sponsored by EPA's Great Lakes National Program Office (GLNPO). The QAPjP, which includes standard operating procedures (SOPs) for sampling and analysis of PCBs, pesticides, and PAHs in sediments, was approved by the EPA. This document has been distributed to private and state agencies and individuals who have requested details of our procedures.

Analytical methods were developed to separate a single extract of a sample into two fractions: a PCB fraction, and a PAH and pesticide fraction. Thus, three classes of compounds can be quantified from a single extraction step. Extraction and clean-up methods were developed for both sediment and biological tissue samples.

Contaminant Effects and the Relationship to Exposure

The goal of this project is to explore the relationship between contaminant exposure and contaminant effects on biota. To accomplish this goal, new procedures (bioassays) will be developed to determine the body burdens (concentration of the contaminant that builds up in the organism's body) required to produce measurable effects in specific biota.

Experimental work to evaluate the validity of the equilibrium partitioning approach occupied most of the efforts for this FY. Tests were performed using two organisms: *Diporeia* spp. and *Hyalella azteca*. Our work showed that it is very difficult to attain an adequate exposure to sediment-associated contaminants for *H. azteca* ,and that the conditions required for application of the equilibrium partitioning approach appeared to be violated for both organisms. These results cast doubt on the utility and validity of the equilibrium partitioning approach, which is currently recommended by EPA to establish sediment quality criteria. A report of our findings was provided to the EPA.

Development of a method to perform sublethal and whole-life-cycle tests for sediment-associated benthos

was initiated, and a first series of studies creating dose response data for chironomids exposed to DDE (a metabolite of DDT) were completed. These data are required by the EPA and the Army Corps of Engineers (COE) to properly interpret their mandated bioaccumulation tests.

Sampling the Resuspendible Pool of Sediments and Associated Contaminants and Measuring Mass and Contaminant Fluxes in Lake Michigan Using Sediment Traps

In the Great Lakes, the largest fraction of persistent trace contaminants reside in the sediments due to sorption and settling processes. Studies of the long-term behavior of fallout radionuclides and stable contaminants in the Great Lakes have shown that higher levels exist in the lakes than expected if settling and burial were the only transport processes. Materials are resuspended into the water column from sediments and are then consumed by biota. It is now accepted that this recycling, caused by the processes of bioturbation and resuspension, is responsible for the continued high levels of trace contaminants (e.g. PCB, DDT) in fish and the slow response of the lakes to nutrient abatement.

Since 1977, GLERL has examined the processes of particle flux and resuspension through the use of sediment traps. We have learned much about the transport of mass, contaminants, and tracers, and the results are now routinely incorporated into program sampling, modeling strategies, and management considerations.

In FY 95, a synthesis of GLERL sediment trap data was forwarded to the EPA LMMB modelers for their use in model calibration. Also this FY, a splitting procedure was developed that allows us to precisely split trap samples for various forms of sample processing and yet reconstruct the total sample weight to within +/- 2%. The procedure was written as a supplement to our QAPjP and was accepted by EPA.

Long-Term Trends in Benthic Populations

The objectives of this project are to determine trends in the population distribution of benthic biota in selected areas of the Great Lakes and to determine the significance and reasons for observed changes. Starting in 1993, this project was expanded to incorporate the requirements of EPA's Environmental Monitoring and Assessment Program (EMAP) for the Great Lakes.

In FY 95, samples collected at EMAP sites in both Lakes Michigan and Superior in 1992 and 1993 were analyzed, and the data were provided to EPA. Data tables gave abundances of each species collected at each site. All benthic invertebrates collected at EMAP sites in Lake Michigan in July 1994 were identified and counted.

Bioavailability of Sediment-Associated Toxic Organic Contaminants

Assessing the environmental risks associated with contaminated sediments requires determining the conditions under which sediment-associated toxic organic compounds accumulate in benthic organisms (bioaccumulation), determining whether the toxins are transferred up the food chain (biotransfer; biomagnification), and developing models for describing bioaccumulation. This work will help define the relationship between sediment characteristics and the bioavailability of organic contaminants, which in turn should improve our ability to predict the effects of contaminants associated with sediments.

In FY 95, experiments were conducted to better describe the factors that affect the bioavailability of sediment-associated contaminants. The accumulation of two biphenyl PCB congeners was shown to be related to the organic carbon content, and this relationship improved when the organic carbon concentration of the fine particle-size fractions was used in place of the concentration in the whole sediment. However, for PAH congeners, the organic carbon content was not an important factor, but the C:N ratio was. The larger the

C:N ratio, the more bioavailable the PAH from sediment.

The length of contact time between the sediment and the contaminants has been identified as a major factor that affects the bioavailability of sediment-associated organic contaminants. Sediment cores were collected from Lake George (on the St. Marys River downstream from Sault Ste. Marie, Michigan/Ontario), and the accumulation of PAH congeners was determined for the oligochaete *Lumbriculus variegatus* from sediments taken at various depths. Our hypothesis was that the bioavailability of sediment-associated contaminants would decrease with increasing depth in the core, due to longer contact time. However, there was no significant variation in the uptake kinetics with depth, except that the surface material was found to be essentially unavailable for bioaccumulation. This finding suggests other factors, such as the binding of PAH in soot particles, are responsible for the differences in bioavailability in these sediments. The hypothesis that the bioavailability would decrease down-core due to increasing sediment contact time was not supported, perhaps due to changes in the chemical speciation.

The assimilation of sediment-associated contaminants was examined for the amphipod *Diporeia* spp. and the oligochaete *Lumbriculus variegatus*. In general, the assimilation efficiency of the oligochaete, which is a non-selective feeder, was successfully tracked by several approaches that were tested. The ability to measure the assimilation efficiency for *Diporeia* spp., which is a very selective feeder, was less certain and more dependent on the method employed. The difficulty in measuring the assimilation efficiency for this species is a result of its extreme feeding selectivity and the unequal distribution of the contaminant among sediment particles. This unequal distribution was not corrected by carbon normalization, and these findings demonstrate the need for a better definition of the actual food source for selective feeders such as *Diporeia* spp.

WATER RESOURCES

Great Lakes water is used for drinking, power generation, commercial shipping, and recreation, and an extensive commercial and sport fishery. Both natural (evaporation) and anthropogenic (diversions, consumption) influences threaten this valuable resource. The goals of this program are to develop improved prediction, climatology, statistics for decision-making, and process studies, and to develop interfaces with policy and decision-makers. It incorporates two ERL research task categories: GLERL 04 - Hydrologic Processes, and GLERL 05 - Water Resources Forecasting.

ERL Research Task Category: GLERL 04 - Hydrologic Processes

Great Lakes Hydrology and Ice Databases

The goal of this project is to develop and provide new or improved historical hydrometeorological and ice cover databases and models of the seasonal cycle of ice formation and loss on the Great Lakes. Geographic information databases of the Great Lakes basin will be developed and linked to the hydrology and ice cover for spatial analysis.

In FY 95, a study of the 1993/94 winter and Great Lakes ice cycle was completed, revealing that the winter of 1994 was one of the coldest in over a decade (Figure 1).

An analysis of long-term trends in Great Lakes open-lake ice cover over the past century was made as part of a study to examine the potential effects of climate change on the aquatic systems of the Great Lakes and smaller lakes in the Precambrian shield region of North America. The decadal average of maximum ice cover was about 61% during the decades from 1900 to 1920, decreased to about 50% during the decades between 1930 and 1960, then increased over the next two decades [ending 1970 (61%) and ending 1980 (64%)] before declining again [ending 1990 (55%)]. These trends are in agreement with ice cover models developed for Lakes Erie and Superior that show decadal average February ice cover was about 10-25% greater during the first quarter of this century (1900-1925) and from 1960 to 1983 than it was in the intervening years (1926-1959). Recent average February ice cover is approximately 90% and 56% for Lakes Erie and Superior, respectively.

ERL Research Task Category: GLERL 05 - Water Resources Forecasting

Next-Generation Runoff Models

GLERL has developed conceptual-model-based techniques for simulating moisture storages and runoff from the 121 watersheds draining into the Laurentian Great Lakes. These refined runoff models will be integrated with atmospheric process models in another task and will incorporate recent advancements in measurements of hydrometeorological data. Linking surface hydrology process models with atmospheric process models will allow feedback between climate and land surfaces and result in more accurate estimates of regional and local impacts of climate change.

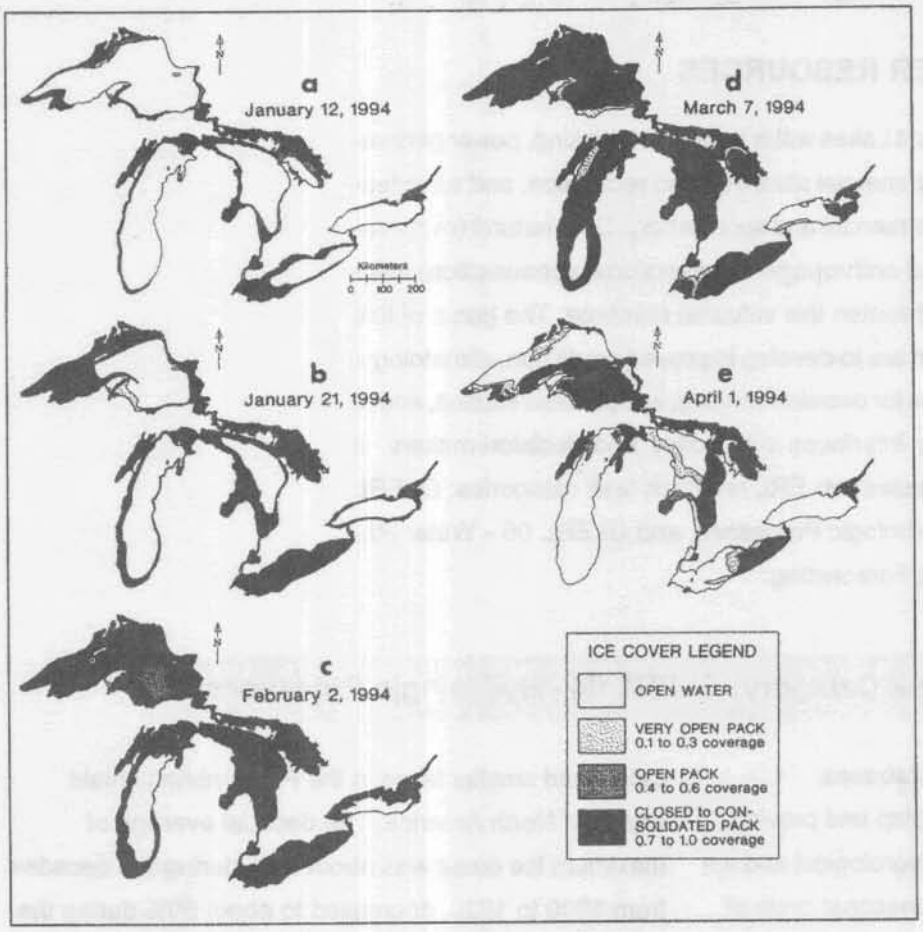


Figure 1. Relative to the past 31 winters (1963-94) the 1994 maximal ice cover of the combined surface area of the five Great Lakes is exceeded only by winter 1979. The U.S. Coast Guard logged the greatest number of hours in over 15 years (5700+ hrs) to support commercial shipping activity. Extensive midlake ice formation (the second half of January) and seasonal maximal ice cover (the first half of February) both occurred about 2 weeks earlier than normal. Spring ice cover was also greater than normal, costing shipping companies millions of dollars in lost revenue due to delays in schedules and damage to vessels.

Water Resources Forecasting System

The availability of adequate water resources to support the Nation's continuing growth and infrastructure will be one of the major issues of the 21st century. Computer models to provide water resource forecasts of variables over large areas at time scales of several days to several weeks or months are needed. NOAA's program to build a nationwide Water Resources Forecasting System (WaRFS) includes GLERL's development of the water resources forecasting capability for the Great Lakes basin.

By the end of FY 95 we had modified our hydrological outlooks to use NOAA's extended climate outlooks as the basis for our probabilistic outlooks. This has resulted in real savings when the model simulations are extensive, as is the case with Great Lakes hydrological outlooks.

The Geographic Information System (GIS) and the relational database management system were incorporated into our existing forecast package.

We completed and tested a user-product interface (or "front end") for our Great Lakes WaRFS as a specially-designed Windows™ application. It aids the user in defining the hydrological outlook and historical-data periods, selecting the periods, probabilities, and priorities from the available climate outlooks, and determining the method for considering the climate outlooks in making the hydrological outlook. The interface computer code is also available as a stand-alone FORTRAN implementation for use under a variety of computer operating systems. In designing the interface, we considered users' wants and addressed compatibility issues with the National Weather Service (NWS) and others.

NOAA's existing climate outlooks can be particularly cumbersome and difficult to use. This new interface greatly clarifies and simplifies their use for making a hydrological outlook. It is particularly effective in

allowing others to utilize NOAA's climate outlooks for making Great Lakes hydrological outlooks and for other purposes. It allows readily understandable user-interpretation of climate outlooks and easy user-assignment of relevant priorities. In fact, the interface is so successful in allowing a layperson to utilize NOAA's climate outlooks that we built a derivative product (also a Windows™ application) to allow anyone to directly use NOAA's climate outlooks in their own applications. (Note: an outlook is a description of expected climatic conditions beyond the range of a forecast. For example, a forecast may cover a time period of a few hours to, perhaps, 10 days, while an outlook may extend to 30 days or more, but with much less detail, accuracy, and confidence than is associated with a forecast).

The Great Lakes WaRFS prototype was demonstrated by installing it on two outside agency computer systems. It was also installed on a GLERL computer system that will receive daily updates of meteorological data in near-real-time.

Coupled Hydrosphere-Atmosphere Research Model

Understanding how the Great Lakes affect the weather and understanding how the weather affects the Great Lakes will improve decision making concerning potential impacts of altered climate and anomalous (wet) seasonal weather patterns, such as that experienced in parts of the Midwest during the summer of 1993. This project has three objectives: (1) develop a Coupled Hydrosphere-Atmosphere Research Model (CHARM) from existing atmospheric and hydrologic models by using two-way dynamic interactions, (2) enhance the model with second-generation surface parameterizations for lake thermal flux and runoff, and (3) refine earlier climate change estimates and estimates from other mesoscale modeling efforts by developing one-way linkages between them and the Great Lakes hydrology models.

Version 1.1 of the CHARM was completed during this FY.

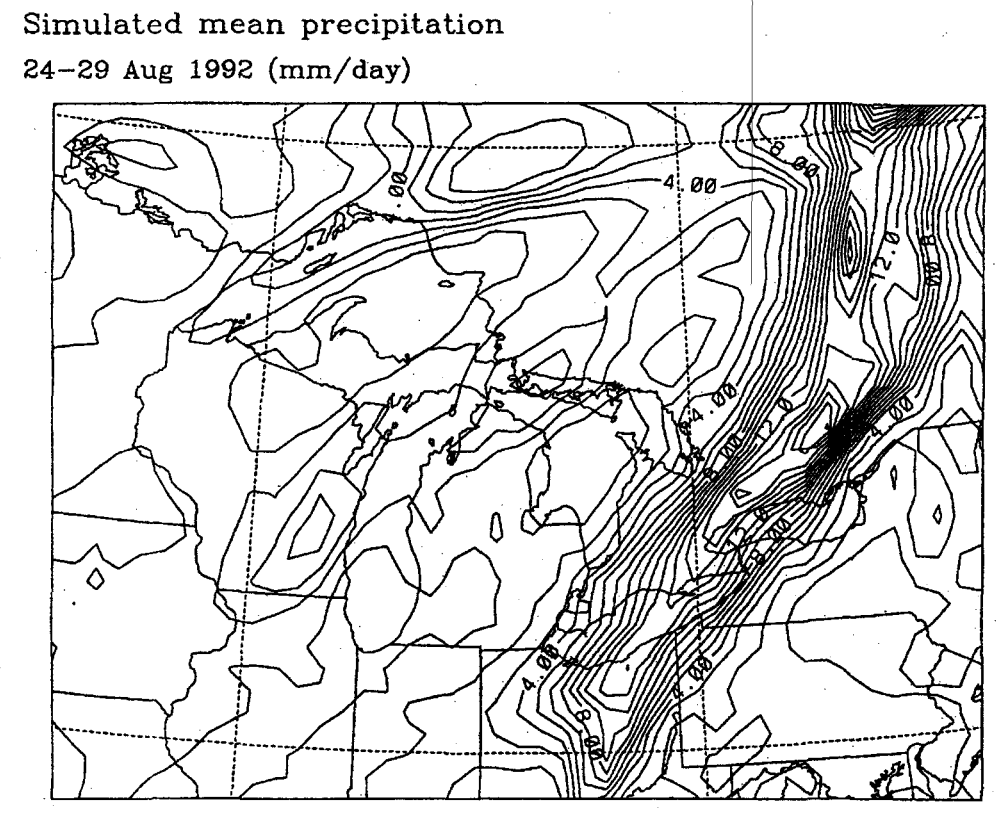


Figure 2. A display of precipitation simulated in CHARM for the period 24-29 August 1992. During this time period, the Great Lakes region was affected by the aftermath of Hurricane Andrew. This result comes from the CHARM model, which has a representation of the atmosphere of the Great Lakes region nested inside observed variables for the larger-scale atmosphere and coupled to a model of the land surface hydrology and a model of lake surface temperatures. At present, the model estimates of precipitation are too low overall and too concentration spatially.

CIRCULATION MODELING

Meteorological and oceanographic conditions in coastal areas can sometimes become dangerous enough to cause significant damage to property (boats, ships, structures, etc.), loss of human life, and social or economic disruption. Large waves, high and low lake levels, heavy snowfalls, ice, and erosion are hazards in the Great Lakes system and in other coastal areas as well. Human-caused hazards also pose serious threats, especially spills of petroleum products and chemicals. The research from this program provides circulation and wind models and other service products to assist in marine hazard prediction, emergency response, damage prevention and reduction, and more effective management of water resources. It incorporates two ERL research task categories: GLERL 01 - Great Lakes Coastal Forecast System, and GLERL 03 - CoastWatch.

ERL Research Task Category: GLERL 01 - Great Lakes Coastal Forecast System

Lake Circulation Studies and the Great Lakes Coastal Forecasting System (GLCFS)

This project is concerned with numerical simulation and prediction of temperatures and currents in the Great Lakes. During FY 95, work being conducted under a separate project titled "Coastal Hazards" was incorporated. The GLCFS is a collaborative effort between GLERL and Ohio State University (OSU). The goal of the GLCFS is to implement and test a system for real-time prediction of the physical status of the Great Lakes based on the hydrodynamic models developed under this project.

In FY 95, a meeting was held with representatives from the NWS Eastern Region Headquarters and the Office of Meteorology to plan for developing a stand-alone workstation version of the Lake Erie prototype GLCFS for use at the NWS Cleveland Forecast Office. The recommendation was to proceed with a system that would be customized for NWS internal use, install it at Cleveland, and evaluate it as a guidance tool for marine forecasting.

Experimental forecasts from the NWS/National Meteorological Center (NMC) meso-Eta (29 km) meteorological forecast model were incorporated into GLCFS operations at OSU in July 1995. Surface heat flux and friction velocity fields at 3 hour intervals at grid points over Lake Erie are extracted from the Eta model forecast. These are used to drive the lake models to produce 24 hour forecasts of water levels, currents, water temperatures, and waves. These forecasts are being evaluated (Figure 2).

An improved version of the GLFSView program for PC analysis of GLCFS products was developed and distributed to over 60 users. A World-Wide-Web (WWW) home page (http://glfs.eng.ohio-state.edu/) on the Internet was developed for real-time dissemination of GLCFS products.

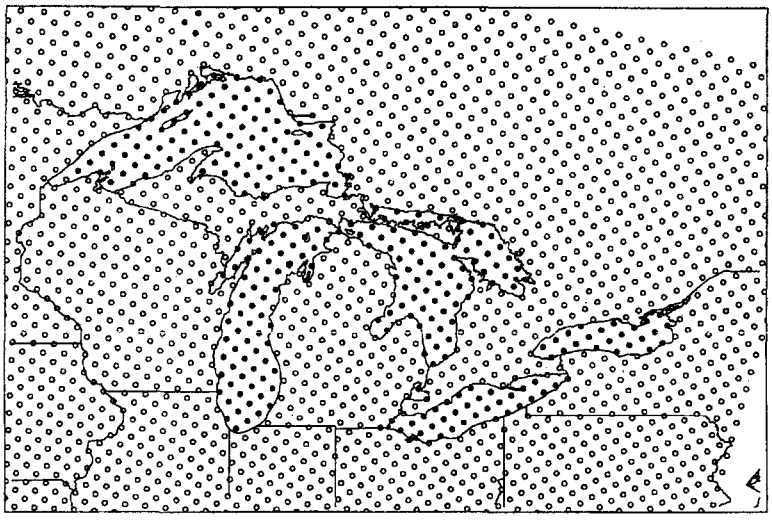


Figure 3. Section of NMC Eta model grid in the Great Lakes region. Filled circles indicate Eta model grid points over water. Forecasts from the Eta model are being used to drive lake model forecasts from the Great lakes Coastal Forecasting System.

ERL Research Task Category: GLERL 03 - CoastWatch

Great Lakes CoastWatch and NOAA Ocean Communications Network

CoastWatch is a NOAA-wide program that originated in NOAA's Coastal Ocean Program (COP). As a CoastWatch Regional Site, GLERL operates the Great Lakes Regional National Ocean Communications Network (NOCN) Node (RNN), identifies regional CoastWatch users and their NOAA data needs, and supplies useful products to participants in the Great Lakes CoastWatch Program. Our scientists also conduct research and develop products specific to the Great Lakes region using CoastWatch data.

In FY 95, the Great Lakes CoastWatch node supported 41 users, up 6 from the previous year. Satellite-derived surface temperature, marine observations, and water level data were provided routinely as CoastWatch products. These products were also provided for use in developing the GLCFS.

A new cloud-mask product was developed and made available to CoastWatch users, and the CoastWatch Great Lakes Surface Environmental Analysis (GLSEA) composite (cloud free) Sea Surface Temperature (SST) chart was produced and provided on a routine basis. New archiving routines were also developed for CoastWatch data on CD ROM's. With the assistance of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), a new data/product download path was implemented directly from the mainframe computer at NESDIS.

In addition, a CoastWatch section was developed and implemented on the GLERL WWW home page (http://www.glerl.noaa.gov/cw/cw.html).

Great Lakes CoastWatch Product Development and Research

The objectives of this project are to evaluate and help validate Great Lakes CoastWatch products, provide input to NESDIS concerning product needs and development, and conduct research to develop products and uses specific to the Great Lakes region.

In FY 95, the first series of analyses of Earth Resources Satellite-1 (ERS-1) Synthetic Aperture Radar (SAR) ice data for classification/mapping algorithm development was completed. Results showed that depending on size and sea state, icebergs could be detected from background and enhanced in the imagery, SAR data can supplement and enhance the utility of satellite visible and infrared data sources for coastal ice monitoring, and that Great Lakes ice cover can be classified by ice type and mapped in SAR data using image processing techniques. Cloud cover, however, was a common problem. Further developments in algorithms and SAR coverage frequency make it a unique and valuable tool for ice detection and monitoring.

ECOSYSTEM DYNAMICS

The Great Lakes and nearshore ocean waters are major national resources used for a wide range of activities: industrial and municipal water supplies, shipping, fishing (sport and commercial), municipal and industrial discharge, boating, and other forms of recreation. Water quality and the value of the biological resources in these systems are directly related to the health and abundances of organisms and their interactions with the physical and chemical aspects of the ecosystem. Therefore, to protect, preserve, and restore these systems, it is essential to understand the function of organisms at all trophic levels and their interactions within the ecosystem. Without this understanding, the response of these organisms to anthropogenic or natural perturbations, the goal of protecting ecosystem health will be difficult to achieve.

GLERL conducts ecosystem research in both the Great Lakes and nearshore ocean environments. However, this research focuses primarily on key components of the Great Lakes lower foodweb and the links between physical, chemical, and biological processes that impact important processes in ecosystem function. Although long-term trends in key components are examined, life history studies and process research are emphasized so that GLERL's expertise can be applied to problems in a variety of ecosystems that are geographically and biologically diverse. This program includes three ERL Research Task Categories: GLERL 09–Ecosystem Dynamics Research, GLERL 10–Nonindigenous Species Research, and GLERL 12–Episodic Events. Due to lack of sufficient funds in FY 95, there was no research activity in Episodic Events.

ERL Research Task Category: GLERL 09 - Ecosystem Dynamics Research

The Role of Sensory Physiology and Behavior in the Remote Detection of Large Particles by Calanoid Copepods

In the Great Lakes, copepods are the dominant grazers of phytoplankton and are important predators of ciliates and invertebrate larvae. Recent studies indicate that calanoid copepods are capable of discriminating between food particles that differ in nutritional quality. High-speed microcinematography has revealed that calanoids can detect the presence of particles as small as 5 μm and use coordinated actions of their mouthparts to capture them. It is not known, however, whether mechanoreception, chemoreception, or both sensory modes are used to detect and discriminate between particles. Because copepods are important mediators of trophic energy movement in the Great Lakes food web, understanding the influences of sensory physiology and behavior on their ability to feed selectively, and defining this selection accurately, is critical to understanding the impact of anthropogenic perturbations to aquatic food webs. This is a new project that is being conducted at GLERL under the

auspices of the NOAA - National Research Council Post-doctoral Research Fellowship Program.

Research Monitoring of the Lake Michigan Ecosystem

Lake Michigan is the only Laurentian Great Lake that lies entirely within US jurisdiction. It has a world-class fishery valued at over $300 million per year and serves as the source of drinking water to over 5 million Americans. GLERL has maintained a long-term monitoring program in southern Lake Michigan for the past 10 years, and this year, revised it to improve the scientific information that is collected. These data are used for research by GLERL on the condition of, and trends in, Lake Michigan's ecosystem health, and also as part of a study in collaboration with Lake Michigan's perch fishermen to investigate possible food-web-based causes of a decline in Lake Michigan's perch population. These data are also used by the US Fish & Wildlife Service (USFWS) and the National Biological Service (NBS) to supplement their upper food web studies and assessments in support of Lake Michigan fisheries conservation and management programs. The combination of GLERL's lower food web data with the USFWS/NBS data on the upper food web (fish) provides essentially complete coverage of the entire pelagic (i.e., water column) fisheries ecosystem, which is necessary for fishery stocking decisions and for computer-based model analyses of proposed fishery management actions.

In FY 95, we completed and published the "Common Planktonic Protozoa in the Upper Great Lakes: An Illustrated Guide." This is one of the first guides to planktonic protozoa in the Great Lakes. It provides taxonomic and ecological information about the planktonic protozoa that commonly occur in the upper Great Lakes, based on more than 70 field collections obtained over a 10-year period (1979-1989). A separate taxonomic profile is presented for each of 35 common protozoan taxa. The profile is organized around six general aspects of each organism's ecology: taxonomic position, morphological description, distribution, a brief list of pertinent references, general comments and observations, and a micrograph of the organism. Finally, dichotomous keys to the common orders and individual taxa are presented

A new more intensive monitoring program was initiated by including ichthyoplankton, *Bythotrephes*, UV light penetration, and phytoplankton production as measured parameters. Sampling was improved by adding three additional stations. A new multi-sensor instrument package was deployed in early spring and retrieved in October.

ERL Research Task Category: GLERL 10 - Nonindigenous Species Research

The objective of this task is to expand our knowledge of the biology and the ecological effects of nonindigenous species in the Great Lakes. Research involves field investigations to monitor ecosystem changes and community response to these species and examines biological traits of the organisms themselves. Research also includes laboratory experiments to determine metabolic features and feeding rates and examines toxicokinetics and bioaccumulation of toxics.

Two new projects were added this FY: one to define the role of the zebra mussel's selective filtering in promoting nuisance blooms of algae in Saginaw Bay and the effect of these blooms on the filtering performance and survival of the mussels; and another to examine the influence of circulation and the Thunder Bay River plume on the threat of zebra mussel infestation on historical shipwrecks in Thunder Bay, Lake Huron, a proposed NOAA National Marine Sanctuary.

Effects of the Zebra Mussel on the Lower Food Web of Saginaw Bay

The objectives of this project are (1) to identify and understand changes in the abundance, biomass, and composition of the lower food web of Saginaw Bay that have resulted from the invasion of the zebra mussel *(Dreissena polymorpha)*, (2) to construct a model of carbon flow through the system and determine major changes in pathways that may have been caused by the zebra mussel disrupting the ecosystem, and (3) to monitor changes in the abundance and distribution of the zebra mussel in the bay.

Data collected in Saginaw Bay from 1990-93 were compiled and interpreted in a collection of scientific manuscripts that are published together in a special issue of the *Journal of Great Lakes Research* (Volume 21, No. 4). A total of 12 papers are included in this issue, entitled "Impacts of the Zebra Mussel on the Saginaw Bay Ecosystem: the Early Invasion Years." In general, results show a dramatic shift in how energy and nutrients are routed through the food chain. Saginaw Bay's energy base has shifted from a pelagic (water column focused) to a benthic (bottom dominated) food base. There is also evidence indicating that zebra mussels encourage growth of harmful blue-green algae by rejecting them as food, and thus giving them a competitive advantage over other algae.

FY 95 monitoring of water quality parameters was completed at 13 Saginaw Bay sites, thus extending the GLERL Saginaw Bay ecological database to 1995. Variables measured monthly were nutrients, chlorophyll, suspended solids, Secchi depth, phytoplankton, zooplankton, and benthos. Also, vertical profiles of temperature and algal fluorescence were obtained.

Effects of the Zebra Mussel on Nutrient and Microbial Dynamics in Saginaw Bay, Lake Huron

By altering the biomass of phytoplankton and bacteria, both of which compete for phosphorus, and removing suspended particulates, zebra mussels may affect nutrient cycles and microbial dynamics in an ecosystem. The goals of this project are to (1) determine the direct and indirect effects of the zebra mussel on nutrient regeneration and uptake by various trophic components in the lower food web, (2) determine the effects of the zebra mussel on bacteria, (3) determine how the sources, cycling rates, and fate of labile dissolved organic matter are affected by the presence of the zebra mussel, (4) collect and determine the "nutritional composition" of feces and pseudofeces produced by the zebra mussel, and (5) compare field observations of standing stocks and process rates with those predicted from bottle and mesocosm experiments.

In FY 95, field work continued to examine the effects of the zebra mussel on benthic and pelagic food webs in Saginaw Bay. A major hypothesis is that the zebra mussel may affect the ratios of regenerated nutrients, which could affect the composition and growth rates of phytoplankton and other organisms. The effects of the zebra mussel on sediment-water nutrient fluxes and oxygen consumption rates in the light and dark were investigated. Chamber experiments were conducted at one inner bay and one outer bay site during two field trips in 1995. Results indicate that zebra mussels increase benthic nutrient cycling and respiration rates. Zebra mussel chambers always showed increased ammonium levels and constant or decreased nitrate levels. The ratio of oxygen consumed to ammonium produced was 290 in chambers with zebra mussels vs. 55 in control chambers without mussels. These results suggest that zebra mussels have a significant effect on benthic metabolism and nutrient transformations at or near the sediment-water interface.

Nutrient fluxes were measured from sediments using a new experimental design with lake water continuously flowing over intact or reconstituted sediments cores. The presence of zebra mussels significantly increased ammonium regeneration in the cores. In contrast to previous results from Lake Michigan and other freshwater systems, where regenerated

ammonium was nitrified and subsequently denitrified, the regenerated ammonium was not quantitatively converted to nitrate in these cores. Mechanisms controlling nitrification/denitrification are important in coastal ecosystems because denitrification is a sink for available nitrogen and, therefore, can contribute to changing concentrations and ratios of available nutrients in regions where it is important.

Direct effects of the grazing activities of the zebra mussel on the natural assemblage of planktonic protozoa and algae from Saginaw Bay were measured in September and October 1994. Despite relatively high growth rates of protozoa on both dates, mussels lowered protozoan numbers by 70-80% and reduced the species richness of the protozoan community by 30-50%. Zebra mussels selectively removed nanoplanktonic *Cryptomonas* and *Cyclotella*, but had no significant effect on the predominant phytoplankton species, *Microcystis*, and overall, *Dreissena* clearance rates were low in the presence of *Microcystis*. These studies demonstrate that zebra mussels cause significant changes in composition of both the protozoan and phytoplankton communities in regions where they are abundant.

Results from a eutrophic site in Saginaw Bay show that the ammonium regeneration rates and uptake rates of the pelagic community both followed seasonal patterns resembling those of chlorophyll concentrations in the treatments without zebra mussels. Pelagic community ammonium regeneration rates were consistently enhanced in the presence of zebra mussels, indicating that zebra mussels could have a dominant effect on nitrogen regeneration in regions where they are abundant.

Our experimental findings from bottle and enclosure experiments indicate that the zebra mussel can have significant short-term effects on phytoplankton abundance, water transparency, water chemistry and phosphorus dynamics. Ecosystem results from these experimental studies were compared to actual field results observed by others at GLERL and the University of Michigan in their Saginaw Bay and Lake Erie monitoring programs. The comparison showed generally good agreement between the two approaches and indicated that experimental and field measurements provide complementary information that can be used together to better understand the effects of zebra mussels on the ecosystems.

Toxicokinetics and Bioaccumulation of Organic Contaminants by the Zebra Mussel

The goal of this project is to assess the impact of the zebra mussel on the distribution of contaminants in ecosystems dominated by this organism. The feeding activities of zebra mussels may result in faster deposition of sediments and may also change the composition and mobility of materials on the bottom. The selected chemicals, primarily PCBs and PAHs, are representative of both their class and the physical and chemical characteristics embodied in the chemicals as model compounds. Compounds from other chemical classes will be used where specific characteristics will be helpful to determine specific processes or mechanisms of action.

In FY 95, studies examining the assimilation of contaminants from algae to the zebra mussel were conducted as part of a study of the trophic transfer of contaminants to zebra mussels. This work is part of a collaborative effort with Ohio State University. The results demonstrated that ingestion is a very important route by which zebra mussels accumulate contaminants in their bodies.

Experiments to investigate the transfer of contaminants from zebra mussels to a predator organism, in this case, the crayfish, were completed. Contaminants were very efficiently transferred from zebra mussels to the crayfish preying on them. This means that zebra mussels may be a significant vector for the transfer of contaminants to higher trophic levels.

Analyses of samples collected in 1993 and 1994 were completed. Preliminary findings suggest that for PCBs with a high octonol:water partition coefficient (log

K_{ow} >5), zebra mussels and gammarid amphipods exhibit seasonal variation in contaminant content that reflects the variability observed for phytoplankton. Seasonal variability in phytoplankton (higher PCB concentrations in spring and fall relative to summer) results from growth dilution and to a lesser degree from lipid content changes. Bioaccumulation factors (BAFs, ratio of PCB in organism to that in phytoplankton) for gammarid amphipods are only slightly higher than those of zebra mussels, indicating that gammarus are not being exposed to a food source especially enriched in contaminants as a result of living in close contact with zebra mussels. Zooplankton BAFs are a factor of 2 higher than both the zebra mussel and amphipod due in part to higher lipid content. Zebra mussel feces/ pseudofeces are enriched in some PCB congeners relative to phytoplankton, though no relation with compound hydrophobicity was observed.

Observations on the Trophic Ecology of *Dreissena* Early Life Stages: The Critical Planktonic Period

The pelagic phase (eggs and larvae) of the zebra mussel is a weak link in its life cycle, with mortalities of nearly 100% depending on environmental conditions. The objectives of this project are to (1) observe feeding mechanisms, particle choice, and feeding rates of *Dreissena* larvae, (2) determine nutritional requirements of *Dreissena* larvae, and (3) determine the vulnerability of *Dreissena* eggs and larvae to zooplankton.

In FY 95, we conducted experiments on the suitability of different freshwater algae as food for culturing zebra mussel larvae, and also experiments using antibiotics to optimize conditions for rearing the larvae. We had some success with the freshwater cryptophyte *Rhodomonas* until it became contaminated, and in one experiment using antibiotics there was an improvement in survival.

Work was completed to greatly improve the resolution of the optics of the Critter Cam (a video system used to observe the behavior and activities of free-swimming larvae). The software and hardware of the motor drive was improved and now allows us to keep track of the camera (and animal) position in 3-D space at a high sampling rate (15 times per s).

The Critter Cam was used to record predation interactions between copepods and *Dreissena* larvae to help explain the results of our bottle experiments with trochophores and D-stage larvae. Almost all trochophores attacked by copepods were ingested, while the D-stage larvae usually escaped. It also appeared that some species of copepods may avoid attacking the D-stage larvae, for unknown reasons.

Long-Term Changes in the Resuspendible Sediments of Saginaw Bay

During feeding, adult zebra mussels capture suspended particulate matter and redeposit it as feces and pseudofeces on the bottom, thereby affecting the composition and mobility of materials in the sediment resuspendible pool in Saginaw Bay, and resulting in changes in residence times of particle-associated constituents. This project focuses on sampling resuspendible sediments and analyzing them for gross compositional changes, nutrients, carbon, and ^{137}Cs, to estimate the resuspension flux of these constituents, and to examine the carbon and nitrogen pathway changes caused by the mussel.

In FY 95, results from sediment traps revealed that the amount of suspended particulate material in the deeper parts of the Saginaw Bay water column increased after the introduction of zebra mussels, while suspended particulate material in the upper part of the water column was substantially removed, presumably by zebra mussel filtering.

We had not expected to see an increase in the deep suspended load. We now believe that the mussels are significantly changing the character and distribution of the particulate material through two processes: (1) filtering and repackaging it as feces and pseudofeces, which have adhesion, compaction, and resuspension characteristics substantially different from

the "normal" particulate matter of the pre-zebra mussel bay; and (2) by contributing to the observed decrease in populations of sediment mixing in-fauna, such as oligochaetes, with a resultant reduction in sediment consolidation. Both these processes lead to formation of a near-bottom pool of highly mobile material that can be more easily transported to deeper waters, where it is not filtered by zebra mussels, and is susceptible to resuspension into the water column.

Based on trap samples, resuspended material appears to reach about 5-10 m above bottom, or about mid-water column, and is mostly composed of feces/ pseudofeces. This phenomena may have a substantial impact on the 20-year reservoir (i.e., average residence time) of material within the sediment mixed layer. It is hypothesized that this layer is being depleted in Saginaw Bay by the feeding behavior of the mussels, with consequences for contaminant trajectories that could be considerable.

Selection and Utilization of Algal Resources by *Dreissena* : Unstable Interactions Between Zebra Mussels and the Algal Community of Saginaw Bay

Because of their high abundance and very high filtering rates in shallow aquatic systems, zebra mussels remove a significant portion of the primary production. In some shallow experimental lakes in Europe, introduced zebra mussels have improved water clarity and quality of the algal resource base so that food web efficiency and fish production have increased. As a result, some scientists have advocated introduction into other aquatic systems. Improvement of water clarity has been seen in Lakes Erie and St. Clair; however, in Lake St. Clair, the increased water clarity may have contributed to massive blooms of vascular macrophytes that have washed up on shore and fouled beaches. In the inner portion of Saginaw Bay, water clarity improved in midsummer of 1991 and 1993; but in 1992 and 1994 there were marked decreases in water clarity owing to massive blooms of *Microcystis* and other large phytoplankton. Also, there have been outbreaks of near-bottom blooms of the filamentous alga *Spirogyra* that have later washed up on beaches.

Our observations on the response of a mussel to a potentially toxic alga strongly suggest that *Dreissena* spp., through its selective rejections, may increase the probability of toxic blooms. It also seems likely that zebra mussels have been a major contributor to *Spirogyra* blooms by increasing water clarity by filtering out small algae and metabolizing the ingested biomass into nutrients used by *Spirogyra*. To explain these unexpected and unstable responses in Saginaw Bay requires us to carefully examine *Dreissena* spp.'s selection, rejection, and utilization of algal resources of different quality and size.

In FY 95, direct measurement of Nitrogen (N) and Phosphorus (P) excretion by the mussels was added to the project because alteration of the N:P ratios by mussels has been hypothesized by Sea Grant investigators to be a driving force in shifting algal community structure to blue-green algae.

Filtering rate experiments using an improved method were conducted using water from our inner and outer bay reference sites in Saginaw Bay, to allow estimation of both filtering and assimilation rates at sites having a high and a low concentration of *Microcystis*. Very low filtering and assimilation rates were seen during the bloom period (Figure 3).

Visual observations of the mussels feeding on natural seston allowed direct correlation between mussel behavior and filtering rate. The filtering rate experiments and direct observations showed that the mussels, for the most part, filtered at full capacity during the blue-green bloom but rejected almost all algae.

Preliminary results of nutrient excretion experiments run in parallel with the filtering rate experiments and suggest that mussels are not altering the N:P ratio in favor of the blue-green algae.

Experiments in which natural seston was spiked with a palatable alga (*Rhodomonas*) showed that the mussels could selectively remove the palatable alga.

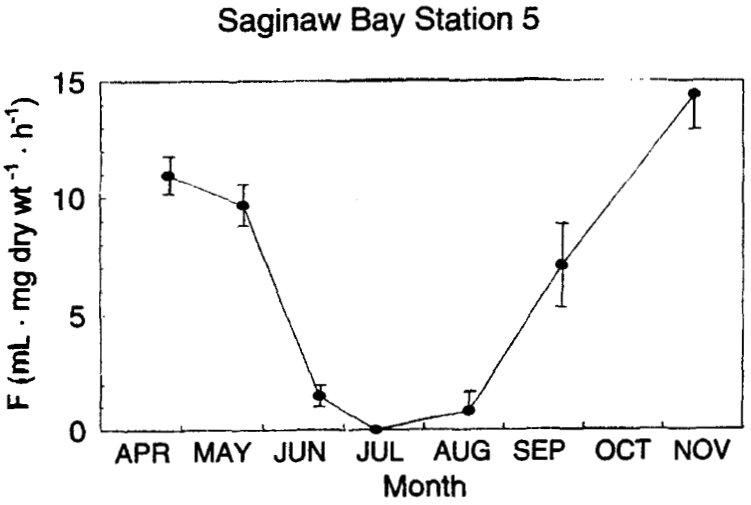


Figure 4. Filtering rate (F) of mussels was low during June, July, and August when Microcystis *was abundant.*

This offers evidence that blue-green blooms are promoted by selective filtering or rejection by the mussels.

Zebra mussels ingested a broad size range of a non-toxic colony-forming strain of *Microcystis* (from the Culture Collection of Algae and Protozoa, Cumbria, England). The result may imply toxicity is a necessary requirement for rejection of smaller colonies.

Evidence that the mussels do not harm the bloom algae (*Microcystis*) was inferred from an experiment in which mussels were confined in small beakers with natural seston for 5 days. Chlorophyll concentrations in beakers with mussels increased relative to controls. During this period the mussels were feeding actively and presumably filtered the water several times over.

Factors Affecting the Infestation of Zebra Mussels on Thunder Bay Shipwrecks: Circulation and Recruitment Patterns

Zebra mussels are present in heavy concentrations near the mouth of the Thunder Bay River, which enters Thunder Bay (Lake Huron) at its northwest end, at the city of Alpena, Michigan. Although there are major research efforts underway concerning the ecological effects, rate of spread across the United States, and control strategies for zebra mussel, little attention has focused on their effects on underwater historical and cultural resources, such as shipwrecks. The primary objectives of this project are (1) to test a hypothesis that the Thunder Bay River is the primary source of zebra mussel veligers to Thunder Bay, and (2) that the location and extent of mixing of the river plume in Thunder Bay is a primary determining factor for the establishment of successful colonies within Thunder Bay, and therefore the greatest risk factor to underwater cultural sites. This project involves the collaboration of scientists and staff at GLERL, the NBS—Great Lakes Science Center, and Alpena Community College.

During FY 95, a shoreside meteorological and Global Positioning System (GPS) reference station was established and maintained at the City of Alpena water treatment plant. We performed nearshore and river-plume studies with drifters in May and June, during which time a rapid springtime warming occurred in this area, and zebra mussels and veligers were found to be widely distributed throughout the western portion of the bay. Because of this and other physical characteristics found during our initial drifter studies, the Thunder Bay River does not appear to be of major importance to the colonization of zebra mussels in the bay.

Based upon the above findings the experimental design was modified to include all of Thunder Bay. Drifter experiments were conducted offshore in July and August and bay-wide conductivity, temperature, and depth (CTD) surveys were conducted as well. Zebra mussel sampling plates were deployed at 10 sites in the bay, with 9 of the sites co-located with shipwrecks. Weekly plankton tows were conducted at five sites in the bay from June through August to estimate veliger densities.

CLIMATE CHANGE AND VARIABILITY

The Great Lakes are excellent for climate change research because of the existence of both physical and biological/chemical measurable signals, the existence of long-term records, ongoing physical process studies, and the importance of resources (a multibillion dollar sport and commercial fishery, fresh drinking water for a large segment of the US population, a multibillion dollar commercial transportation waterway, etc.). Large lakes, including the Laurentian Great Lakes, are "closed systems" with boundaries on spatial scales that make them more tractable for study than the oceans. Many of the environmental conditions and processes related to climate that make oceanic systems important for studying climate change and variability are also present in the Great Lakes and can be studied with smaller logistical budgets. This program incorporates ERL Research Task Category GLERL 11 - Climate Variability and brings together projects that examine the potential effects of climate change on the Great Lakes water resources and ecosystem.

ERL Research Task Category: GLERL 11 - Climate Variability

Effect of Climate Change on Large-Lake Ice Cycles

The duration and extent of ice cover on the Great Lakes have a major impact on the economy of the region by impeding commercial navigation, interfering with hydropower production and cooling water intakes, and damaging shoreline structures. The ice cover also has an impact on the water balance of the lake, by affecting lake evaporation and other heat and momentum transfers, and on the biology and chemistry of the lakes, which are affected by the length and extent of ice cover. Climate change associated with global warming will possibly affect the ice cover, which in turn will affect other physical, chemical, and biological processes. Objectives of this project include (1) developing improved models to better stimulate the seasonal cycle of ice formation and loss on the Great Lakes, (2) estimating the Great Lakes ice cover for past winters, and (3) providing historical information on ice cover trends, cycles, and other variations that will be useful in placing the ice cover of the 1990s and beyond in historical perspective.

A study of the 1993/94 winter and Great Lakes ice cycle was completed, revealing that winter 1994 was one of the coldest in over a decade. Winter severity in the Great Lakes affects both the ecosystem and economy of the region.

A computer animation of long-term average ice cover and water temperature was made available over GLERL's anonymous file transfer protocol (FTP) server. This animation makes it possible to visualize climatological spatial and seasonal trends in ice formation and loss and the climatological seasonal and

spatial patterns of water temperature during the spring warming, summer maximum, and fall cooling periods.

Thermal Structure Monitoring for Climate Change

The main objectives of this project are (1) to develop improved climatological information by means of observations, new instrumentation, and improved analysis of the distribution and variability of coastal and offshore temperatures and by studying their dependence on meteorological and hydrological forces, with emphasis on potential changes in climate, and (2) to concurrently provide data for improving numerical models that can simulate and predict the thermal structure in the lakes.

In FY 95, the entire Thermal Structure Monitoring project was reexamined and redesigned. The number of subsurface moorings in Lake Michigan was reduced to one. The new mooring has integrated the temperature and current measurements into one string of instruments. This string contains 5 current meters and 10 independent temperature sensors and data loggers plus 1 near surface sensor with pressure measurement capabilities.

Impacts of Climate Change on the Hydrology of the Great Lakes

The primary goal of this task is to determine potential impacts of future climate change on the hydrology of the Great Lakes basin, and specifically on net basin water supplies. Of particular concern is how various climate regimes may affect variability from year to year in net basin supplies and in lake levels.

In FY 95, historical climate scenarios, based on 41-yr data periods from the southeastern and southwestern continental US, were used in hydrological models of the Great Lakes to examine possible changes in variability associated with various hydrological conditions. We used GLERL's conceptual models for simulating moisture storages in, and runoff from, the 121 watersheds draining into the Laurentian Great Lakes, over-lake precipitation into each lake, and the heat storages in, and evaporation from, each lake. We combined these components as net water supplies for each lake and estimated lake levels and connecting channel flows to consider transposed climate scenarios. We transposed four climate zones, ranging from 6° south and 0° west to 10° south and 11° west of the Great Lakes, to the Great Lakes area. These represent analog climates that could occur over the Great Lakes basin under global warming.

Average air temperatures increased between 4 and 11°C, and precipitation ranged from 80% to +170% of the current climate, over various lakes under various scenarios. These resulted in Great Lakes whole-basin water supply changes from -1% to -54% of the current condition. The higher air temperatures under the transposed climate scenarios led to higher over-land evapotranspiration and lower runoff to the lakes with earlier runoff peaks, since snowpack is reduced up to 100%, and the snow season is eliminated in some scenarios. This also resulted in a reduction in available soil moisture. Water temperatures increased and peaked earlier; heat resident in the deep lakes increased throughout the year. Mixing of the water column diminished, as most of the lakes become mostly monomictic, and lake evaporation increased. Water supplies decreased dramatically for the two driest scenarios, with Lake Superior becoming a terminal lake. Also, lake level variability increased for all lakes for most of the scenarios. Maximum lake levels exceeded the recorded maxima for several scenarios on the lower lakes.

NEARSHORE PROCESSES

Wind and waves are primary driving forces for water movements in the oceans and lakes and are major factors in determining lake hydrodynamics. Understanding these processes, especially in the nearshore area, will enable us to develop models to identify, forecast, and assist in managing or mitigating nearshore water quality and natural resource problems. The specific scientific objectives of this program are to (1) synthesize the results of research on large lake hydrodynamics, biological processes, and water chemistry, with emphasis on the nearshore region, and apply them to practical problems of coastal environmental management and planning, and (2) sponsor basic and applied research into critical coastal environmental problems. This program incorporates one major ERL Research Task Category: GLERL 02–Nearshore Hydrodynamics.

ERL Research Task Category: GLERL 02 - Nearshore Hydrodynamics

Milwaukee harbor and its nearshore environment were chosen as a research site under this program in 1993, because of the outbreak of *Cryptosporidium* and the related human death toll and illnesses in the Milwaukee area. The Milwaukee area can also serve as a surrogate for other important urbanized coastal areas in the Great Lakes. This work has been conducted in collaboration with researchers at the University of Wisconsin and the Wisconsin Department of Natural Resources.

Current Measurements in the Nearshore Area

This project is designed to characterize the three-dimensional structure of physical and biological fields in the nearshore region of Milwaukee, Wisconsin and determine the interaction between nearshore and offshore areas. Last year, a National Data Buoy Center (NDBC) buoy was deployed near Milwaukee Harbor in western Lake Michigan, and a current meter mooring was deployed near the NDBC buoy. Three additional current meter moorings were deployed across the lake, and meteorological data from land stations were obtained and archived.

In FY 95, nearshore (23 m depth) current and temperature data were collected from August 1994 to November 1995 at two depths. The data show distinct seasonal characteristics that impact the cross-shore and longshore transport. Ancillary data, e.g. meteorological data from NDBC buoy 45010 and current measurements by other investigators and from other years, are being incorporated in the analyses.

Additionally, three current meter moorings on a transect between Muskegon and Milwaukee that had been deployed in May 1994 were retrieved in June 1995 (Figure 4). The data are in the initial processing stage. The purpose of the measurements is to attempt

to estimate cross-shore interaction between nearshore and offshore waters, and correlate sediment deposition in sequential sediment traps with currents.

Nearshore Hydrodynamics and Wind Wave Studies

Surface waves in the Great Lakes are primarily generated by wind. As these surface waves propagate from the deep water toward the coastal nearshore region, decreasing depths and bottom effects influence near-bottom orbital motions, modifying the wave kinematics, and bringing-on shoaling, refraction, diffraction, and breaking in the waves. This leads to the inception of longshore and cross-shore currents, and thus, nearshore waves decisively affect the transport, fates, suspension, and resuspension of coastal sediments and pollutants.

While oceanic nearshore wave studies have been active in recent years, studies of nearshore Great Lakes have been conspicuously lacking. The objective of this project is to understand and quantify the impact of nearshore surface wind waves on the transport, fate, suspension, and resuspension of coastal sediments and pollutants.

The resources and focus of this project were redirected in 1993 to the Milwaukee area study. In FY 95, surface wind, wave, and temperature measurements were continued in the nearshore Milwaukee area using the NOAA Data Buoy Center instrumented buoy 45010. These data were collected and added to data from previous field years and made available to our collaborators at University of Wisconsin for nearshore circulation and flow models.

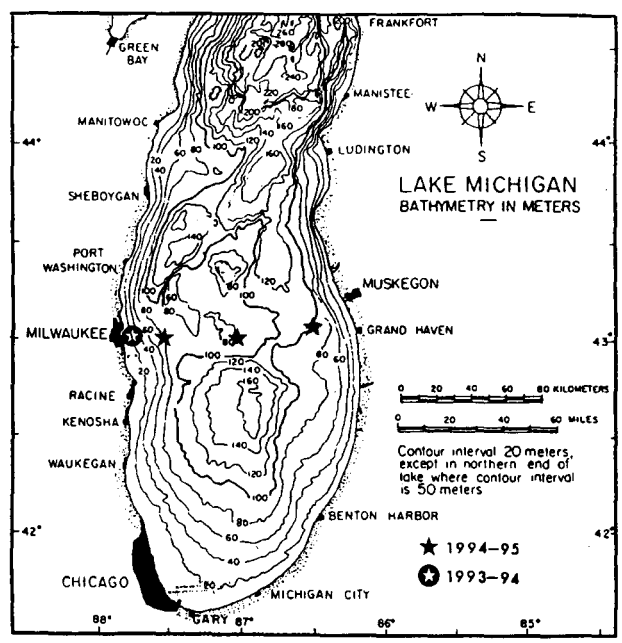
Figure 5. Location (stars) of the three current meter moorings on the midlake ridge in Lake Michigan, 1994-95.

Lake Circulation and Bottom Boundary Layer Studies

This project has been primarily a long-term study of the bottom boundary layer in Lake Michigan. It is based on measuring bottom currents and sediment resuspension to study the physics of the bottom boundary layer, and to relate the frequency of sediment resuspension in varying water depths and sediment types to the causative forces driving lake circulation.

In 1993 the continuing work in Lake Michigan was deferred to respond to a Congressional requirement to conduct work in Lake Champlain. We established a new research activity under this project which is in collaboration with local Lake Champlain scientists at Vermont's Middlebury College, and is focused on determining the circulation and sediment resuspension dynamics of Lake Champlain.

Data on water mass exchange processes between the main basin of Lake Champlain and several of its sub-basins were collected. In FY 95, data collection in the north end of Lake Champlain was completed. All field data from 1992-1994 have been compiled and edited. An archive of these data is available from both GLERL and Middlebury College. Development of models to simulate Lake Champlain's hydrodynamics was begun, and several reports are in preparation.



BIOGEOCHEMISTRY RESEARCH

Great Lakes and coastal ecosystems are continually exposed to various stressors such as increased or decreased nutrient loads, human-induced changes in the carbon cycle and climate, and the introduction of toxic contaminants. The goal of this program is to help answer questions and address issues about the system's biogeochemical response to these stressors. This program contains ERL Research Task Category GLERL 07–NECOP, and GLERL 08–Biogeochemistry in Lakes and Coastal Ecosystems.

ERL Research Task Category: GLERL 07 - NECOP

The Nutrient Enhanced Coastal Ocean Productivity (NECOP) Program is one of a series of NOAA-wide programs dealing with major problems in the coastal ocean. The central hypothesis is that increased nutrient input from the Mississippi River has led to increased productivity, with undesirable consequences for the nearshore region of the northern Gulf shelf.

Retrospective Analysis of Nutrient Enhanced Coastal Ocean Productivity in Sediments from the Louisiana Continental Shelf

The objectives of this project are to (1) identify areas in the coastal region where sediments with coherent geochronologies of approximately 200 years can be collected, and (2) examine the selected cores for tracers of past water and ecosystem conditions (e.g., carbon, nitrogen, diatom frustules, and stable isotopes).

All samples were analyzed this FY and data synthesis was begun. Paleo-reconstructions of the regional productivity and intensity of hypoxia revealed that productivity began to increase in the northern Gulf shelf early in the 1950s, coincident with the increase in nutrients (nitrogen) from the Mississippi River. It is clear that productivity and hypoxia/anoxia have a large anthropogenic component. Interpretation is continuing and further synthesis products will be forthcoming.

The Fate and Effects of Riverine (and shelf-derived) Dissolved Organic Nitrogen on Mississippi River Plume/Gulf Shelf Processes

The amount, composition, and biological lability of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) may be important factors affecting productivity in the Mississippi River Plume/Gulf Shelf (MRP/GS) region. Specifically, we hypothesized that riverine DOC and DON supply a significant portion of total heterotrophic and autotrophic nutrients for growth in the MRP/GS system. The importance of dissolved organic matter (DOM) to microbial growth rates in the MRP/GS is being evaluated by (1) characterizing the chemical and isotopic composition of DOC and DON in the river outflow and offshore stations, and (2) examining the biological reactivity of the DOC and DON. This project is being conducted in collaboration with researchers at the University of Texas at Austin.

In FY 95, sample analysis and data synthesis from the last NECOP cruise in July 1993 continued. Significant results from this research include the development of a conceptual model that shows different modes of

cycling for dissolved organic carbon and nitrogen components in surface waters of the Mississippi River plume. Available organic nitrogen appears to mainly cycle rapidly through low molecular weight compounds, such as free amino acids, that are rapidly assimilated by bacteria for biomass accumulation. In addition to this mode observed for low molecular weight organic compounds, significant quantities of carbon appear to recycle as high molecular weight organic compounds with a high C:N ratio that provide energy for bacterial respiration. These compounds are labile but do not turn over as rapidly as the low molecular weight organic nitrogen compounds. These findings give insights about processes responsible for the development of hypoxia in certain regions of the northern Gulf of Mexico.

A second significant result was the development of an experimental index to demonstrate the presence of available labile organic carbon in natural waters. This index was defined as the fraction of assimilated Amino acid-^{15}N that was recovered as ^{15}N-Ammonium (ANRA) after addition and incubation of high levels (4 mM) of ^{15}N-labeled amino acids to sea or lake water. ANRA is inversely related to the quantity of available labile organic carbon (with a high C:N ratio) because if other sources of carbon are available to support bacterial respiration, the bacteria are able to incorporate the added amino acids into biomass rather than respire them and release the nitrogen as ammonium. This index provides a tool to help evaluate organic carbon and microbial dynamics in the Gulf of Mexico and in other ecosystems such as Saginaw Bay and Florida Bay. This ANRA index is being used in our studies of all three ecosystems.

Results on the role of water column nitrification in O_2 depletion—hypoxia production shows that in addition to respiration and Fe+Mn oxidation (which is small), the oxidation of NH_4^+ (nitrification) occurs within the water column at intermediate salinities in the river plume. Measurements showed that up to 50% of the oxygen consumed in these mid-salinity waters is through nitrification. This reaction is usually confined to the sediment-water interface, but production is so high that the appropriate microbial communities can survive within the water column. This process had not been included in our earlier models of O_2 depletion since it is extremely rare, however it will be critical to include it in order to appropriately simulate nutrient cycling and O_2 depletion.

Primary Production and Vertical Flux of Organic Carbon

The goal of this project is to determine primary production and vertical flux of organic carbon in the Gulf of Mexico. Objectives are to (1) characterize photoautotrophic community dynamics in relation to optical conditions, nutrient inputs, and other aspects of the physical and chemical environment, (2) examine the relationship between phytoplankton production, growth, and biomass and the vertical export of fixed carbon from the service waters of the MRP/IGS, and (3) develop conceptual and predictive models that describe the production and fate of fixed carbon as a function of optical conditions, nutrient inputs, and other environmental variables.

Overall, the project has been very successful in addressing the specific goals, and 11 papers have been published. To summarize, the rates of phytoplankton production and growth in the outfall region of Mississippi River are primarily controlled by the supply of nitrogen from the river. In general, both growth and loss rates are very high in this region. The fate of this fixed carbon appears to be primarily controlled by phytoplankton composition. This project has been completed.

ERL Research Task Category: GLERL 08 - Biogeochemistry in Lakes and Coastal Ecosystems

Environmental Radiotracers

This research emphasizes the use of radiotracers to identify and model fundamental lake/watershed transport processes in diverse aquatic systems. Objectives of the project are to (1) identify principal transport mechanisms in aquatic systems and determine transport scales and rates, (2) investigate and quantify sediment depositional and geochemical processes, (3) develop geochronological information from sediment radionuclide profiles for paleolimnological studies, (4) determine and account for relationships between system loadings and sedimentary records of tracers, contaminants, and other constituents, and (5) apply techniques, insights, and models arising from radiotracer studies to specific problems of ecosystem dynamics, environmental contamination, and regional effects of climate change. There are many sub-projects within this project, many of which involve collaboration with investigators from other agencies.

Florida Bay: this project was one of several requiring major efforts in FY 95. This project seeks to understand the causes of the degradation of the bay that has occurred over the past several decades (decline in bird and animal populations, die-back of sea grasses and mangroves, and episodes of plankton blooms) by assigning dates to sediment layers to reconstruct the history of biological and chemical changes in the system. In FY 95, additional sediment cores were collected, and numerous samples were analyzed at the GLERL laboratory for ^{226}Ra. ^{210}Pb data generated at the US Geological Survey (USGS) Denver laboratory were combined with the GLERL results to develop a recent chronology of sediments at a key site in the Bay. Chronological models were developed and applied to radionuclide profiles. Selected samples of cores were analyzed for lead by collaborators at the University of Michigan School of Public Health, as the combination of Pb and ^{210}Pb proved critical for dating recent sediments.

Lake Michigan Mass Balance Program: another major focus this FY has been on the Sedimentation in Lake Michigan project, which is part of the EPA-sponsored Lake Michigan Mass Balance program. Results from this project will provide the basis for calibrating EPA-developed mass balance models for Lake Michigan and help to determine the history of accumulation of biogenic silica, mercury, and other contaminants in the lake over the last 100 years. We began this year by coring in the lower half of Lake Michigan. A total of 19 box cores were collected, subcored, and sediment sections isolated for analysis. In September, additional box cores were collected at 31 sites using the EPA vessel, R/V *LAKE GUARDIAN*. Preliminary results indicate that changes are required in the models to account for differences in radiocesium and radiolead profiles, which emphasize horizontal redistribution processes over local mixing of sediments.

Florida Everglades: a third major effort was devoted to the use of radionuclides to determine rates of soil accretion in the Florida Everglades. This project is part of a multi-million dollar project of the South Florida Water Management District to re-size vast storm treatment areas and calibrate water quality models. Samples from 16 cores received from the University of Florida were analyzed for ^{137}Cs. Additionally, selected samples were analyzed for ^{210}Pb. We determined that the predictions of the regional loading of radiocesium were developed based on incomplete records of fallout to the Miami area. Vertical sediment transport models were adapted to account for ^{137}Cs in terms of advection and diffusive migration of ^{137}Cs through pore fluids.

Terrace Reservoir, Colorado: the objectives of this sub-project are to determine the history of contamination of the Terrace Reservoir and establish sediment

transport parameters for modeling mining residues. This year, three sediment cores from the lake were analyzed for ^{137}Cs and ^{210}Pb. Preliminary application of vertical sediment transport models indicates changes over time consistent with the history of upstream mine tailing operations. This project is in collaboration with the USGS.

Coeur D'Alene Lake, Idaho: work on this project has been completed. Coeur D'Alene Lake suffers from widespread and severe heavy metal contamination of its bottom sediments. Under this project, GLERL was able to develop a history of contamination, extracted from sediment cores with well established geochronologies, which shows that the onset and subsequent record of sediment contamination, is consistent with the history of mining activities in the drainage basin. This project is in collaboration with the USGS.

Carbon Biogeochemistry in Lakes and Coastal Ecosystems

This project focuses on processes regulating the major biogeochemical cycles and fluxes in lakes and coastal ecosystems, with an emphasis on carbon. Carbon is central to many of the perceived issues related to the impact of humans on the environment. The GLERL Climate Change and Variability, Aquatic Contaminants, and Ecosystem Dynamics Programs will all be affected by ongoing changes in the carbon cycle. It is generally agreed that climate change is driven by increasing atmospheric concentrations of certain gases, especially CO_2 and CH_4. In addition to potentially altering global and local climates, the CO_2 increase will have a major impact on the carbon geochemistry of the Great Lakes, such as the elimination of annual $CaCO_3$ precipitation from the water column, which will impact trace contaminant removal, primary productivity, and zooplankton grazing. The long-term goal of this research is the development of a hierarchy of calibrated numerical models of processes regulating the biogeochemical cycle of carbon in the Great Lakes, with subsequent applications to coastal ecosystems. In order to accomplish this, we need to better understand important processes that affect the biogeochemical cycle of carbon, including CO_2 gas exchange, remineralization of organic carbon, formation of $CaCO_3$, vertical flux of carbon species, dissolution rate of $CaCO_3$, remineralization of carbon in sediments, and transport across the sediment water interface.

Lake Michigan: In FY 95, sequencing sediment trap samples and net plankton from GLERL's 100 m deep monitoring station off Grand Haven were analyzed for carbon and nitrogen isotopes. There is a large seasonal pattern in both isotopes, probably due to nutrient depletion and productivity (Figure 4). We need to quantify these patterns in order to improve our paleoreconstructions from isotopic and other information in sediment cores.

Green Bay, Wisconsin: Seven cruises were completed in Green Bay, Lake Michigan, to study the air-water exchange of CO_2 and CH_4. Samples for dissolved inorganic carbon and isotopic composition were collected. These data are required for a Green Bay carbon model. This activity is supported by the Wisconsin Sea Grant Program and is conducted in collaboration with academic scientists and students at the University of Wisconsin-Milwaukee, and Michigan State University.

Yellowstone Lake, Wyoming: With the assistance of the USFWS, we successfully deployed three arrays of our 4" diameter single-sample sediment traps in Yellowstone Lake in June 1995. In mid-September, we successfully retrieved these traps and deployed two sequencing sediment traps for a whole year of collection. Our primary interest is in particle mass fluxes, and nutrient and carbon cycling. However, this lake is also responding to a major nonindigenous specie, lake trout, which is expected to have a major impact on the lake's ecology and also affect the fish-eating birds within the park. The trout were first found in 1994, and subsequent surveys have identified 3 year-classes going back to 1991. The available habitat and prey in Yellow-

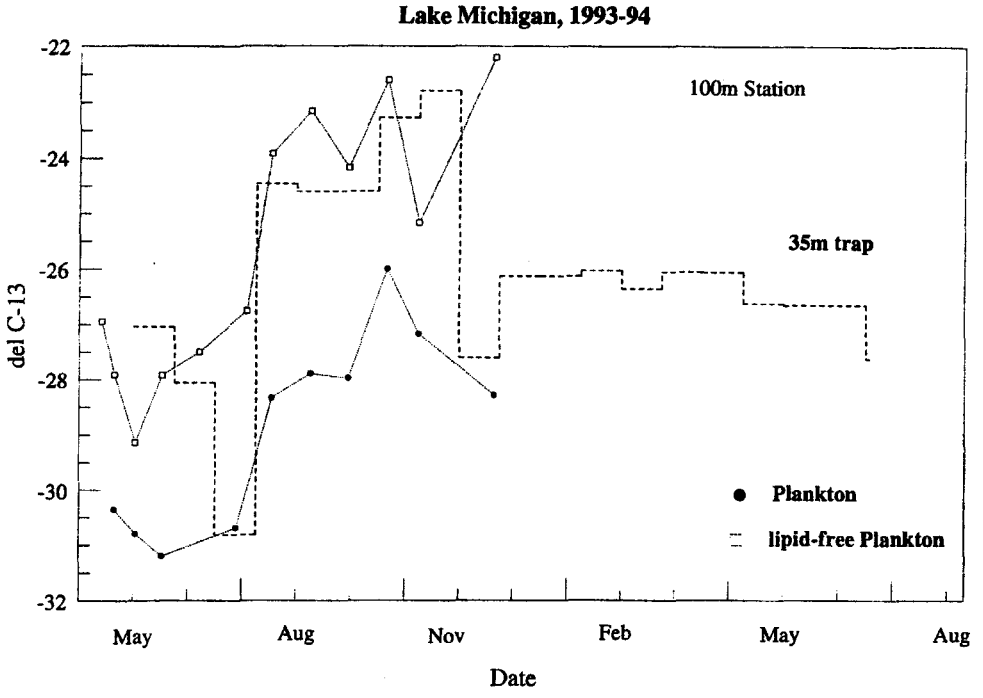


Figure 6. Carbon isotope distribution for sediment trap and net plankton in Lake Michigan. The measured isotopic distribution measured in traps and net samples provide considerable information on the annual cycle of this element in the lake. In spring, when the lake is well-mixed, the trap samples are a mixture of plankton and, isotopically heavy, resuspended sediments. After stratification, the trap carbon is the same as net plankton for one 16-day collection interval; this is the period of tight pelagic-benthic coupling. Grazing pressure from zooplankton has not caught up with the spring bloom of diatoms that settle rapidly to the bottom and supply the benthos with a rich source of food. Subsequent trap samples (at 35 m) from the stratified period are significantly heavier than net plankton; little of the isotopically light plankton lipids survive the bacterial oxidation in the epilimnion. After stratification breaks down, the traps re-acquire the isotopic composition of resuspended sediment.

stone Lake are considered excellent, and the invading lake trout are now predicted to become the major top predator, replacing, and virtually eliminating, the present cutthroat trout. The data collected will provide information of the lake's status very early in this process. This activity is conducted under the National Undersea Research Program (NURP) and Wisconsin Sea Grant funding in collaboration with academic scientists at the University of Wisconsin–Milwaukee.

Nitrogen Dynamics

Nitrogen occurs in all living organisms and is an important element in aquatic ecosystems. Nitrogen is dynamic in all aquatic ecosystems and occurs in several forms in the sediments, water, and the atmosphere. Nitrogen transformations are often biologically mediated in aquatic ecosystems. The forms, fluxes, and transformation rates of nitrogen compounds therefore reflect organism and ecosystem dynamics in freshwater and marine environments.

Although nitrogen biogeochemistry is a crucial part of aquatic ecosystem dynamics, our understanding of nitrogen cycling in fresh water and marine systems is incomplete, in part because methodology is often inadequate to efficiently determine nitrogen forms and transformation rates. In contrast to carbon and phosphorus, nitrogen does not have radioactive forms (with sufficient half lives) that can be used for tracer studies. Nitrogen transformations are usually similar in fresh and salt water environments, but some important

differences have been observed. Understanding the reason(s) for such differences may provide a basis for management practices that would minimize the effects of nitrogen enrichment in marine coastal waters. Comparative studies of nitrogen dynamics in fresh and salt water systems will provide insights on similarities and differences between the two systems and should improve our understanding of nitrogen dynamics in both systems.

Great Lakes: In FY 95, comprehensive experimental data on seasonal natural abundances of nitrogen isotopes and on nitrogen cycling rates through the various organic and inorganic pools were collected in Lake Michigan to determine rates and mechanisms of pelagic nitrogen cycling. These experiments will provide one of the most comprehensive data sets of N-cycling in a freshwater ecosystem. Significant results to date show (1) significant amounts of recycled ammonium are nitrified rather than directly taken up by phytoplankton, and (2) large shifts are observed in the isotopic composition of DON. These results imply that, contrary to previous beliefs, the DON pool can have a relatively high turnover rate in surface waters. Nitrogen sample preparation techniques for mass spectrometry, that were adapted or developed in this investigation, are currently being incorporated into GLERL's sample-preparation protocols.

Laboratory experiments on water collected from Old Woman Creek, Lake Erie, and Saginaw Bay, Lake Huron, have shown the first evidence for a cascading trophic effect on nitrification (Figure 5). These experiments demonstrated that grazing of bacteria by heterotrophic protozoa, which are, in turn, grazed by larger zooplankton or filtered by zebra mussels, can have an important effect on nitrification rates in the water column. This result is significant because nitrification is a globally important process and mechanisms controlling it in different ecosystems are not completely understood. Biotic trophic effects as a mechanism controlling nitrification have not been considered before in limnology or oceanography.

Florida Bay: Following up on our August 1994 trip to Florida Bay, a second field trip was taken during February-March 1995 to examine (1) nutrient-limitation of phytoplankton and bacteria, (2) sediment-water nutrient fluxes and oxygen demand, (3) water-column nutrient transformations, and (4) lower food web

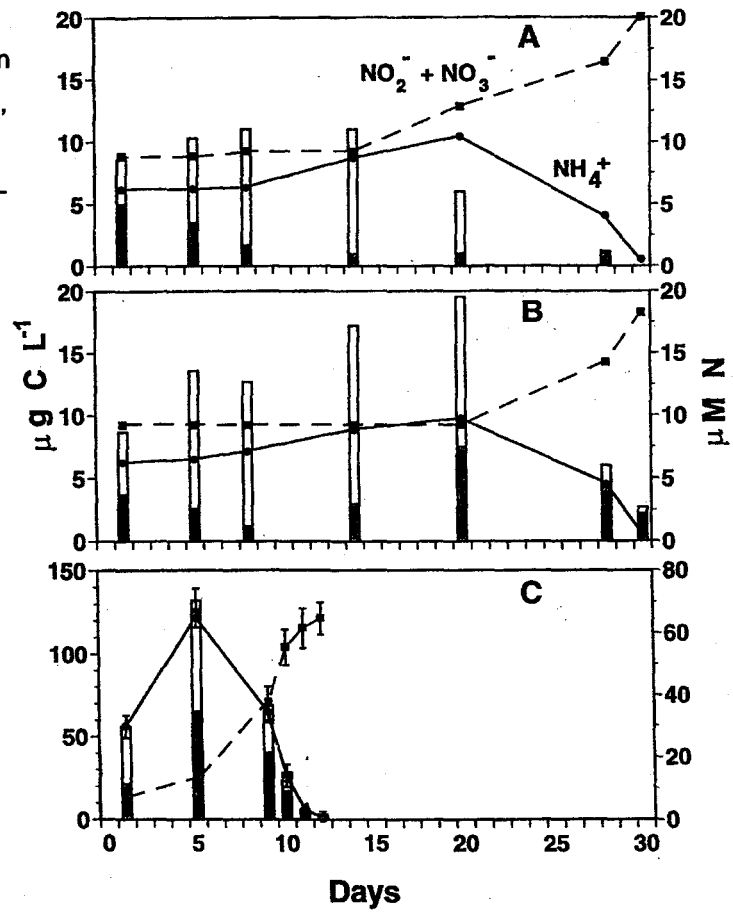


Figure 7. Dynamics of ammonium (solid line with dots), nitrates (dashed line with squares), and biomass of protists (open bars=flagellates, striped bars=ciliates) in Experiment 1. (A) In the bottle with unfiltered Saginaw Bay water, (B) in the bottle with 53-micron filtered Saginaw Bay water, and (C) in duplicate bottles with unfiltered Old Woman Creek water (+/- SE). The figure demonstrates that as the biomass of protists declined due to zooplankton grazing, nitrification increased due to diminished protists grazing on nitrifying bacteria.

abundance and composition in selected regions of Florida Bay. Detailed bottle and sediment-chamber experiments were conducted on an east-west transect of northern-bay stations (near Duck, Rankin, and Murray Keys), and at a more central station (near Rabbit Key). Seston nutrient composition, dissolved nutrient levels, and lower food web organisms were examined at a total of 12 stations.

The severity and spatial distribution of phytoplankton nutrient-limitation were assessed by measuring suspended and dissolved nutrient concentrations and ratios and by conducting nutrient enrichment experiments.

Preliminary results from these experiments show that the degree of phytoplankton P-limitation in Florida Bay decreases from east to west where N becomes a co-limiting nutrient. Internal nutrient cycling in the water, as well as at the sediment-water interface, is a very important supply mechanism for available nutrients. Bacterial uptake accounts for a large fraction of water column phosphorus demand. The microbial food web plays a fundamental role in both nutrient cycling and lower food web dynamics and is an important indicator of water quality degradation and food web changes in the bay.

FACILITIES

GLERL's Ann Arbor research facility contains 17 laboratories equipped with general and specialized laboratory equipment including a stable isotope mass spectrometer (SIMS), a fully equipped radiotracer laboratory, several gas chromatographs and liquid scintillation counters, a high pressure liquid chromatography system, a multi-channel Coulter Counter, growth chambers and incubators, stereo and inverted microscopes, and a fully equipped multi-purpose epifluorescence microscope. GLERL also has high speed micro-cinematography equipment located in a temperature-controlled environmental chamber that is maintained for conducting experiments and growing biological cultures at low temperatures.

GLERL's Lake Michigan Field Station, located in Muskegon, includes three buildings and research vessel dockage. One building contains a research laboratory, offices, and research storage. One scientist conducts biological research on-site.

Computer Facility

The GLERL computer facility is a Local Area Network (LAN) of computing resources. This network consists of 8 VAXs, 10 UNIX/RISC workstations, 6 Macs, and about 80 PCs connected via ethernet. The LAN is connected to the Internet via MichNet.

A variety of scientific applications, including real-time and near real-time data acquisition, data reduction, graphical display, image processing, statistical and mathematical analysis, etc., are accessed by GLERL personnel and collaborators.

GLERL is the Great Lakes Redistribution Node of the National Ocean Communication Network (NOCN) and makes satellite imagery available to government, private, and academic users throughout the Great Lakes region. GLERL is also a partner in the Great Lakes Commission's Great Lakes Information Network (GLIN).

Library

The GLERL library's collection supports the laboratory's research activities. The collection reflects an emphasis on freshwater studies—particularly in the Great Lakes basin. Current holdings include 6,269 periodical volumes, 8,655 book/technical report volumes, and 233 dissertation volumes in subject areas of climatology, contaminant organics, hydraulics, hydrology, ice, limnology, mathematical models, meteorology, nutrients, oceanography, sediments, and wave motion. The library currently receives 213 subscription titles. Books dating from 1980 onward, as well as many earlier books, are included in the online union catalog by the Online Computer Library Center, Inc. (OCLC). These books are also reflected in the NOAA Library Catalog available via remote online access, commercial CD-ROM, and the library's public access catalog workstation. Interactive searches may be made of library records using Boolean search options and displays in various formats. GLERL library facilities are

open to the public during normal business hours.

During FY 95, the library expanded services with the addition of four new CD-ROM databases making a total of 29 titles supporting bibliographic and reference needs. The public services area was also enhanced with numerous new resources on the internet.

Future plans include the addition of a read only version of the PC-based databases used for reprints and dissertations to facilitate access by library users. The library staff also hope to have Internet access to a newly implemented NOAA libraries catalog that will include the GLERL library holdings.

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

Information Services—Publications Unit

The Publications Unit provides editorial and publications support to the scientific staff, prepares and distributes GLERL publications, responds to publications and information requests from the public, and produces reports, brochures, and displays concerning GLERL's work.

Research results published during FY 95 include 72 scientific publications; 60 formal presentations were given. Requests for information this fiscal year were received from universities, schools, media, federal, state, and local government agencies as well as from private citizens in the U.S. and 49 foreign countries.

The establishment of GLERL's home page on the WWW (www.glerl.noaa.gov) has created an excellent avenue for dissemination of our research products. Many complete publications have been added as well as a complete history of GLERL publication abstracts, covering the years 1974-1995. Additionally, several NOAA Technical Memorandum and Data Reports have been converted and placed on the WWW. The number of GLERL products available on the WWW will continue to increase as conversion continues on past, current, and future products. The number of items sent to requestors using both the Internet and traditional methods totalled 42,532.

Marine Operations and Instrumentation Laboratory

Vessel Operations. The Research Vessel *SHENEHON* is owned and operated by GLERL. The *SHENEHON* is based at the Lake Michigan Field Station in Muskegon, MI and is the primary platform used in support of GLERL's field operations. The *SHENEHON* was built in 1953. It is 65.6 feet long, with a 6.5-foot mean draft, a 700-nautical-mile cruising range, and a 10-knot cruising speed. Navigational equipment includes a Sperry Gyrocompass, Raytheon Radar, GPS and two LORAN-C positioning systems, Sperry Auto Pilot, and a Raytheon Depth Sounder. An electro-hydraulic articulated crane is used for deployment and retrieval of water and bottom sediment samplers and heavy instrument moorings. Electrohydraulic winches handle hydrographic wire and multiconductor cable for sample casts and *in situ* measurements. An on-board wet laboratory is available for on-site experiments and sample processing.

Two small boats are used as auxiliary research platforms. A 23-foot Monark workboat, the *Remorse*, is outfitted as a research launch with navigational and safety equipment and an electric winch and crane. A SeaArk workboat, the *CYCLOPS*, is 28.5 feet in length, including a 2.5 foot deck extension, and is used primarily for the Non-Indigenous Species Program in Saginaw Bay and in Lake St. Clair.

During FY 95, cruises were made in Lake Michigan, Lake Huron, Lake Erie, Lake Ontario, the Straits of Mackinac, and in Saginaw Bay.

Marine Instrumentation Laboratory. Our engineering and technical staff acquire and maintain scientific equipment and when necessary, design and develop equipment to collect data in the Great Lakes. They work

closely with GLERL researchers to ensure that instruments are compatible with their needs. They also participate in field experiments by providing support for the deployment and retrieval of field equipment, assistance with the collection of samples and data, and in-field maintenance or repair of equipment.

In FY 95, MOIL staff began the design of an automated water sampling system for deployment in Lake Michigan and a control system for an underwater video microscope. A major re-design of a wave measurement buoy data collection system was tested and deployed.

MOIL members also prepared equipment for use throughout Lake Michigan in support of the EPA LMMB project, in Saginaw Bay in support of zebra mussel research, and in Lake Champlain hydrodynamic studies. GPS drifter buoys were prepared for deployment in Lake Huron's Thunder Bay in support of investigations on bay currents and zebra mussels. Also in support of the Thunder Bay effort, a meteorological station was installed to provide real-time weather data through the GOES satellite system.

Geographic Information System Laboratory

The development of GLERL's GIS laboratory was initiated in the fall of 1992. The laboratory is composed of commercial GIS and relational data base software resident on a UNIX workstation, 10 GB of external disk storage, a high accuracy digitizer, a color thermal wax transfer printer, and a CD-ROM drive. A full-time GIS specialist operates the system.

GLERL's Data Collection Equipment

Current Measurement, Fixed Point
39 AMF Vector Averaging Current Meters
5 Marsh McBirney 585 Current Meters
3 ODE Current Meters with Thermistor Strings
1 Sontek Acousic Doppler Current Meter
1 RD Instruments DR-1200 Acoustic Doppler Profiler (ADCP)
2 SC-600 Narrow Band ADCPs
1 SC-600 Broad Band ADCP

Current Measurement, Drifters
7 LORAN Drifter Buoys
10 GPS Drifter Buoys

Wave Measurement
1 Datawell Waverider Buoy

Miscellaneous Equipment
10 Computer Controlled Sequential Sediment Samplers
1 Sea-Bird Real-Time CTD, PAR, pH, Oxygen Measurement and Water Sampling System
3 Sediment Transport Measuring Tripods
2 Meteorological Data Collection Platforms
16 Acoustical Releases
6 TR-1 Aanderaa Thermistor String Recorders
7 TR-7 Aanderaa Thermistor String Recorders
16 Branckner Temperature Loggers
4 CTDs with fluorometer and transmissometer

If you would like to be added to GLERL's mailing list, or would like additional information on GLERL's research, please write to:

Publications Office
NOAA/GLERL
2205 Commonwealth Blvd.
Ann Arbor, MI 48105

OUTREACH

The GLERL mission includes the development of environmental information, data, and service tools for users in government, academia, and private organizations. Staff participation on boards, commissions, task forces, and committees helps to identify environmental information needed by our users and to guide our research focus and the development of usable products.

GLERL has regular interactions with dozens of organizations and collaborates with scientists and managers from a variety of research institutions and agencies. Following is a list some of these partnerships and collaborations:

- *NOAA/National Research Council (NRC)/Postdoctoral Research Fellowship Program* - GLERL hosts one or two NRC post-doctoral researchers each year, usually for 2 years.
- *Cooperative Institute for Limnology and Ecosystems Research (CILER)* - this institute promotes collaborative research between GLERL scientists and academic scientists from throughout the Nation, but primarily from the Great Lakes basin, addressing a wide variety of topics.
- *International Joint Commission (IJC)* - GLERL staff actively participate on boards and committees of this policy recommending bi-national commission with oversight of Great Lakes water quantity, lake levels, water quality, and ecosystem issues for both the US and Canada.
- *U.S. EPA* - since the mid-1980s the EPA Great Lakes National Program Office, the EPA Large Lakes Research Station, and the EPA Environmental Research Laboratory in Duluth, MN have worked closely with GLERL scientists to plan, conduct, and/or participate in major multi-institutional, multi-disciplinary research programs, such as the Upper Connecting Channels Study, the Green Bay Mass Balance Program, the Lake Michigan Mass Balance Program, and EMAP.
- *Great Lakes Commission* - this eight-state compact organization represents the interests of the eight Great Lakes states and is a leader in evaluating and promoting environmental and economic policy in the Great Lakes basin. GLERL scientists work closely with Commission staff to provide scientific expertise and advice on a variety of environmental and policy issues, and serve on several task forces and panels sponsored by the Commission.
- *USGS* - GLERL's radionuclide geochemistry and retrospective analysis expertise is the basis for several important collaborations with scientists at the USGS, including sediment-derived environmental chronologies related to Florida Bay, the Everglades, the record Midwest floods of 1993, and several contaminated lake sites.
- *U.S. Army Corps of Engineers* - GLERL's roots go back to the Corps of Engineers, and close ties have been maintained with the Corps for the entire 22 year history of GLERL. In particular, GLERL

hydrologists and physical limnologists interact with Corps staff concerning Great Lakes water levels, river flow models, and general lake circulation.

- *U.S. Coast Guard* - the Coast Guard often provides field support (ships and aircraft of opportunity) for GLERL research projects, and GLERL provides scientific expertise, information, products, and advice concerning Great Lakes environmental topics, including trajectory models used for spill response, and search and rescue, ice forecasts and historical ice cover data, and various environmental regulatory issues facing the Coast Guard.
- *Various academic institutions* - in addition to research interactions conducted through our cooperative institute (CILER), GLERL scientists regularly collaborate with colleagues at several major academic institutions, including the University of Wisconsin, Ohio State University, and Kent State University.

GLERL outreach also takes the form of presentations, and transfers of information, data, and technology.

GLERL and Great Lakes Education

In keeping with NOAA's desire to better inform the public of its research activities, GLERL is involved in a number of Great Lakes community education programs. In FY 95:

- GLERL's Lake Michigan Field Station in Muskegon held an Open House from August 25-27. The theme for this event was "Lake Michigan Science Partners '95 - Working Together to Keep our Lake Great" emphasizing cooperation among government, education, and the public in managing the Lake Michigan ecosystem. The event featured displays, exhibits, and demonstrations and was attended by approximately 500 visitors throughout the weekend.
- GLERL staff made presentations concerning the Great Lakes and GLERL programs at area schools and gave several tours of our facility to interested students and teachers.
- GLERL was represented at several community environmental awareness functions.
- GLERL staff participated as judges in science fair.
- One GLERL employee served as a contact and mentor to a group of high school science students.
- Several GLERL staff assisted local elementary school students and staff in the installation and configuration of a digital weather instrument system. Students are chosen on a daily basis to read the instruments (air temperature, relative humidity, wind speed and direction) and make a weather report over the school PA system.
- GLERL scientists provided assistance to students as they began a "Future Cities" project. The project challenged the students to design a city for the future, taking into account limited natural resources and population increases. The students focused on building an underwater city and elicited the expertise of GLERL scientists to help make their project successful. The students placed first at the regional competition and second at the National Competition in Washington, DC.
- Provided materials for a Great Lakes Environmental Educators Workshop sponsored by Ohio Sea Grant.
- Participated as a judge for the Women in Science and Engineering Conference in Washington, DC.

LakeWatch

GLERL's lead scientist at the Lake Michigan Field Station developed and coordinates a citizen volunteer sampling program on White and Muskegon Lakes. Both of these lakes are Great Lakes Areas of Concern (AOC). These volunteers measure and monitor water quality and will help the advisory councils make informed decisions on how to improve and protect the lakes.

Partners for Excellence

GLERL continues its involvement with the Science Department of the Ann Arbor Public Schools' Partners

for Excellence Program. This program seeks to enrich the schools' curriculum in the area of environmental science, particularly with respect to the Great Lakes and aquatic sciences. Partnership activities include:

- ✦ providing mentors to help students with science fair projects.
- ✦ providing practical "hands-on" experience to promising science-oriented students via participation in a *Student Volunteer Program.*
- ✦ providing information on careers in environmental science and acting as consultants for the science curriculum.
- ✦ inviting science teachers to laboratory-sponsored seminars.

Student Volunteer Program

GLERL and the Ann Arbor Public Schools established a Student Volunteer Program authorized by the Civil Service Reform Act of 1978 (Public Law 95-454). This program provides selected high school students with the opportunity to perform volunteer work at GLERL after school.

Great Lakes Education Kit

The Publications Unit has compiled and is continually updating a kit composed of materials for teachers who wish to integrate Great Lakes education into their curriculum. The kit is available on a loan basis. Contact the Publications Unit for more information 313-741-2262.

Southeast Michigan Science Fair

In conjunction with the 35th Annual Southeast Michigan Regional Science Fair, GLERL sponsored awards for outstanding projects in aquatic science in each of the Science Fair divisions: Senior Projects, Junior Projects, and Junior Models and Collections. GLERL staff (T. Croley II, T. Hunter, D. Lee, D. Schwab, H. Vanderploeg, J. Saylor, and A. Beeton) acted as general science fair judges and also as judges for the GLERL award in the Southeast Michigan Science Fair.

Satellite Technology Education Program (STEP)

This program was coordinated and implemented by the Environmental Research Institute of Michigan (ERIM). It is a NASA and NOAA program to introduce and use satellite images and data in the K-12 classroom. GLERL participates by providing CoastWatch data and products.

Take A Girl to Work Day

Each year, girls are invited to spend the day at GLERL observing and working with several GLERL employees. The girls have hands-on learning in many areas, such as statistics, the GIS, collecting and testing water samples, labelling sample containers, grinding sediment samples, and digitizing zebra mussels. They are given presentations, a lab tour, a special lunch, and a certificate for their participation in the program.

Internet Outreach
http://www.glerl.noaa.gov/

Accesses to our website showed a steady increase throughout 1995, and we continue to expand and upgrade the services available on our internet site. During FY 95, the following information was available :

- GLERL 1994-95 Programs and Plans
- CoastWatch
- Great Lakes Surface Environmental Analysis map
- CILER
- Great Lakes Bathymetry data maps
- Non-Indigenous Species
- GLERL Data and Information Services
- Pollutant Effects
- Nearshore Hydrodynamics
- Lake Erie Great Lakes Forecasting System
- GLERL history
- Climate Variability
- Water Resources
- GLERL Publications
- GLERL News
- Sample CoastWatch images
- Marine Hazards
- NECOP
- Great Lakes Topographic Relief Map
- GLERL Personnel
- Physical Sciences Division

During 1995, our Web site had a total of 38,400 outside accesses from throughout the U.S. and 50 foreign countries. The most popular items during 1995 were the GLERL Programs and Plans for 1994-95, the Great Lakes CoastWatch page, and the daily Great Lakes Surface Environmental Analysis (GLSEA) map.

About 26% of outside access to our Web site during 1995 came from U.S. colleges and universities. Activity from numerical domains accounted for about 25%, and U.S. commercial addresses about 20%. Over 10% of external accesses were from domains outside the U.S., mostly Canada. U.S. government agencies and military addresses combined for about 6% of all requests.

Great Lakes CoastWatch Data Users

Argonne National Laboratory
Bloom Trail High School
CAPAC Community Schools
Eastern Michigan University, Dept. of Geography-Geology
Environmental Research Institute of Michigan (ERIM)
Illinois Department of Conservation
Illinois-Indiana Sea Grant Program
Indiana DNR, Fish & Wildlife/Lake Michigan Investigations
Lake Superior Center, Duluth, MN
McMaster University, Environmental Hydraulics Program
Miami University, Department of Geography
Michigan DNR Forest Management Division
Michigan State University
    Sea Grant Extension—Marquette
    Sea Grant Extension—Grand Haven
    Michigan Sea Grant Program
    Center for Remote Sensing
Michigan Technological University
    Dept. Biological Sciences
    Dept. of Civil and Environmental Engineering
Minnesota Sea Grant Extension Program, Duluth Campus
Ohio State University, Dept. Civil Engineering
Ontario Ministry of Natural Resources, Lake Huron Unit
State University of New York
    Great Lakes Center, Buffalo State College
    Dept. of Earth Sciences
U.S. Army Corps of Engineers, Chicago District
U.S. Dept. of Commerce
    NOAA NWS (Central Region, Cleveland, Gaylord, Grand Rapids, Negaunee)
    NOAA Pacific Marine Environment Laboratory
U.S. Dept. of Interior
    Hammond Bay Biological Station
    National Fisheries Research Center, Great Lakes
    USGS, Water Resources Division
    Lower Great Lakes Fishery Resources Office
U.S. EPA - Environ. Monitoring Systems Lab, Great Lakes National Program Office
University of Florida, Dept. of Fish & Aquaculture
University of Illinois, Illinois-Indiana Sea Grant Program
University of Michigan - Biological Station, Dept. Biology, Dept. of Atmospheric, Oceanic and Space Science
University of Minnesota
    Large Lakes Observatory
    Center for Water and the Environment
University of Toronto in Mississauga, Erindale College
University of Wisconsin
    Madison (Wisconsin Sea Grant Program)
    Milwaukee, Center for Great Lakes Studies
Wisconsin DNR, Fisheries Management
Woods Hole Oceanographic Institute

SEMINARS

The following seminars were presented at GLERL during FY 95:

Lake Maracaibo: Current status of cleanup.
Lenin Herrera, Institute for the Control and Conservation of Lake Maracaibo, Venezuela, February 17, 1995.

The environmental status of Laguna de Bay.
Dr. Zenaida Batac Catalan, Institute of Environmental Science and Management, University of the Philippines. June 20, 1995.

Carbon and phosphorus recycling and retention in the plankton ecosystems of Lake Erie.
Rochelle Sturtevant, Water Research Institute, Kent State University. June 7, 1995.

Interaction between groundwater and lakes.
Dr. Igor Zektser, Water Problems Institute, Russian Academy of Sciences. May 23,1995.

Groundwater pollution.
Dr. Jozef Kryza, Wroclaw University, Institute of Geological Sciences, Poland. May 26, 1995.

Ribosomal RNA-based probes reveal archaea in bacterioplankton from the North American Great Lakes.
Dr. Randall E. Hicks, Dept. of Biology, University of Minnesota, Duluth. May 19, 1995.

High-resolution quaternary sequence stratigraphy of the Virginia inner shelf and coastal zone.
Anthony Foyle, Old Dominion University. March 30, 1995.

Nutritionally deficient resources and balanced diets for zooplankton.
Dr. William R. DeMott, Dept. of Biological Sciences, Indiana University, Purdue University. March 16,1995.

Turbulence and mixing in Lake Geneva.
Dr. Shuimin Zhang, Suisse Federal Institute of Technology. May 9, 1995.

Regional aquifer systems analysis.
Norman Grannemann, USGS, Lansing, MI. May 12, 1995.

Effect of contaminated sediments on invertebrates.
Dr. Jan Ciborowski, Dept. of Biological Sciences, University of Windsor, Windsor, Ontario, Canada. December 14, 1994.

Estimating net community oxygen production by modeling and data assimilation of dissolved gases.
Dr. Rebecca R. Schudlich, School of Oceanography, Univ. of Washington. December 20, 1994.

Lake circulation model studies.
Dr. Dmitry Beletsky, Institute for Lake Research, St. Petersburg, Russia. December 15, 1994.

Dynamics of the Great Salt Lake: Climatic connections, system identification, predictability, and forecasting.
Dr. Upmanu Lall, Utah Water Research Laboratory. February 24, 1995.

Impact of zebra mussel activity on water quality of the Seneca River, New York.
Dr. Ray Canale, Dept. of Civil and Environmental Engineering, University of Michigan. January 25, 1995.

STAFF -- FY 95

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Fang, A. (volunteer)
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Faust, W.R.
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Kumar, J. (volunteer)
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Lang, G.A.
Lansing, M.B.
Liebig, J.R.
Morehead, N.R.
Nalepa, T.F.
Nelson, A.S.*
Rigterink, D. (high school intern)
Robbins, J.A.
Rood, R.W.[C]
Siedel, K. (summer intern)
Stone, R.[C]
Tigue, E.[C]
Vanderploeg, H.A.
VanHoof, P.A.
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Wang, H.W.[C]
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Wilcoxin, S.E. (volunteer)

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Hunter, T.S.
Lee, C.[C]
Lee, D.H.
Leshkevich, G.A.
Liu, P.C.
Lofgren, B.M.[C]
McCormick, M.J.
Meyer, D.E.[C]
Miller, G.S.
Muhr, G.C.
Norton, D.C.
Nowak, B.[C]
O'Connor, W.P.[C]
Saylor, J.H.
Schwab, D.J.
Sellinger, C.E.
Winkelman, A.[C]

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= - Indicates Co-op Employee
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FY 95 PRESENTATIONS

ASSEL, R.A. Changes in winter air temperature near Lake Michigan during 1851-1993, as determined from regional lake-ice records. Freshwater Ecosystems and Climate Change in North America: A Regional Approach, Leesburg, VA, October 25, 1994. American Society of Limnology and Oceanography.

ASSEL, R.A. The Great Lakes environmental Research Laboratory ice research projects: 1994 activities, 1995 plans. International Great lakes-St. Lawrence Ice Information Work Group, Sarnia, Ontario, Canada, October 4, 1994.

ASSEL, R.A. Great Lakes ice cover climatology and data rescue project. GLERL/NIC Great Lakes Ice Products Workshop, National Ice Center, Suitland, MD, July 11-12, 1995.

*ASSEL, R.A., J.E. Janowiak, S. Young, and D. Boyce. Winter 1994 weather and ice conditions for the Laurentian Great Lakes. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

*ASSEL, R.A., D. NORTON, and D. MEYER. Climatic analysis of Laurentian Great Lakes ice cover. Fourth U.S./Canadian Workshop on Great Lakes Operational Meteorology, Syracuse, NY, September 13-14, 1995.

*BELETSKY, D., A.M. Kryutchov, L.V. Sergeeva, and E.A. Yidin. Large scale circulation impact on efficient transport and trace element distribution in bottom sediments of Lake Ladoga. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

*BELETSKY, D., W.P. O'CONNOR, and D.J. SCHWAB. Hydrodynamic modeling for the Lake Michigan mass balance project. Workshop on the Next Generation Environmental Models Computational Methods, Bay City, MI, August 7, 1995. U.S. EPA.

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*BOOTSMA, H.A., R.E. Hecky, S.J. Guildford, E.J. Fee, and G. Patterson. Estimating phytoplankton photosynthesis in Lake Malawii: How well do surface waters represent the euphotic zone? International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

*CAVALETTO, J.F., W.S. GARDNER, and J.R. JOHNSON. Autotrophic and heterotrophic nitrogen dynamics at an eutrophic site in Saginaw Bay. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

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*FAHNENSTIEL, G.L., T.F. NALEPA, M.J. McCORMICK, and G.A. LANG. Zebra mussels in Saginaw Bay: I can see clearly now or love that muddy water. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

GARDNER, W.S. Effects of light and high molecular weight dissolved organic matter on nitrogen dynamics in the Mississippi River plume. Gordon Research Conference, Plymouth, NH, June 22, 1995.

GOSSIAUX, D.C. Effects of sediment composition on the bioavailability of PAH and PCB congeners to *Diporeia* spp. 15th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO, October 31-November 3, 1994.

*HARKEY, G.A., P.L. VAN HOOF, and P.F. LANDRUM. Bioavailability of sediment-associated PAH's by *Lumbriculus variegatus* in sediment cores. 15th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO, October 31-November 3, 1994.

Capitalized names represent GLERL authors.
*For presentations with multiple authors, asterisk represents presenter.

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HAWLEY, N. Sediment transport processes in the Great Lakes. Informal Seminar, State University of New York at Stony Brook, Marine Sciences Research Center, Stony Brook, NY, April 4, 1995.

Holcombe, T.L., D.F. REID*, and W.T. Virden. Bathymetry of Lake Michigan. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

*JOHENGEN, T.H., and J.B. Cotner. Nutrient cycling and respiration rates of zebra mussels in Saginaw Bay Lake Huron measured using 'in situ' benthic chambers. International Association for Great Lakes Research, Michigan State University, East Lansing, MI, May 28-June 1, 1995.

LANDRUM, P.F. Bioavailability of organic contaminants from sediments. Great Lakes Colloquium, Ohio State Univesity, Columbus, OH, November 9, 1994.

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ACRONYMS

AAPS	Ann Arbor Public Schools
ADCP	Acoustic Doppler Current Profiler
AGU	American Geophysical Union
ANS	Aquatic Nuisance Species
AOC	Area of Concern
AOML	Atlantic Oceanographic Marine Laboratory
ARCS	Assessment and Remediation of Contaminated Sediments
ASLO	American Society for Limnology and Oceanography
ASSP	Approved Species-Specific Protocol
ASTM	American Society for Testing and Materials
AVHRR	Advanced Very High Resolution Radiometer
BAF	Bioaccumulation Factor
BaP	Benzo(a)pyrene
CCIW	Canada Centre for Inland Waters
CD-ROM	Compact Disk - Read Only Memory
CER	Coordinated Ecosystem Research
CHARM	Coupled Hydrosphere Atmosphere Research Model
CILER	Cooperative Institute for Limnology and Ecosystems Research
COE	Corps of Engineers
COP	Coastal Ocean Program
CSCS	Consolidated Scientific Computing System
CTD	Conductivity, Temperature, and Depth
CZE	Capillary Zone Electrophoresis
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DON	Dissolved Organic Nitrogen
DYNMX	Dynamic Mixing Model
EC_{50}	Effective concentration at which 50% of worms will leave sediment.
EEO	Equal Employment Opportunity
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERIM	Environmental Research Institute of Michigan
ERL	Environmental Research Laboratories
ERS	Earth Resources Satellite
ESDIM	Earth System Data and Information Management
FEDLINK	Federal Library and Information Network
FIBS	Field by Information Blending and Smoothing
FNOC	Fleet Numerical Oceanographic Center
FORTRAN	Formula Translation
FTP	File Transfer Protocol
FY	Fiscal Year
GB	Gigabyte
GC/MS	Gas Chromatography/Mass Spectrometry
GCM	General Circulation Model
GIS	Geographic Information System
GLCFS	Great Lakes Coastal Forecast System
GLERL	Great Lakes Environmental Research Laboratory
GLFS	Great Lakes Forecasting System
GLIN	Great Lakes Information Network
GLNPO	Great Lakes National Program Office
GLSEA	Great Lakes Surface Environmental Analysis
GOES	Geostationary Observational Environmental Satellite
GPS	Global Positioning System
HCBP	Hexachlorobiphenyl
HOC	Hydrophobic Organic Compound
HPLC	High Performance Liquid Chromatography

ACRONYMS

IAGLR	International Association for Great Lakes Research
IDIDAS	Interactive Digital Image Display and Analysis System
IJC	International Joint Commission
IMSL	International Mathematics and Statistical Library
LAN	Local Area Network
LATEX	(Gulf Marine Minerals Management) Louisiana Texas Experiment
LAMP	Lakewide Management Plant
LAVc	Local Area VAXcluster
LC50	Lethal concentration in environment resulting in 50% mortality.
LD50	Lethal dose which results in 50% mortality of population.
LMMB	Lake Michigan Mass Balance
LORAN-C	Location Radio Navigation-Coordinates
MAR	Mississippi Atchafalaya River
MARC	Machine-Readable Cataloging
MCC	Midwest Climate Center
MCSST	Multi-Channel Sea Surface Temperature
MICIS	Midwestern Climate Information System
MIL	Marine Instrumentation Laboratory
MLC	Michigan Library Consortium
MOIL	Marine Operations and Instrumentation Laboratory
MRP	Mississippi River Plume
MRP/GS	Mississippi River Plume/Gulf Shelf
MRP/IGS	Mississippi River Plume/Inner Gulf Shelf
NBS	National Biological Service
NDBC	National Data Buoy Center
NECOP	Nutrient Enhanced Coastal Ocean Productivity
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NLIN	NOAA Library and Information Network
NLSST	Non-Linear Sea Surface Temperature
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NOCN	National Ocean Communication Network
NOS	National Ocean Service
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIPS	NRL Satellite Impage Processing Systems
NURP	National Undersea Research Program
NWS	National Weather Service
OAR	Office of Oceanic and Atmospheric Research
OCLC	Online Computer Library Center
OCNMAP	Ocean Map
OSU	The Ohio State University
PAH	Polycyclic Aromatic Hydrocarbons
PC	Personal Computer
PCB	Polychlorinated Biphenyls
PDMS	Polydimethylsiloxane
PI	Principal Investigator
PMEL	Pacific Marine Environmental Laboratory
PMF	Probable Maximum Flood
POC	Particulate Organic Carbon
POM	Particulate Organic Matter
QAPjP	Quality Assurance Project Plans
RAMS	Regional Atmospheric Modeling System
RNN	Regional Network Node

ACRONYMS

ROV	Remote Operated Vehicle
SABRE	South Atlantic Bight Recruitment Experiment
SAR	Synthetic Aperture Radar
SEAS	Shipboard Environmental Acquisition System
SIMS	Stable Isotope Mass Spectrometer
SOP	Standard Operating Procedures
SPM	Suspended Particulate Material
SST	Sea Surface Temperature
SUNY	State University of New York
TM	Thematic Mapper
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VACM	Vector Averaging Current Meter
WaRFS	Water Resources Forecasting System
WLLN	Washtenaw-Livingston Library Network
WRIPS	Wave Rider Information Processing System
WWW	World-Wide Web
XBT	Expendable Bathythermograph
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
US NWS	U.S. National Weather Service