TECHNICAL PLAN
for the
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

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

Ann Arbor, Michigan January 1986

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Dr. Eugene J. Aubert, Director

January 1986

National Oceanic and Atmospheric Administration
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PREFACE

The Great Lakes Environmental Research Laboratory (GLERL) was established on April 25, 1974, to provide a focus for NOAA's environmental research on the Great Lakes. GLERL was formed by combining the staff of the International Field Year for the Great Lakes (IFYGL) Project Office, Rockville, Maryland, with the Limnology and Computer Divisions, Lake Survey Center, Detroit, Michigan. The Ann Arbor, Michigan, laboratory was opened in August 1974.

GLERL's functional statement, broadened recently, is as follows:

> Conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters with a special emphasis on the Great Lakes. The laboratory performs field, analytical, and laboratory investigations to improve understanding and prediction of coastal and estuarine processes and interdependencies with the atmosphere, land, and sediments. It places special emphasis on a systems approach to problem-oriented environmental research in order to develop environmental service tools. It provides assistance to resource managers and others in obtaining and applying the information and services developed by the laboratory.

The format of this Technical Plan is different from those previously published (through January 1985), although the material included remains the same. Each of the eleven GLERL projects is now broken down into identifiable subsections which give the Objectives, Background, Interrelationships With Other (GLERL) Projects, Approach, Grants and Contracts (if applicable), and Tasks and Task Objectives for the project.

Information about GLERL, GLERL publications, and other products may be obtained by contacting:

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INTRODUCTION

This Technical Plan, the 12th in an annual series, documents the GLERL research program as of December 1985. Organized in terms of projects, it updates the plan dated January 1985. This version of the Technical Plan outlines both the projects and tasks. Projects are conceived as broad units of research of significant duration. Tasks are shorter term and more definitive and identify products targeted for completion at a particular time.

The projects in this Technical Plan have evolved from those in existence one year ago because of additional accomplishments, evolution of our understanding of ecosystem processes, and redefinition of objectives. An evolution of the research structure has occurred and is continuing. Our research mission to improve understanding and prediction of the Great Lakes ecosystem has a problem orientation to develop information and environmental service tools relevant to priority issues of resource managers and users of the Great Lakes. Our research is focused on four perceived critical Great Lakes issues or problems, i.e., toxic organic contaminants, nutrient overenrichment, water quantity changes, and Great Lakes hazards. Toxic contaminants are found in trace amounts throughout the ecosystem, but some fish contain contaminant levels considered unsafe for human consumption. While the Great Lakes eutrophication problem is now less severe due to a major reduction of nutrient loads resulting from improved sewage treatment plants, serious consideration is being given by resource managers to further nutrient reduction from non-point sources. Lake levels are breaking hundred-year records on the four upper lakes and are associated with increased shoreline flooding and erosion; water management issues are being raised on regulation, diversions, and consumptive use. Users of the Great Lakes and its shoreline are stressed by hazards such as wind waves, storm surge, flooding, erosion, ice, and spills of toxic chemicals.

The GLERL technical program is organized into eight disciplinary projects and one environmental systems project. Different combinations or groupings of these projects are required to address systematically the four multidisciplinary Great Lakes issues discussed above. A mapping of the projects into these four issues is shown in Table 1. The status of completed and discontinued tasks is noted in the background section of the respective project descriptions. Each completed task has a final task report on file that summarizes accomplishments.

Perspectives

This Technical Plan was prepared to facilitate coordination with managers, researchers, and users of GLERL products.

The GLERL research program is dynamic. Ideas and accomplishments are the keys to a successful research program. Since ideas and suggestions are encouraged at all levels, it is desirable to put in perspective what GLERL is trying to accomplish in the Great Lakes.

Table 1.--GLERL projects and Great Lakes issues

Project	Issues			
	Toxic Organic Contaminants	Nutrient Overenrichment	Water Quantity	Hazards
1. Water Movements	P	P		P
2. Waves	S			P
3. Particle Dynamics	P	P		
4. Toxic Organics	P			
5. Ecological Succession	S	P		
6. Nutrient Cycling	S	P		
7. Hydrologic Properties	S	S	P	S
8. Ice		S		P
10. Environmental Systems	P	P	P	P

P = primary focus
S = secondary focus

GLERL has a two-part mission: to conduct research directed toward better understanding and prediction of environmental processes in coastal and estuarine waters, especially the Great Lakes and their basin, and to assist in the solution of environmental problems of resource management, water-related activities, and environmental services. Our goal is to build useful environmental simulation and prediction models that provide suitably precise information to support the best possible use of the region's resources. To achieve this goal, there needs to be improved understanding of first-order processes and phenomena of the lake-land-atmosphere-sediment system. Our comprehension of user needs for environmental information in relation to our capabilities and understanding of the relative importance of environmental problems influences the styling of the problem-oriented research program. And always, we must guard against undertaking too many unrelated projects and tasks, and thereby spreading our staff too thin, or our accomplishments will be small owing to overcommitment of limited resources.

Planning Process

This 1986 version of the GLERL Technical Plan was developed with several objectives in mind: (1) to sharpen the focus on key Great Lakes environmental problems and key environmental processes; (2) to sharpen the focus of project and task objectives; (3) to initiate multi-disciplinary research, where desirable; and (4) to identify new research initiatives, as appropriate. A summary of the Great Lakes environmental problems and activities for project emphasis is contained in Table 2.

Research Structure

The research sequence of Figure 1 conceptually portrays the overall approach to our process and problem-oriented research. In problem-oriented research, our research objectives are defined to solve environmental problems of Great Lakes resource management or to develop or improve environmental services for Great Lakes activities. Scientific objectives are defined to improve our understanding of environmental processes in the interactive lake-land-atmosphere-sediment system so we can improve our problem-oriented simulation and prediction models. After suitable objective definition, an interdependent approach sequence includes data collection, analysis, modeling, and evaluation with various feedback loops. Few of our research projects address all components of this research sequence, although several projects have experimental, theoretical, and numerical modeling tasks. Our projects have a large degree of interdependence in the sense of this problem-oriented approach. GLERL research products support an advisory service and include reports, articles, presentations, consultation, advice, and tools (e.g., data bases and models) for coordination with resource managers and the scientific community.

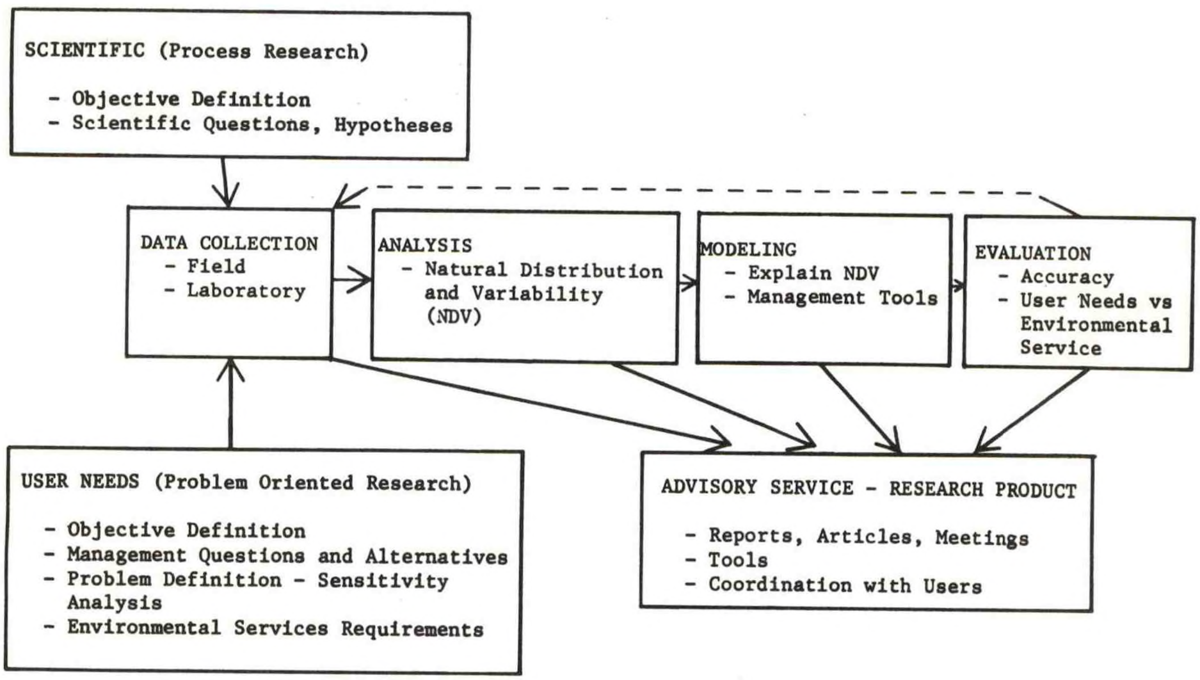

Figure 1.--Research sequence.

Table 2.--Project-problem emphasis

Project	Problem
P-1	1. Nearshore and boundary layer (air-water and water-sediment) processes and phenomena. 2. Importance of baroclinic and nonlinear processes. 3. Research to develop, test, and evaluate a hierarchy of improved numerical models to simulate and predict water movements and transport for use in spill prediction, and as required for transport of dissolved and particulate contaminants and ice in Projects 3, 4, 6, 8, and 10, and to identify 1st-order phenonema and processes that require experimental research investigations; models to support trade-off analyses in water-related activity planning, i.e., siting of water intakes, wastewater outfalls, etc. 4. Experimental research to further understanding of phenomena and processes as required to improve numerical prediction models (also applies to Project 2).
P-2	1. Development and validation of prediction models for surface waves, wind tides, storm surges, seiches, and flooding; effects on sediment resuspension, disposition, and transport. 2. Climatology of waves and water level fluctuations. 3. Atmospheric boundary layer model; process parameterization; experimental studies. 4. Interdependent processes that relate offshore and nearshore waves and coastal currents.
P-3	1. Transport and diffusion prediction of conservative properties and contaminants. 2. Processes of particulate transport, sedimentation, resuspension, aggregation, and sediment mixing. 3. Simulation and prediction modeling.
P-4	1. Key chemical biological processes of toxic organics cycling in the Great Lakes, e.g., sorption, benthic food chain dynamics, benthos uptake and release, bacterial uptake and release. 2. Simulation modeling of seasonal properties and budget modeling.
P-5	1. Experimental research to detect long-term trends in Great Lakes biota. 2. Assessment of long-term trends in biota.
P-6	1. Experimental ecosystem research: to quantify specific interactions between pelagic and benthic food webs; to quantify processes and pathways of nutrient and energy cycling from photosynthesis to top predator fishes; and to relate food web dynamics to changes in water quality (i.e., nutrient overenrichment and toxic contaminants). 2. Research to develop, validate, and improve ecosystem simulation and prediction models of nutrient cycling, food web dynamics, and plankton succession.

Table 2.--Project-problem emphasis (continued)

Project	Problem
P-7	1. Research to develop, validate, and improve simulation and prediction models of water levels and flows and chemical and particulate transport in connecting channels and tributary rivers. 2. Develop, validate, and improve simulation and prediction models of intergrated water supply and lake levels to support assessments of management problems involving water regulation, diversions, and consumptive use. 3. Climatology of flows in connecting channels. 4. Water level and flow information to support ocean engineering and marine resource decision processes.
P-8	1. Prediction of ice formation, growth, transport, distribution, and breakup in the lakes, bays, harbors, and connecting channels. 2. Experimental research to acquire suitable data bases to identify ice and snow characteristics and variability. 3. Ice information to support ocean engineering, marine resources management, and winter navigation decision processes.
P-9	1. Environmental advisory service. 2. Participation on Boards, Committees, and Task Forces of the IJC, federal and state agencies, etc., to provide advice and products and to determine research needs.
P-10	1. Environmental models and information to support decisions in water-related activities, resource development and environmental management. 2. Systems methods for analysis of balanced growth, i.e., marine resource and development and use with environmental quality and utilizing concepts of benefits, risks, and costs. 3. Water resource studies and applications. 4. Integration of ecological and socioeconomic information into broad systems perspective.
P-11	1. Great Lakes Long-Term Effects Research; environmental prediction and simulation with emphasis on the marine ecosystem and with stresses of toxic organics, nutrient enrichment and particle dynamics. 2. Research in numerical prediction of circulation, waves, particulates and the ecosystem of the Great Lakes and coastal regions. 3. Environmental research to develop improved understanding and prediction to support balanced and cost-effective growth and use of the marine resources with acceptable risks and costs.

PROJECT 1. WATER MOVEMENTS AND TEMPERATURE

PROJECT SCIENTISTS. D.J. SCHWAB AND J.H. SAYLOR

Objectives

(1) To develop improved climatological information (via observations, new instrumentation, and improved analysis) on the distribution and variability of coastal and offshore currents and temperatures, and to study their dependence on meteorological and hydrological forces.

(2) To develop and test improved numerical hydrodynamic models that can simulate and predict the information from objective (1) for both coastal and offshore regions.

(3) To improve the understanding of the physics of the lakes by analyzing the results of objectives (1) and (2).

(4) To extend the models developed in objective (2) to simulate and predict the transport and diffusion of pollutants, and to participate in coupling these models to aquatic ecology and water quality models. A hierarchy of such numerical models will be developed and tested for use in water resources planning.

Background

This project is concerned with observing and predicting certain aspects of the physical environment of the Great Lakes. In general, the physical state of these lakes can be predicted in terms of the distribution of temperatures, currents, waves, and water levels. Each of these variables has an impact on environmental, chemical, and biological processes and influences many user activities, such as water supply management, waste water management, power plant sitings, shipping, recreational boating, and shoreline erosion.

These physical processes have a wide range of space and time scales (Fig. 2). Some phenomena, such as upwelling and coastal jets, are confined to nearshore regions, whereas others, such as mean circulations and seasonal stratifications, are lakewide. The driving atmospheric forces (wind stress, pressure gradient, heat fluxes) also change seasonally and exhibit spatial and temporal variations. In order to form a coherent picture and to understand the various processes in the lake, these different space/time scales must be separated. This is also essential for applying the information to user activities. For example, problems related to water supply management and power plant sitings are affected by the long-term characteristics of transport, whereas shipping and boating are affected by the short-term wave characteristics.

The primary emphasis in this project is on studies of circulation and stratification on coastal and lakewide scales and how these are impacted by seasonal and episodic changes in atmospheric forcing.

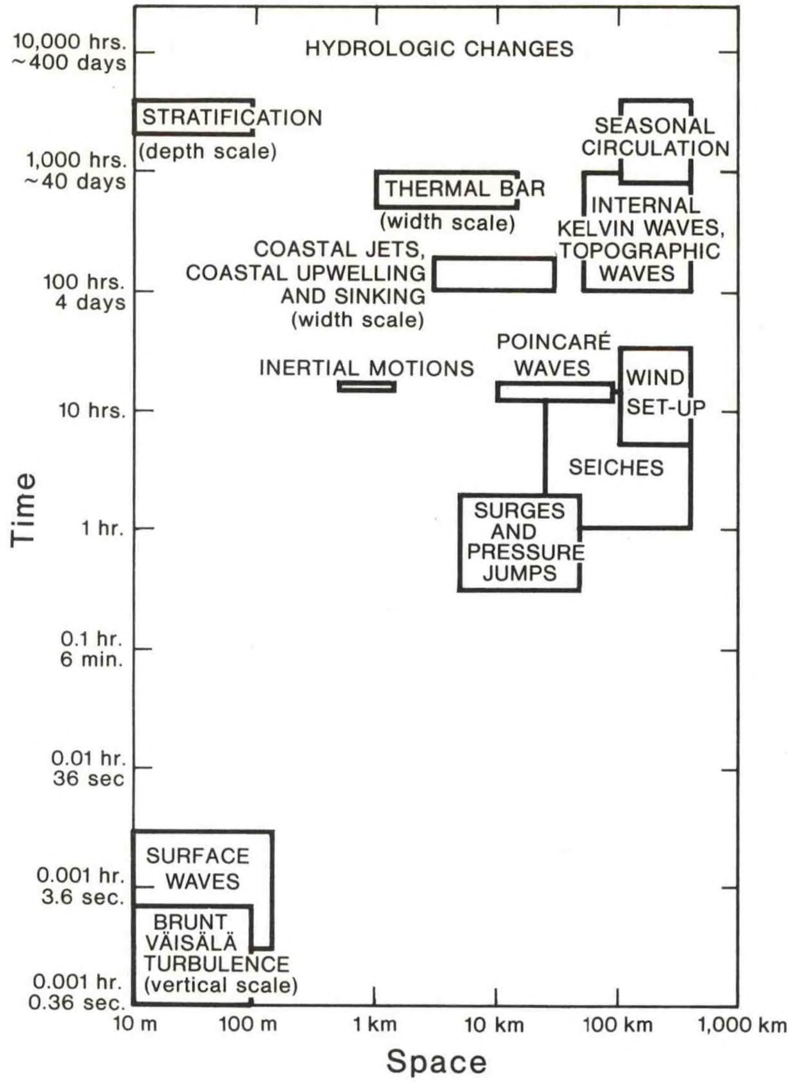

Figure 2.--Scales of lake physical phenomena.

The following tasks have been completed and final task reports are on file:

Task 1.2, Analysis of Lakes Erie and Michigan Data.

Task 1.3, Development of a GLERL Data Access System (GDAS).

Task 1.4, Computation of Rotational Normal Models.

Task 1.5, Deep Currents.

Task 1.6, Advanced Current Measuring Techniques.

Task 1.9, Modeling Transport of Toxic Substances.

Task 1.12, Lagrangian Effectiveness of Satellite-Tracked Surface Drifters.

Interrelationships With Other Projects

Temperature governs the metabolic rate of biological organisms and the rate of chemical reactions. The temperature distribution also determines the heat content of a lake, which in turn influences local meteorology and ice formation and breakup (Project 8, Lake Ice). The distribution of currents and temperatures governs the diffusive and advective effect on dissolved and suspended substances in a lake (Project 3, Particle Dynamics). Hence, the processes and phenomena studied in this project provide the necessary background information for a proper interpretation and understanding of the results of several of the GLERL projects, e.g., Project 4, The Cycling of Toxic Organics, Project 10, Environmental Systems Studies and Applied Modeling, and Project 8, Lake Ice.

Approach

The approach consists of either defining scientific problems based on gaps in knowledge of lake processes or responding to problems of immediate need for a specific user. The solutions to these problems are then obtained through a combination of data collection and analysis (what is there?), theoretical studies (why is it there?), and numerical modeling (where will it be in the future?). Systematic efforts will also be made to compare model predictions to observations in order to improve or define the limitations of the models.

The ultimate purpose of Project 1 is to predict Great Lakes currents and temperatures, along with the associated transport and dispersion of dissolved and suspended materials. Hence, this project will directly support aquatic ecology and environmental engineering modeling at GLERL. The eventually support these projects, tasks must be selected to focus on specific steps or problems. These tasks represent goals either already achieved or achievable in the very near future. Examples of some of these short-term goals are:

(1) Improvement and Validation of Numerical Circulation Models.

New techniques have been developed for comparing observational data from current meters and satellite-tracked drifters to values generated by numerical models. Because the Great Lakes are simpler to survey than the oceans, the research has been very quantitative in the past and will continue to be so.

(2) An Operational Storm Surge Model for Real-Time Forecasts and Climatological Studies.

An operational storm surge model for Lake Erie is currently being used by the National Weather Service (NWS). Future work in this area can build on the operational model.

(3) An Improved Oil Spill and Trajectory Model.

GLERL's oil spill model has been used frequently as a training and spill cleanup tool. An improved version was implemented for evaluation by the U.S. Coast Guard and NWS in 1984. The new model incorporates greater numerical accuracy and operational improvements for users.

(4) A Planning Trajectory Model.

Many applied problems require long-term trajectory calculations with the option of calculating both future motions (forward trajectories) and past motions (backward trajectories) of particles. This model also needs the ability to calculate statistics of particle motion.

(5) Thermal Forecasting.

Existing models to predict thermal structure can be tested against observed temperatures in Lakes Erie and Michigan. Improved versions incorporating physics of the Great Lakes environment are being developed.

(6) Boundary Layer Processes.

Boundary layer processes controlling the dynamics of bottom currents, sedimentation, and resuspension can be compared with the results of coastal ocean research. Processes unique to the inland lake environment are being quantified with analytical description.

Research for this year will focus on the following:

Task 1.1, We will explore the potential of the new CYBER-205 computer and develop numerical methods which will best utilize it to improve the models.

Task 1.7, A method for predicting thermal structure in lakes will be published.

Task 1.8, Data from fixed current meters and satellite-tracked drifting buoys will be used to verify the circulation and objective analysis models.

Task 1.10, The trajectory model will be verified using satellite-tracked drifters.

Task 1.11, An experimental program to measure currents in the bottom boundary layer will be coordinated with measurements of suspended sediments. The goal of this research is to improve the sediment dynamics model.

Task 1.13, Numerical simulations of circulation patterns in Lake St. Clair will be used to investigate transport pathways for dissolved and suspended material.

Task 1.14, Observations of currents in Lake St. Clair will be analyzed to determine synoptic circulation patterns.

Grants and Contracts

(1) Title. Internal Motion and Related Internal Waves in Lakes Michigan and Ontario as Responses to Impulsive Wind Stresses, Part II.

Principal Investigator. C.H. Mortimer (University of Wisconsin-Milwaukee).

Objective. Description of near-inertial period internal waves and currents in the lakes in terms of the Poincare wave conceptual model.

Tasks and Task Objectives

Task 1.1. General Numerical Models for Computing Currents

Task Scientist. D.J. Schwab

Objective.

The objective of this task is to develop and verify a hierarchy of improved water quality and circulation models that will predict the transport of suspended or dissolved substances in the Great Lakes. In doing this, we will develop general numerical methods that can be applied to other physical problems, such as ice and wave prediction.

Task 1.7. Thermal Structure Forecasting

Task Scientist. M.J. McCormick

Objectives.

(1) To evaluate four representative thermocline models as forecasting tools for predicting temperature profiles in the Great Lakes.

(2) To assess the implications of model selection on vertical mixing from a water quality modeling viewpoint.

Task 1.8. Rotational Mode Experiment

Task Scientists. J.H. Saylor and G.S. Miller

Objective.

The objective of this task is to study the seasonal circulation of southern Lake Michigan and the properties of long-period vorticity waves in it's basins.

Task 1.10. Spill Model Verification Using Satellite-Tracked Drifter Buoys

Task Scientists. D.J. Schwab, A.H. Clites, J.E. Campbell, and E.W. Lynn

Objectives.

(1) To verify the improved general-purpose spill model using data from satellite-tracked drifter buoys.

(2) To analyze the existing drifter buoy data base in conjunction with Vector Averaging Current Meter (VACM) data collected in Lake Michigan concurrently.

(3) To study the surface current patterns for specific areas of interest using satellite-tracked drifter buoys.

Task 1.11. Lakes Environment Benthic Boundary Layer Experiments

Task Scientists. J.H. Saylor and G.S. Miller

Objectives.

(1) To investigate and test available equipment for measuring currents, sediment concentrations, and other important parameters necessary for parameterization of bottom material resuspension and near-bottom sediment transport processes.

(2) To quantify the distribution of bottom current intensities as functions of both space and time in order to parameterize the distribution and frequency of resuspension events.

(3) To develop a coherent plan for continuing studies of boundary layer dynamics, which are closely coupled with concurrent investigations of particle dynamics.

Task 1.13. Modeling Particle Transport in Lake St. Clair

Task Scientists. A.H. Clites and D.J. Schwab

Objectives.

(1) To use numerical circulation models to identify particulate transport pathways in Lake St. Clair.

(2) To provide information on the physical environment of Lake St. Clair in terms of current distribution patterns for Upper Great Lakes Connecting Channels Study (UGLCCS) Task 10.24, Generic Contaminant Model.

Task 1.14. The Currents of Lake St. Clair

Task Scientist. G.A. Meadows and L.A. Pflaum

Objectives.

(1) Conduct three synoptic current surveys of Lake St. Clair on appropriate spatial and temporal scales to determine flow patterns and time-dependent response not obtainable from conventional moored current meters.

(2) To compare these data to predictions of Lake St. Clair circulation arising from physical and numerical models.

(3) To utilize these data to improve and verify the GLERL Lake Circulation Model for shallow enclosed basins.

(4) To provide data on the currents of Lake St. Clair to support the analyses of other Upper Great Lakes Connecting Channels Study (UGLCCS) investigators.

Task 1.15. Greenhouse Effects on Great Lakes Temperatures

Task Scientists. M.J. McCormick and J.E. Campbell

Objectives.

(1) To predict the long-term effects of increased atmospheric carbon dioxide on the temperature structure of each of the Great Lakes.

(2) To predict the long-term consequences of changes in the heating cycle on lake levels, evaporation, and ice formation.

PROJECT 2. PREDICTION OF SURFACE WAVES, WATER LEVEL FLUCTUATIONS, AND MARINE WINDS

PROJECT SCIENTIST. D.J. SCHWAB

Objectives

To predict waves and other water level oscillations primarily generated by the wind, the objectives of this project are to:

(1) Improve climatological information on the distribution and variability of surface waves, wind setups, surges, seiches, and marine winds.

(2) Develop and test improved statistical or dynamical models for predicting surface waves, wind setups, surges, seiches, and marine winds.

(3) Improve our understanding of the underlying physical processes by analyzing the results of objectives (1) and (2).

Background

The goals in Project 2 are similar to those in Project 1, namely, improved observation, analysis, and prediction. In contrast to Project 1, which deals with long-period processes, the surface wave and water level fluctuations considered here have short periods. These phenomena are often hazards in activities such as shipping, recreational boating, and fishing, and can result in loss of life and property damage; consequently, there is an urgent need for improved methods of forecasting these phenomena. Statistical information on waves and water level fluctuations is necessary in problems of ship design, shoreline protection, navigation, etc. In addition, waves and water level fluctuations facilitate processes of dispersion, shore erosion, bottom sediment resuspension, and flooding.

Theories are well-developed for surface waves in deep water. In the Great Lakes, however, these waves are only poorly understood because of complicating factors such as shallow depths, limited fetch, and boundaries. In view of this, continued effort is necessary to develop theoretical and empirical lake wave models, and to test them with properly designed field studies.

Large, short-term fluctuations in the mean water level also occur in the Great Lakes as a result of wind forcing. The horizontal scale of this response is much wider than the small horizontal scale of surface waves. The amplitude of this response may exceed both surface waves and hydrological changes, making it an important factor in shore erosion, shipping, and lake use management. Also in this category of water level fluctuations are wind tides, surges, and seiches resulting from the passage of atmospheric disturbances.

In predictions of both waves and water level fluctuations, details of wind, pressure, and temperature in the atmospheric boundary layer over the lake are important. Such information has generally not been available in routine weather observations or forecasts. In recent years, the deployment of NOMAD weather buoys in the Great Lakes during the shipping season by NOAA's National Data Buoy Center (NDBC) has helped considerably in providing open lake marine observations. In addition, Coastal-Marine Automated Network (CMAN) weather stations have been installed by NDBC on several islands and exposed shoreline locations around the Great Lakes. This project intends to make full use of these observations in developing climatological information and in developing and verifying predictive models.

The following research tasks have been completed and a final task report is on file:

Task 2.1, Surface Wave Observations and Analysis.

Task 2.2, Free Oscillations of Lake Michigan.

Task 2.3, Oscillations of Lake Huron.

Task 2.4, Wind-Induced Changes in Water Levels on Lake Erie.

Task 2.5, Prediction of Winds Over the Great Lakes.

Task 2.6, Lake Michigan Surface Wave Measurements.

Task 2.7, Testing and Evaluation of Wave Prediction Models.

Task 2.8, Lake Superior Surface Wave Measurements and Analysis.

Task 2.9, Lake Huron Storm Surges.

Task 2.10, Lake Erie Surface Wave Measurements.

Task 2.11, The Use of Water Level Measurements to Infer Wind Stress Over Lake Erie.

Task 2.12, Lake Erie Directional Wave and Coastal Boundary Layer Measurements.

Task 2.15, Nearshore Transformation of Wind-Wave Characteristics.

Interrelationships With Other Projects

The lake-atmosphere boundary layer observations and analyses are common with Project 1, Water Movements and Temperature. In view of the environmental hazards associated with waves, surges, etc., this project lends support to Project 9, Environmental Information Services. This project is also related to Project 7, Hydrologic Properties, since the extent of shoreline damage caused by waves and water level fluctuations is governed by hydrological changes in the lake levels.

Approach

The approach in this project includes field data collection and analysis, and model development, testing, and evaluation. Routine meteorological and marine observations will be obtained from the National Weather Service (NWS) and evaluated for potential use in the development of climatological information and model verification. For surface waves, special data acquisition systems will be deployed to measure the lake and marine boundary layer. Analyses of field wave data should determine the effects of short fetch, partially developed waves, shallow water depth, and boundary layer processes. Studies on wind setups and seiches will involve an evaluation of the existing prediction techniques using available meteorological and water level data. Improved numerical models will be developed, based upon both theoretical and empirical relationships. Such models will be verified by using data bases developed from field data collections and NWS and NDBC observations.

In the near future, tasks under this project will focus attention on the following:

(1) Adaptation of the operational Great Lakes numerical wave model to microcomputers.

(2) Climatological analysis of NDBC NOMAD buoy data and CMAN meteorological data.

(3) Development of wave statistics from wind statistics.

(4) Analysis of shallow water wave measurements in Lake St. Clair.

(5) Study of shoaling, refraction, and bottom friction effects on wind waves.

Tasks and Task Objectives

Task 2.13. Prediction of Wind-Generated Waves on the Great Lakes

Task Scientist. D.J. Schwab

Objectives.

The broad objective of this task is to improve Great Lakes wave forecasts by developing and testing improved wave models. The specific objectives addressed to meet this broad objective are to:

(1) Develop a parametric wave prediction model and implement it within the framework of the GLERL numerical modeling system developed in Task 1.1.

(2) Test the model in a hindcast mode against field data gathered in Tasks 2.12, 2.14, this task, and NDBC buoy data.

(3) To test the model in a forecast mode against NOAA/NWS operational wave forecasts.

(4) To implement the model for operational use if it proves superior to current forecast methods.

Task 2.14. Great Lakes Wave Climate From NDBC Data

Task Scientist. P.C. Liu

Objectives.

(1) To synthesize wave, wind, and temperature data recorded from NDBC NOMAD buoys in the Great Lakes and to delineate climatological information on Great Lakes waves.

(2) To examine the individual, joint, and multivariate long-term distributions of the parameters and to develop statistical models for representation and prediction.

Task 2.16. Lake St. Clair Shallow Water Wave Experiment (WAVEDISS '85)

Task Scientists. D.J. Schwab, P.C. Liu, and G.A. Meadows

Objectives.

(1) To measure the change with fetch in the wave energy spectrum of wind waves propagating in shallow water.

(2) To determine the rate of energy loss in the wave spectrum due to bottom dissipation and shallow water effects.

(3) To develop mathematical formulations of these effects that can be used to improve wave forecast models and models of particle resuspension in shallow water.

PROJECT 3. PARTICLE DYNAMICS

PROJECT SCIENTIST. J.A. ROBBINS

Objectives

(1) To characterize the physical and chemical properties of particulate matter in water and sediments of the Great Lakes.

(2) To characterize and quantify the temporal and spatial distribution of particulate material in water and sediments.

(3) To characterize the movements of particulate materials in water, as well as in sediments.

(4) To characterize and quantify sources of particulate materials in the lakes with emphasis on resuspension processes and rates.

(5) To characterize and quantify the ultimate sinks of particulate material, with emphasis on resuspension processes and rates.

(6) To identify and quantify chemical and biological processes affecting the hydrodynamic characteristics of particles.

(7) To develop mathematical models for the transformation and movement of particulate matter in water and sediments.

Background

Concentrations of many contaminants found in the Great Lakes tend to be determined by their association with particulate matter. Organic pollutants, such as chlorinated aromatics and polycyclic aromatic hydrocarbons, are very insoluble in the aqueous phase and rapidly sorb onto most solid substrates, particularly to small particles present in the water column. Such particles enter the lakes from the atmosphere, shoreline erosion, tributaries, in situ chemical and biological processes, and resuspension of sediments. Particles originating from these different sources carry variable amounts of organic pollutants and differ in their sorption capacities. How pollutants are distributed among various particle classes may determine whether or not their associated compounds are available to the biota, what settling and resuspension rates these compounds possess, and whether such compounds are subject to photolysis, bacterial degradation, etc. Other constituents are also strongly particle-associated. Many heavy metal contaminants and radionuclides, such as those resulting from nuclear testing or nuclear energy production, strongly sorb on particulate matter and acquire the hydrodynamic characteristics of their particle hosts. Moreover, the major nutrient cycles in the Great Lakes occur partly as a result of in situ particle production processes that convey nutrients to hypolimnetic waters, where intensified dissolution occurs. In addition, particulate material suspended in the water column may itself be regarded as a contaminant. Undesirable levels of turbidity in nearshore or shallow waters may result from dredge spoil operations, dispersion of turbid river waters, and short-term, high intensity resuspension events. Thus, to properly account for the concentrations, transport, and fate of many classes of contaminants, as well as major nutrients, it is essential to understand the hydrodynamic behavior of particulate matter in the lakes. The movements of particles in the water column are more complicated than the water mass movements themselves and are, therefore, of interest from a theoretical and modeling standpoint as well. Particles are subject to processes such as settling, aggregation (or disaggregation), or resuspension, which are not yet adequately characterized or properly represented by deterministic models.

The following research tasks have been completed and a final task report is on file:

Task 3.1, Characteristics of the Nepheloid Layer and Suspended Material in Southern Lake Michigan.

Task 3.2, A Model for Particle Aggregation and Disaggregation in a Turbulent Shear Layer.

Task 3.3, Carbon Dynamics.

Task 3.4, Development of Radiotracer Methods for Particle Dynamics Studies.

Task 3.8, Response of Sediments to Long-Term Increases in the Concentration of Conservative Substances in Overlying Waters.

Task 3.13, Investigation of Benthic Boundary Layer Sampling Techniques.

Task 3.14, Observation of Erosion and Deposition in Lake Superior.

Interrelationships With Other Projects

This project will depend upon modeling techniques and results of Projects 1, Water Movements and Temperature, and Project 2, Prediction of Surface, Waves, Water Level Fluctuations, and Overlake Winds, and will provide input at several levels to Projects 4, The Cycling of Toxic Organics, Project 6, Eutrophication and Nutrient Cycling, and Project 10, Environmental Systems Studies and Applied Modeling. Application of radiometric methods, for example, can be expected to provide one means of parameterizing and calibrating the ecosystems models of Projects 4, 6, and 7 and Project 10 models describing the long-term response of the lakes to nutrient and contaminant loadings. Projects 4, 6, and 10 in turn will inform the particle dynamics planning activity.

Approach

Particle dynamics research will be developed in several areas. In the area of particle fluxes and sinking rates, it is expected that short-term studies of mass fluxes using sediment traps will complement the longer term studies now underway (Task 3.1). New field methods may be developed to determine *in situ* particle sinking rates. Laboratory studies of the motions of individual particles in natural media may complement the field work.

In the area of resuspension process research, field work will be aimed at understanding the origins and significance of the benthic nepheloid layer, and will include turbidity mapping and investigation of the relationships between resuspension and bottom currents. Such work may involve the development of new boundary layer observational and sampling devices: continuous turbidity and current measurements, vertical sampling of the lower several meters of water, and continuous flow centrifuge water sampling or high volume filtration (to collect gram quantities of particulate matter) are needed. Related to this, a new benthic boundary layer sampler developed by B. Lesht (Argonne National Laboratory) has been deployed and tested in Lake Michigan (Task 3.13) and is being applied to studies of erosion and deposition processes in Lake St. Clair (Task 3.15). Field studies of resuspension may be complemented by laboratory investigations of resuspension of undisturbed sediments collected by specialized coring equipment.

Research activities in the area of particle transformation processes will be expanded to include studies of the chemical and biological factors that may alter the hydrodynamic properties of particulate matter, especially in the benthic nepheloid layer. Studies have included (Task 3.2) both particle aggregation and disaggregation modeling and laboratory experiments on the vertical dependence of particle distribution size, aimed at verifying model calculations of particle aggregation processes. Studies may be initiated to examine the kinetics of aggregation of particles subject to chemical additions or presence of selected zoobenthos. A study is in progress (Task 3.12) to statistically characterize the size distributions of particulate matter collected from Lake Michigan. The study of carbonate dynamics (Task 3.3) has shown that the dynamics of all transient particles, that is, those whose lifetime in the water is comparatively short (days to months), must be included when estimating the role of particulate matter in tracer and contaminant cycling. Silica, as well as carbonate particulate material, is transient in this sense and its behavior in the water column is of both theoretical and practical interest. Both silica and carbonate particles probably scavenge contaminants from the epilimnion, but may release them in hypolimnetic waters. The hydrodynamic behavior of transient particles is strongly time-dependent and closely related to their kinetics of dissolution. Thus, field and modeling efforts in this area must be carefully approached and coordinated with kinetic studies made by other groups (Project 6, Eutrophication and Nutrient Cycling).

In the area of sedimentation research, the particle dynamics project will provide sedimentation rate information for geochronological studies of contaminant fluxes in the Great Lakes. Rates of sediment accumulation combined with concentration data provide estimates of present and historical contaminant deposition. An initial task (Task 3.5) aimed at investigating the contaminant and nutrient fluxes in high sedimentation areas of the lakes will be expanded to include a contaminant deposition map on a lake-wide basis. The methods and results of this sedimentation study and radionuclide transport modeling (Task 3.7) will be applied to determine characteristics of sediment transport, deposition, and storage of selected tracers in Lake St. Clair (Task 3.16). This Task is being developed as part of the Upper Great Lakes Connecting Channels Study (see Project 10).

Another area of activity within the particle dynamics project is that of post-depositional movement of sedimentary materials. Studies have been undertaken to determine the spatial scales and extent of sediment reworking by benthic fauna, the effect of particle reworking on solute transport across the sediment water interface, and factors affecting sediment reworking rates (Task 3.6).

The approaches described above are intended to characterize and parameterize processes for inclusion in comprehensive ecosystem and transport models of the behavior of particulate matter in the water column. Models will be developed in several levels as part of the particle dynamics program (Task 3.7). Vertically integrated transport models, successful in describing oil spills and dispersion of mirex into Lake Ontario, will be refined and applied to known fluxes of mass, radionuclides, and selected contaminants in the lakes. Development of vertically integrated transport models must go in two directions: (1) the accurate prediction of long-term deposition, such as sedimentation rates and deposition of contaminants in sediment, and (2) the description of the horizontal distribution and movement of contaminants, nutrients, and radiotracers on time scales on the order of days to months. Horizontally integrated models combining transport and kinetic terms between various ecosystem compartments will be used to inform field research efforts. An ultimate aim of the particle dynamics project is to provide a basis for a unified transport and ecosystems model.

Radiotracer methods (Task 3.4) have been developed as a tool for quantifying the collective motions of particulate matter in the lakes. Radiotracers have already proven to be of considerable value for determination of whole-lake contaminant residence times, sedimentation rates, and the range and rates of sediment reworking (bioturbation). These parameters are of critical importance to most comprehensive ecosystem models of nutrients and contaminants. Further studies of these processes (sedimentation, bioturbation, and factors affecting overall residence times) will go forward under this program. However, there will be new initiatives to better identify radiotracer source terms, particle associations, and the collective motions of particles across in-lake boundaries. Radiolimnological investigations will include short-term studies of resuspension processes, determination of residence times of particulate matter (in the epilimnion, the nepheloid layer, and nearshore areas of the lakes), investigations of thermocline transport of particulate matter, and measurements of the vertical distribution of tracer concentrations in the water column. The development of radiotracer methods will depend on the construction of realistic models for the transport of particle-associated contaminants in the water column. In turn, knowledge of the distribution of radiotracers in the water and in sediments can serve to calibrate both transport and ecosystem models.

Unlike most organic contaminants, whose loadings are poorly known and whose fates are poorly characterized, many natural and man-made particles associated with radiotracers are exceptionally well-behaved. Radiotracers such as beryllium-7, lead-210, polonium-210, cesium-137, plutonium-238, and plutonium-239 have unique, comparatively well-defined sources and, for natural elements, a seasonal periodicity that can be accurately defined. In addition, radiotracers are not removed via photolysis or biological degradation, but are subject to removal only by outflow, which is generally negligible, and by radioactive decay, which is precisely known. Hence, radiotracers are ideally suited to calibration of ecosystem models and the approach within particle dynamics is to treat development of particle tracer methods as being parallel to, but lagging behind, that of toxic organic and nutrient cycling research efforts. Therefore, samples will be taken from the lakes that are subject to chemical and biological fractionation procedures equivalent to those of the lakes used for other projects. The nature of the associations of radiotracers with particulate matter has been investigated under Task 3.9.

Grants and Contracts

(1) Title. Concentration and storage of Tracers and Contaminants in Sediments of Lake St. Clair.

Principal Investigator. R. Rossmann (University of Michigan)

Objective. To determine the vertical distribution of selected major and minor elements in radiometrically characterized cores as a basis for developing transport/fate models of the Lake St. Clair ecosystem.

(2) Title. Bottom Sediment Resuspension in Lake St.Clair.

Principal Investigator. B. Lesht (Argonne National Laboratory)

Objective. To determine relationships between bottom currents and sediment resuspension rates in Lake St. Clair using a previously developed instrumented bottom-resting tripod.

(3) Title. Benthic Nepheloid Layer in Southern Lake Michigan.

Principal Investigator. B. Lesht (Argonne National Laboratory)

Objective. To determine relationships between bottom currents and sediment resuspension rates in southern Lake Michigan.

Tasks and Task Objectives

Task 3.5. Present and Historical Records of Contaminant Fluxes in High Sedimentation Areas of the Great Lakes

Task Scientists. J.A. Robbins and B.J. Eadie

Objectives.

(1) To make precise determinations of sedimentation rates, ages of individual layers of sectioned sediment cores, and ranges and rates of biogenic mixing using radiometric methods.

(2) To determine the concentration of selected elements and inorganic and organic chemical compounds in dated sediment sections.

(3) To develop models that quantitatively describe the history of deposition of contaminants and take into account processes such as transport and degradation within the sediment column.

(4) To use models to estimate the flux of contaminants from sediments into overlying water.

Task 3.6. Role of Zoobenthos in Vertical Sediment Transport

Task Scientists. J.A. Robbins and D.S. White (University of Michigan)

Objectives.

(1) To determine rates of sediment reworking by natural benthos populations.

(2) To relate benthic densities and reworking rates to sedimentation and nutrient deposition rates.

(3) To relate the vertical distribution of zoobenthos to sedimentation and mixing parameters determined radiometrically.

(4) To quantify the effects of benthos-mediated particle reworking on transport of solutes.

(5) To develop mathematical models of the effects of benthos on particle and solute transport in sediments.

Task 3.7. Particle Tracer Model Development

Task Scientist. J.A. Robbins

Objectives.

(1) To obtain optimal estimates of the flux of radionuclides and stable element tracers to the Great Lakes.

(2) To develop a one-dimensional (horizontally averaged) model describing the seasonal behavior of particle-associated tracers in the water column.

(3) To develop two-dimensional (vertically averaged) and whole, well-mixed lake box) models describing the long-term time-dependence of radiotracer concentrations in the lakes.

(4) To interface models with those describing the behavior of organic contaminants.

(5) To calibrate models on the basis of known distributions of radiotracers in water, trap materials, and sediments.

(6) To use the models to predict distributions of tracers and to develop optimum field strategies.

Task 3.9. Multitracer-Particle Associations

Task Scientists. B.J. Eadie, N.R. Morehead, and J.A. Robbins

Objectives.

(1) To determine the equilibrium distribution (partition) coefficients for organic contaminants and radionuclides onto Lake Michigan particulate matter.

(2) To determine the dependence of the distribution coefficients on the concentration of solids in sediment-water suspensions.

(3) To determine the role of dissolved organic carbon on partitioning.

(4) To determine the effect of prolonged contact of tracers with sediments on the distribution coefficient for desorption.

Task 3.10. Flux Measurements in Lakes Michigan, Huron, and Superior

Task Scientists. G.L. Bell, B.J. Eadie, and J.A. Robbins

Objectives.

(1) To measure the primary and resuspension mass fluxes in Lakes Michigan, Huron, and Superior during thermally stratified and unstratified periods.

(2) To quantify the chemical fluxes for selected tracers in these lakes.

(3) To develop a model to simulate the process of settling and resuspension of particulates.

Task 3.11. Seasonal Variations in the Vertical Distribution and Transport of Short-Lived Radionuclides

Task Scientists. N. Hawley, J.A. Robbins, G.L. Bell, and B.J. Eadie

Objectives.

(1) To determine seasonal variations in the vertical distribution of particulate and dissolved short-lived (beryllium-7, polonium-210), as well as long-lived (lead-210, cesium-137) radionuclides in the open lake.

(2) To determine seasonal variations in the vertical distributions of the flux of these radionuclides.

(3) To determine seasonal variations in the distribution and storage of these radionuclides in sediment underlying the sampling site.

(4) To provide an experimental basis for development of whole lake and vertical transport models (Task 3.7).

Task 3.12. Statistical Techniques for the Analysis of Suspended Particles

Task Scientist. N. Hawley

Objectives.

(1) Develop statistical techniques which permit the quantitative characterization of suspended particle populations based on:

    a. Particle-size distribution, and
    b. Particle composition as a function of size.

(2) Use these techniques to quantify differences in suspended populations.

Task 3.15. Sediment Transport in Lake St. Clair

Task Scientist. N. Hawley

Objectives.

(1) To make observations of bottom currents, wave activity, and sediment concentration in Lake St. Clair.

(2) To experimentally determine sediment erosion rates as a function of current velocity.

(3) To determine sediment resuspension and transport in Lake St. Clair.

Task 3.16. Transport and Fate of Particle-Associated Tracers in Lake St. Clair and the Connecting Channels

Task Scientist. J.A. Robbins

Objectives.

(1) To determine levels of selected stable and radioactive tracers in sediments of Lake St. Clair and connecting channels.

(2) To determine patterns of accumulation and storage of tracers in the system.

(3) To determine the extent and intensity of local integration processes such as biological and physical mixing.

(4) To determine system response times and "trapping efficiency" by comparison of present and historical sediment inventories with known time-dependent loadings.

(5) To reconstruct, in optimal cases, the time history of contamination from sedimentary records.

PROJECT 4. THE CYCLING OF TOXIC ORGANICS

PROJECT SCIENTISTS. B.J. EADIE AND P.F. LANDRUM

Objectives

(1) To develop a model hierarchy to simulate the cycling and transport of selected toxic organic substances in the Great Lakes.

(2) To perform laboratory and field experiments designed to provide information on various pathways and rates of removal of the toxic organics from the ecosystem.

Background

The leakage of toxic synthetic organic contaminants into aquatic ecosystems is a well-recognized global problem. The conclusion of a recent workshop cosponsored by GLERL--The Scientific Basis for Dealing With Chemical Toxic Substances in the Great Lakes--was that the Great Lakes are particularly susceptible because of high population density, concentration of heavy industry, and slow (decade-century) flushing rates. Similar evaluations have been expressed by the Great Lakes Science Advisory Board, Water Quality Board, and Toxic Substances Committee of the International Joint Commission (IJC). Over 900 toxic contaminants have been identified to date within the Great Lakes' ecosystems and the extent of the hazards for most of these are poorly understood.

While most of these contaminants were perceived to be detrimental to environmental quality (e.g., all 42 of the IJC Areas of Concern), several toxic organics have been identified as a source of serious problems. High concentrations of DDT in Great Lakes fish severely impacted the herring gull population of the basin in the late 1960s and early 1970s. This once common predator is now beginning to reestablish itself, although high levels of PCB and TCDD may slow its recovery. PCB levels in Lake Michigan sport fish have been significantly above the Food and Drug Administration (FDA) recommended level of 2 ppm. A report by the National Research Council states that the Great Lakes are the largest reservoir of PCBs in the United States. Another identified problem is mirex in Lake Ontario. This compound, a fire ant pesticide manufactured in the basin, leaked into the lake and contaminated the fish to a level that resulted in a New York State ban on their commercial sale. Increased incidences of neoplasia (tumorous lesions) have been found in the fishes of the Great Lakes and tentatively attributed to relatively high concentrations of polynuclear aromatic hydrocarbons (PAHs). High levels of dieldrin, toxaphenes, and dioxin have been measured, indicating that other real problems there waiting to be found in the Great Lakes basin.

Task 4.3 has been completed and a report is on file.

Interrelationships With Other Projects

The major removal mechanism of most toxic organics is through sorption onto particulate matter and settling into the sediments. Thus, to understand and be able to simulate the transport and fate of toxic organics, we will need information supplied through Projects 1 and 3, that concerns the characteristics and transport of particulate matter. Ecosystem dynamics will be obtained from Projects 5 and 6. There will be collaboration with work ongoing in Project 10.

Approach

Many persistent toxic organics behave similarly in the aquatic environment-they are only slightly soluble and partition onto particulate material, they tend to photodecompose and evaporate as major removal pathways, they are generally resistant to microbial attack, and they concentrate in the sediments. This similarity of behavior makes a modeling approach attractive. These models require compound-specific experimental rate process information, tailored for the ecosystem to which it is applied.

Attempts to model the fate of toxic organic compounds in aquatic ecosystems appear to provide a good first-order estimate of their long-term behavior. These models are excellent tools for assembling existing information, testing system sensitivity, and designing a coherent research program. In time, they will be useful tools in the decision-making process as well. Interactions between modeling and experimental approaches enable us to make stepwise improvements in our understanding of the cycling, behavior, and fate of synthetic contaminants. Such information is necessary to identify the contaminants that pose the greatest threat to the environment, which organisms or regions within the lakes are most affected, what can be expected in the years ahead, and what can be done to reduce the level of ecosystem stress.

We propose to employ an approach in which a series of models will be developed for both diagnostic and prognostic applications. These include the calibration of an available equilibrium (fugacity) and steady-state model (EXAMS; EPA) for the Great Lakes, the development of a one-dimensional, time-dependent process model, and the calibration of a coupled lakes model. Our models will be continuously upgraded through the results of our process research experiments, both in-house and under contract, along with other information entering the literature. Carrying out process research and modeling simultaneously will allow us to continually determine the weakest or most sensitive areas in our systems approach and to define research necessary to address those specific problems. Ultimately, our goal is to combine calibrated fate models with ecosystem information to calculate exposure and to estimate effects.

A reanalysis of GLERLs toxic organic program conducted during 1985 concluded that a holistic contaminant study should be divided into 5 categories: (1) loads, (2) fate, (3) exposure, (4) effects, and (5) assessment. GLERL's program has focused predominantly on fate and exposure related processes of seasonal or longer time scales. Another major class of contaminant-related problems exists at shorter time scales (e.g., nearshore). Our evolving project is beginning to conduct process research applicable to this scale.

Currently, and for the foreseeable future, direct bioassay assessments are much more useful to the toxic management decision process than fate and exposure model results. Effects research is potentially an extremely fruitful area, and a new task is being initiated. Since project resources are declining, the effort in effects research will be low and we will continue to focus on fate and exposure related processes near the sediment water interface. These processes control the long-term fate and exposure patterns of hydrophobic contaminants in aquatic systems.

Because of their existence in the Great Lakes and their solubility characteristics, PCBs and PAHs have been the focus of our efforts to date. Field and laboratory studies on the rates of volatilization, photodecomposition, sorption onto particles indigenous to the Great Lakes, aggregation, settling, and post depositional behavior have been designed to support our toxic organic cycling model.

Grants and Contracts (No cost extensions)

(1) Title. Redistribution of Sediment-Bound Toxic Organics by Benthic Invertebrates

Principal Investigator. D.S.White (Great Lakes Research Division, University of Michigan)

Objective. To measure the effect of chronic exposure of trace organic contaminants on sediment reworking rates of benthic invertebrates.

(3) Title. Models for the Behavior and Fate of Long-lived Contaminants in the Upper Trophic Levels of the Great Lakes

Principal Investigator. J.E. Breck (Environmental Sciences Division, Oak Ridge National Laboratory)

Objective. To develop an upper trophic level model to examine contaminant transport in the Great Lakes.

Tasks and Task Objectives

Task 4.1. Polynuclear Aromatic Hydrocarbons in the Great Lakes Ecosystem

Task Scientist. B.J. Eadie

Objectives.

(1) To develop analytical capability to accurately quantitate selected polycyclic aromatic hydrocarbons (PAHs) in different parts of the Great Lakes ecosystem.

(2) To quantify the levels of selected PAHs in parts of the Great Lakes ecosystem.

(3) To calibrate a first-order assessment model for PAH in Lake Michigan.

Task 4.2. Toxic Organic Modeling in the Great Lakes

Task Scientists. B.J. Eadie and J.A. Robbins

Objectives.

(1) To synthesize available information on the aquatic cycling of PCBs and PAHs into a numerical model hierarchy for the Great Lakes ecosystem.

(2) To aid in the identification of process research needs.

Task 4.4. The Effect of Environmental Factors on the Toxicokinetics of Polycyclic Aromatic Hydrocarbons (PAH) in *Pontoporeia hoyi*

Task Scientist. P.F. Landrum

Objectives.

(1) To determine the toxicokinetics of the sediment-sorbed polycyclic aromatic hydrocarbons, phenanthrene, and benzo[a]pyrene, in *Pontoporeia hoyi*.

(2) To investigate the influence of temperature, seasonal variability, geographical distribution, and sediment type on the uptake and depuration of selected PAH in *P. hoyi*.

(3) To examine the competitive interaction of various additional xenobiotic mixtures on uptake and depuration by *P. hoyi*.

Task 4.5. Vertical Dynamics of Toxic Organics in the Great Lakes

Task Scientist. M.J. McCormick

Objectives.

(1) To develop a mathematical model for predicting the vertical distribution of toxic materials in the Great Lakes.

(2) To identify research needs and estimate prediction uncertainties by first-order error propagation.

Task 4.6. Toxicokinetics of Representative Polynuclear Aromatic Hydrocarbons in *Mysis relicta*

Task Scientists. P.F. Landrum and W.A. Frez

Objectives.

(1) To modify current culture methodology used for maintaining *Pontoporeia hoyi* to maintain mysids.

(2) To design appropriate modifications of experimental test chambers to expose mysids to polynuclear aromatic hydrocarbons (PAH).

(3) To determine the uptake, depuration, and biotransformation rate constants for PAH in this invertebrate.

(4) To determine the extent to which various environmental parameters such as temperature and food type affect the uptake, depuration and biotransformation rate constants for PAH in *M. relicta*.

Task 4.7. Food/Sediment as a Source of Xenobiotics to *Pontoporeia hoyi* and Higher Trophic Levels

Task Scientist. P.F. Landrum

Objectives.

(1) To establish the relative importance of sediments as a source of organic xenobiotics to *P. hoyi*.

(2) To perform preliminary studies on the role of *P. hoyi* as a source of toxic organics to higher trophic levels.

Task 4.8. Toxicokinetics of Organic Xenobiotics in the Mayfly Larvae, *Hexagenia*

Task Scientists. P.F. Landrum and T.F. Nalepa

Objectives.

(1) To determine the uptake, depuration and biotransformation of selected polycyclic aromatic hydrocarbons (PAH) to mayfly larvae for parameterization of fate and transport models.

(2) To examine the relationship between respiration and toxicokinetics, to determine the efficiency of uptake of organics from water, the effects of the xenobiotics on the respiration rate, and/or the role of oxygen consumption on biotransformation.

(3) To develop the empirical relationships between environmental variables and the toxicokinetic parameters.

Task 4.9. Phase Distribution and Sorption Kinetics of Organic Contaminants on Great Lakes Particulate Matter

Task Scientists. B.J. Eadie and N.R. Morehead

Objectives.

(1) To measure the equilibrium phase distribution of selected organic compounds in Lake Michigan.

(2) To identify and quantify the major variables which mediate phase distribution.

(3) To measure the rates of adsorption and desorption of selected organic compounds with Great Lakes particulate matter.

Task 4.10. Acute Toxicity of Selected Organic Xenobiotics to Great Lakes Invertebrates

Task Scientists. P.F. Landrum and T.D. Fontaine

Objectives.

(1) To determine the acute toxicity of Great Lakes invertebrates to well-studied systemic toxins.

(2) To develop time, body burden, and toxicity data for parameterizing effects simulation models.

(3) To initiate the development of a predictive simulation model of the effects of toxic organics.

PROJECT 5. ECOLOGICAL SUCCESSION AND TRENDS OF GREAT LAKES BIOTA

PROJECT SCIENTIST. D. SCAVIA

Objectives

(1) To describe and simulate plankton succession and pelagic carbon flow.

(2) To detect long-term trends in the biota of the Great Lakes and to determine their causes.

Background

The modeling of the ecology of the Great Lakes has so far been limited to including all the plankton and benthos species under a very few groupings. It is already obvious, however, that modeling at such a gross level will not be able to simulate a number of processes of immediate practical concern and will not provide a reliable capability to predict the effect of man's activities on Great Lakes ecosystems. For example, different types of algae vary greatly in their potential to clog water intakes and to cause taste and odor problems. Also, different types of plankton differ greatly in their ability to serve as food to higher levels in the food chain. Analysis of water quality control through manipulation of upper trophic levels (e.g., fish stocking) also requires information and models with more ecological detail. Thus, treating all plant and animal species alike obscures many of the processes and allows simulation of only the least complex relationships. This project attempts to detect and describe successional and other trends that have occurred or are occurring in populations of Great Lakes biota on both long and short time scales. It then attempts to determine the underlying mechanisms of these trends and to develop models simulating these situations.

The following tasks are completed and the final reports are on file:

Task 5.1, Variations in Physical and Chemical Parameters, Nutrient Concentrations, and Primary Productivity in Lake Michigan.

Task 5.2, Zooplankton Grazing.

Tasks 5.3 and 5.4 (combined), Feeding and Culturing of Great Lakes Cyclopoid Copepods.

Task 5.5, Seasonal Variations in Soluble Reactive Phosphorus Concentrations in Southern Lake Michigan.

Task 5.7, Studies on the Coulter Counter.

Task 5.8, Laboratory Observation of Selection and Ingestion of Algae in Mixed Assemblages by *Diaptomus*.

Task 5.9, In Situ Predation by Mysis relicta on Zooplankton in Lake Michigan.

Task 5.13, Consequences of Microscale Patchiness of Nutrient Supply.

Task 5.14, Twenty- to Thirty-Year Simulation and Analysis of Ecosystem Succession in Lake Washington.

Task 5.16 Nutrient-light Regulation of Phytoplankton Growth in Subsurface Phytoplankton Populations.

Task 5.22, Lake Michigan Ecosystem Experiment--Ambient Conditions.

Task 5.6 has been moved to Project 6; Task 5.15 has been combined with Task 5.21; and Task 5.20 has been combined with Task 5.18.

Interrelationships With Other Projects

The results from this project will be used to improve the treatment of nutrient cycling models of Project 6. Nutrient cycling models of Project 6 will be the template for models herein. Trend information will also be used in evaluating the effects of toxic organics and in modeling their cycling in Project 4. Data, analysis, and advice on water movements from Project 1 will be needed.

Approach

Our approach to achieve objective 1 will be a combination of field, laboratory, and model studies. Field investigations will measure changes in densities and characteristics of planktonic algae, zooplankton, and bacteria populations and assemblages over various time and space scales. Field programs will also estimate species-specific growth and loss rates of these populations, with initial emphasis on phytoplankton. These estimates of growth and loss, along with physical transport characteristics measured or estimated in this or other projects (e.g., Project 1), will be combined with changes in populations via numerical models to determine the adequacy of proposed hypotheses (i.e., models) for simulating plankton dynamics. These tests should provide continued evolution of research initiatives, eventually narrowing in on a concise statement (model) of plankton dynamics and succession. Laboratory studies will be carried out on specific process relationships that require further definition and are identified as critical by the combined field and modeling efforts. Examples of this approach are the simulation analysis of Lake Washington ecosystem dynamics (Task 5.14) and the collected efforts of the Lake Michigan Ecosystem Experiment (Tasks 5.17-5.22).

Our approach to achieve objective 2, focusing on the benthos, will be obtaining samples by the same methods and at the same locations and seasons as taken in past studies. The results from the two studies will be compared in order to determine whether changes have occurred. If changes are detected, the distribution of these changes in space and time, the magnitude of changes for various types of organisms, and the literature information concerning similar changes will be evaluated in an attempt to develop a hypothesis concerning the cause or causes of the changes. Our approach to achieve objective 2, focusing on the pelagic zone, will be to establish station DS-7 (the 100-m deep station, 26 km west of Grand Haven, MI) and other stations in Lakes Michigan, Superior and, Huron, if possible, as long-term monitoring stations. On at least a seasonal basis, samples will be collected from that station to assess changes in water clarity, total phosphorus, chlorophyll, and phytoplankton and zooplankton composition.

Tasks and Task Objectives

Task 5.10. Phosphate Uptake and Phytoplankton Growth Rates in Southern Lake Michigan

Task Scientists. S.J. Tarapchak and L.R. Herche

Objectives.

(1) To investigate the relationships among, and the underlying physiologic causes of, variations in orthophosphate uptake and phytoplankton growth rates in southern Lake Michigan.

(2) To (a) provide physiological data for interpreting patterns in phytoplankton succession and phytoplankton nutrient competition, and (b) to test mathematical constructs describing phosphorus-limited phytoplankton growth in whole-lake ecosystem models.

Task 5.11. Analysis of Growth Rates of Phytoplankton Species in Southern Lake Michigan

Task Scientists. S.J. Tarapchak and H.A. Vanderploeg

Objectives.

(1) Document the seasonal succession pattern of algae in Lake Michigan and describe the significance of nutrient competition, algal sinking, and zooplankton grazing on this succession.

(2) Test the Schelske-Stoermer (1972) hypothesis that has been advanced to explain the development of blue-green algal populations in Lake Michigan.

Task 5.12. Long-Term Trends in Lake Michigan Benthic Fauna

Task Scientist. T.F. Nalepa

Objective.

The objective of this task is to determine and interpret long-term trends in the benthic fauna of Lake Michigan.

Task 5.17. Lake Michigan Ecosystem Experiment--System Synthesis and Modeling

Task Scientists. D. Scavia, G.A. Lang, G.L. Fahnenstiel, and G.A. Laird

Objective.

To combine process measurements made in Tasks 5.18-5.22 in a model of plankton dynamics and test prediction against observed changes for the purpose of evaluating models and experimental coverage of natural processes.

Task 5.18. Lake Michigan Ecosystem Experiment--Plankton and Particulate Loss Rates

Task Scientists. D. Scavia and G.L. Fahnenstiel

Objectives.

(1) To measure vertical flux of planktonic algae and particulate nutrients on variable time scales (hours-weeks) for the purpose of determining loss from specific vertical strata.

(2) To determine loss rates of algae (community and populations) due to zooplankton grazing.

Task 5.19. Lake Michigan Ecosystem Experiment--Bacterial Growth and Loss Rates

Task Scientists. D. Scavia and G.A. Laird

Objective.

To determine growth and grazing loss rates of planktonic bacteria for the purpose of comparing bacterial carbon growth requirements to algal organic carbon release rates.

Task 5.21. Lake Michigan Ecosystem Experiment--In Situ Species Specific Growth Rates and Subsurface Phytoplankton Maxima in Lake Michigan

Task Scientists. G.L. Fahnenstiel and D. Scavia

Objectives.

(1) To determine the magnitude and role of species-specific in situ growth in the development and maintenance of subsurface phytoplankton populations.

(2) To determine species-specific photosynthesis vs. light relationships for surface and subsurface phytoplankton populations and compare those results with in situ measurements of primary production.

Task 5.23. The Selectivity and Feeding Rate Responses of a Copepod in Algal Mixtures: Concentration and Time History Effects

Task Scientists. H.A. Vanderploeg and J.R. Liebig

Objectives.

(1) Describe the selectivity and feeding rate response for the copepod *Diaptomus* in equilibrium with varying concentrations of mixtures of small and large algae.

(2) Examine effect of prior feeding history in a simulated algal patch on selectivity and feeding of a copepod encountering a new patch of phytoplankton having a different relative and total concentration of a small and large algae.

Task 5.24. Direct Observations on the Plant-Copepod Interface: The Rules of the Game

Task Scientists. H.A. Vanderploeg, G.-A. Paffenhofer (Skidaway Institute of Oceanography), and J.R. Liebig

Objectives.

Describe (1) the mechanisms of algal capture employed by *Diaptomus* spp., (2) the defense mechanisms of the algae, and (3) microscale interactions between copepods and algae that could lead to the algae benefiting from a nutrient plume around the copepod.

Task 5.25. Observations of Long-Term Trends in the Pelagia of Lake Michigan

Task Scientists. G.A. Laird and D. Scavia

Objective.

To monitor water quality and ecological properties in Lake Michigan with special emphasis on comparison of "top-down" vs. "bottom-up" control.

PROJECT 6. FOOD WEB DYNAMICS AND PELAGIC/BENTHIC INTERACTIONS

PROJECT SCIENTIST. W.S. GARDNER

Objectives

(1) To develop (and provide data for) conceptual and mathematical models to simulate and predict processes controlling food web dynamics in the Great Lakes and coastal ecosystems.

(2) To experimentally quantify important pathways of nutrient transformations and biochemical energy flow from photosynthesis to fish.

(3) To quantify specific interactions between pelagic and benthic food webs.

(4) To relate food web dynamics to prediction of changes in water quality (e.g,. nutrient overenrichment and contaminant problems) and fishery resources.

Background

The value of the Great Lakes as a resource depends in large part on the quality of their water and on the types and amounts of fish that are produced in them. Both water quality and fishery resources are a direct function of ecosystem dynamics (Fig. 3). GLERL's research on ecosystem dynamics is relevant to both water quality management and fisheries research (Fig. 4). Understanding food web interactions is critical in predicting anthropogenic effects on water quality and fish production in the lakes. For example, the pathways of organic contaminants through the biotic system may be directly related to the flow of energy from photosynthesis to fish. Nutrient over-enrichment directly affects phytoplankton dynamics and water quality but also can detrimentally affect fish production due to food web changes. On the other hand, determining the effects of fish-management practices on the water quality of the lakes also requires an understanding of food web interactions between fish and phytoplankton. Interactions among and within ecosystem trophic levels thus are important to understanding and predicting accumulation and transfer of toxins, production of harvestable fish, and the impacts of nutrient overenrichment and fishery management practices on water quality. An understanding of the dynamics of carbon (energy) and other nutrients is needed to evaluate various impacts on the ecosystem stemming from a broad range of human activities (e.g., nutrient loads, toxic loads, fishery management) as well as uncontrollable forces (e.g., meteorology).

An important but incompletely understood aspect of food web dynamics in the Great Lakes is the quantitative significance of energy and nutrient inter-actions between the pelagic and benthic communities. The two communities are obviously very closely linked. For example, benthic communities derive most of their energy from pelagic photosynthesis; the pelagic system appears to be

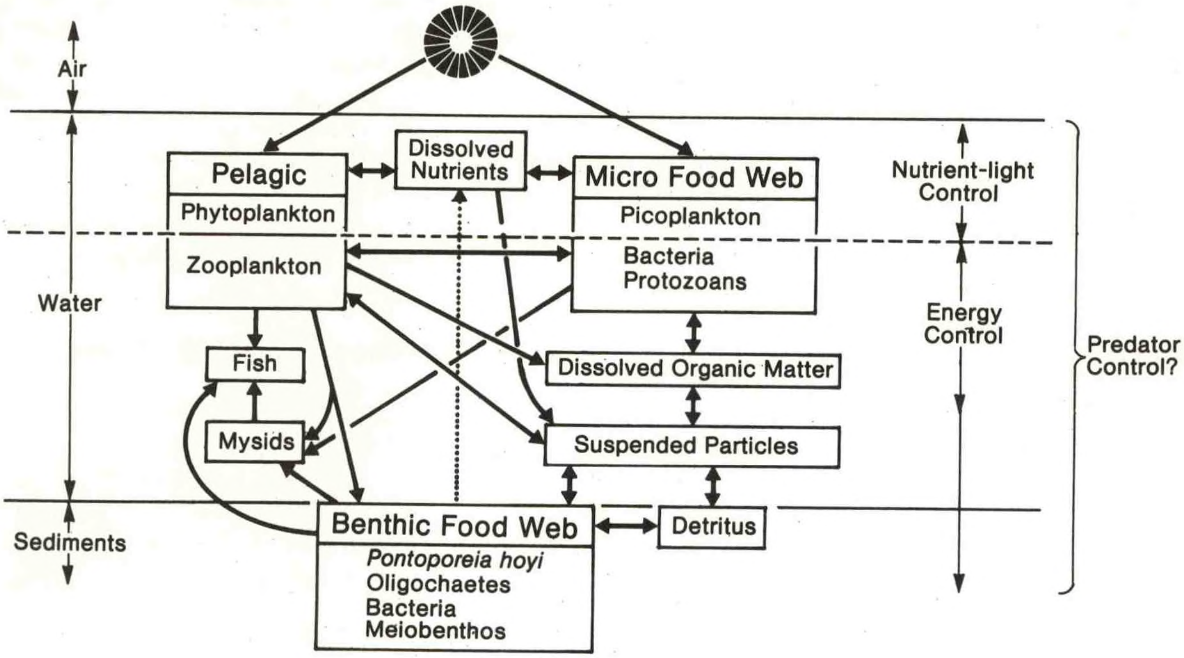

Figure 3.--Conceptual diagram of nutrient/energy interactions in Great Lakes food webs.

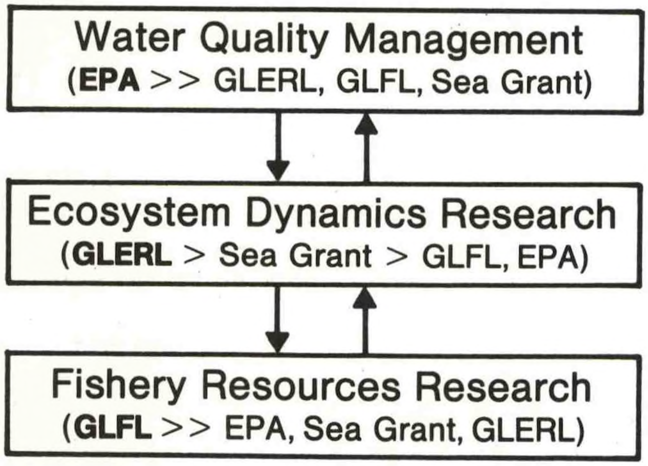

Figure 4.--Relationships between Great Lakes management and research activities and qualitative comparison of federal agency responsibility levels.

driven in large part by nutrients associated with suspended or resuspended particles, fish feed both on pelagic and benthic invertebrates; contaminant transport and fate involves both systems. However, despite these overlaps, the two systems are usually studied separately.

Interdisciplinary research is needed to provide a better understanding of these interactions. Previous examples of GLERL work in this direction are: sediment trap studies, the Lake Michigan Ecosystem Experiment, the High-Sed Program, and studies of the role of the benthos in nutrient regeneration and energy flow in the Great Lakes. In this project, research will build on this background to quantify, and develop the ability to predict, nutrient and energy flow within and among these interactive communities.

The following research tasks have been completed and final task reports are on file:

Task 6.1, Physical-Chemical Study of the Detroit River, Lake St. Clair, and the St. Clair River.

Task 6.2, Analysis of the Lake Ontario Oxygen Profiles.

Task 6.4, IFYGL Chemical Intercomparison.

Task 6.5, Characteristics of Oswego River Plume.

Task 6.6, Chemical-Physical Variability in Southern Lake Michigan.

Task 6.7, Water and Sediment Chemistry: Southern Lake Michigan.

Task 6.8, Distribution of Benthic Invertebrates.

Task 6.9, Presentation of Lake Survey Center (LSC/GLERL Chemical Field Data, 1965-75).

Task 6.11, Characterization and Transport of Nearshore Material.

Task 6.15, Size partitioning and Lability of Phosphorus in Southeastern Lake Michigan.

Task 6.16, Development of Methods to Chemically Speciate Dissolved Phosphorus and Organic Compounds in Lake Michigan.

Task 6.17, One-Dimensional Multilayer Ecological Model.

Task 6.18, Two-Dimensional Transport Ecological Model.

Task 6.20, Phosphorus Cycling in the Great Lakes--Theoretical Investigations.

Task 6.21, Uncertainty Analysis in Eutrophication Models.

Task 6.23, Effects of Small-Scale Heterogeneity on Nutrient Phytoplankton-Zooplankton Relationships.

Task 6.24, Effects of Feeding Rates and Food Types on Release of Nutrients by Zooplankton.

Task 6.25, Kinetics and Magnitude of Nutrient Release by *Daphnia magna* and Lake Michigan cladocera.

Task 6.26, Mineralization of Phosphorus and Nitrogen in Aerobic Lake Sediments by Benthic Invertebrates.

Task 6.28, Direct Measurement of Ammonia and Phosphorus Release by Zooplankton in Suspensions of Food.

Task 6.29, Speciation of Dissolved and Particulate Phosphorus Components in Tributary and Lake Water and Sediments.

Task 6.31, Biological Availability of Phosphorus from Atmospheric Precipitation and Other Sources.

Task 6.32, Factors Affecting Nitrogen Release Rates of Two Species of Marine Copepods.

Task 6.35, Mechanisms of Release and Uptake of Dissolved Organic Nutrients in Lake Michigan.

Task 6.37, Lipid Content and Energy Flow Through *Pontoporeia hoyi* and Other Benthic Invertebrates in Lakes Michigan and St. Clair.

Task 6.12, Analysis of LSC/GLERL Limnological Data 1965-75, Task 6.19, Comparative Study of the Upper Great Lakes, and Task 6.27, Phosphorus Cycling in the Great Lakes--System Synthesis and Simulation, have been terminated. Task 6.13, Characteristics of the Nepheloid Layer and Resuspended Material in Southeastern Lake Michigan, and Task 6.3, Carbon Dynamics, have been moved to Project 3, Particle Dynamics, and Task 6.22, Long-Term Trends in Lake Michigan Benthic Fauna, has been moved to Project 5.

Interrelationships With Other Projects

Information obtained in this project will help in the interpretation of long-term trend observations (Project 5). Likewise, ecological observations made in Project 5 have direct relationship to food web dynamics being addressed here. This project is highly dependent on understanding particle dynamics in the lakes (Project 3) and is closely related to studies of contaminant transfer dynamics (Project 4). Understanding material and biochemical-energy transport will depend on knowledge of water movement (Project 1) and on the effects of particle resuspension by wave action (Project 2).

Approach

Simulation and prediction of food web dynamics in lake ecosystems and their effects on water quality and the fishery resource require understanding and quantification of nutrient and energy transformation processes in and between various interacting compartments (Fig. 9, pg. 156). Research will build on the base of modeling- and process-research previously established in Projects 5, 6, and others, but will focus more specifically on pelagic benthic interactions. The long-term objective is to ultimately be able to accurately follow and model energy transformations in the Great Lakes from photosynthesis to fish. This approach will also provide information and understanding needed to predictively model the fate of anthropogenically-added nutrients and contaminants in the Great Lakes and their effects on the biota and water quality in the lakes.

Tasks and Task Objectives

Task 6.14. The Role of Benthic Animal Communities in Nutrient Regeneration Processes of Southern Lake Michigan

Task Scientists. M.A. Quigley and T.F. Nalepa

Objectives.

(1) To determine the extent of nutrient regeneration from nearshore sediments and to evaluate the importance of benthic animal activities in influencing such regeneration.

(2) To determine the vertical distribution of animals in sediments in relation to vertical profiles of nutrients, dissolved oxygen, organic carbon, water content, and particle-size distribution.

Task 6.30. Phosphorus-Phytoplankton Dynamics in Lake Michigan

Task Scientist. S.J. Tarapchak

Objective.

The objective of this task is to evaluate the role of secondary limitation of algal growth by silica on phosphorus cycling in the epilimnion of an offshore station in Lake Michigan.

Task 6.33. Nutrient Mineralization in "Aerobic" Lake Sediments: Benthic Invertebrate-Microbial Interactions

Task Scientists. W.S. Gardner and T.F. Nalepa

Objectives.

To determine nitrogen mineralization rates and the relative importance (and interactions) of benthic invertebrates and microbes to the mineralization process in aerobic lake sediments.

Task 6.34. Pelletization of Lake Michigan Sediments by the Amphipod *Pontoporeia hoyi*

Task Scientist. M.A. Quigley

Objectives.

(1) To identify *P. hoyi* feeding mode (continuous vs. intermittent) throughout individual size classes and season.

(2) To determine particle size selection and sediment throughput rates of *P. hoyi* feeding in Lake Michigan sediments with respect to how such processes affect nutrient regeneration from sediments to overlying water.

(3) To describe the fate of *P. hoyi* fecal pellets including decomposition and disintegration rate, incidence of coprophagy, and probability of permanent burial.

Task 6.36. Dissolved Phosphorus Release Rates From Lake Michigan Sediments and Relation to Benthic Invertebrate Abundances

Task Scientists. T.F. Nalepa, W.S. Gardner, and M.A. Quigley

Objectives.

(1) To obtain phosphorus release rate measurements on intact sediment cores from several locations in Lake Michigan.

(2) To estimate the quantitative significance, relative to other phosphorus inputs, of sediment phosphorus release in Lake Michigan.

(3) To determine the relation between sediment phosphorus release rates and benthic invertebrate abundances.

Task 6.38. Nitrogen Excretion Rates of Two Estuarine Zooplankters, *Parvocalanus crassirostris* and *Acartia tonsa*, as Related to Temperature and Composition of Food

Task Scientists. W.S. Gardner and G.-A. Paffenhofer (Skidaway Institute of Oceanography)

Objectives.

(1) To determine ammonium excretion rates for two species of copepods that are common in estuaries of the southeastern United States.

(2) To evaluate the effects of food type and temperature on excretion rates of these zooplankters.

Task 6.39. Nutrient Release from Sediments of Lake St. Clair and Connecting Channels

Task Scientists. T.F. Nalepa, M.A. Quigley, and W.S. Gardner

Objectives.

(1) To quantify the release of phosphorus from sediments in Lake St. Clair and connecting channels.

(2) To assess the relative importance of benthic invertebrates and diffusion in the release process.

(3) To estimate the quantitative significance, relative to other nutrient sources, of sediment nutrient release.

Task 6.40. Benthic Invertebrate Research in Lake Superior with a Submersible

Task Scientists. T.F. Nalepa and M.A. Quigley

Objectives.

(1) To determine benthic invertebrate distribution patterns and to relate distributions to sediment characteristics, particularly microbial abundances.

(2) To examine the sampling efficiency of the Ponar grab sampler.

Task 6.41. Effects of Starvation on the Physiology and Nutrient Cycling Rates of *Pontoporeia hoyi*

Task Scientists. W.S. Gardner, J.M. Gauvin, and T.F. Nalepa

Objectives.

To determine nutrient release rates and lipid content in *P. hoyi* on freshly collected animals and during various stages of food deprivation.

Task 6.42. Phosphorus Cycling in the Lake Michigan Microbial Food Web: Phytoplankton-Bacterial Competition

Task Scientist. S.J. Tarapchak

Objective.

To determine if heterotrophic bacterioplankton compete with phototrophic phytoplankton for dissolved inorganic phosphorus in lake waters.

Task 6.44. Transfer of Energy from Pelagic Phytoplankton to *Pontoporeia hoyi* in Lake Michigan

Task Scientists. W.S. Gardner, T.F. Nalepa, and M.A. Quigley

Objectives.

(1) To examine mechanisms of energy transport from the pelagic food web to *P. hoyi*, the dominant benthic macroinvertebrate in the upper Great Lakes.

(2) To measure caloric content and lipid composition in seasonal detrital food supplies (sediment trap material and surface sediments) potentially available to to *P. hoyi* in Lake Michigan.

(3) To determine the proportion of assimilated energy in *P. hoyi* that is derived from bacteria, living algae, and detritus.

Task 6.45. Primary Production and Autotrophic Micro Food Webs in Lakes Huron and Superior

Task Scientist. G.L. Fahnenstiel

Objectives. To determine the rates of primary production and significance of micro food webs in Lakes Huron and Superior.

Task 6.46. Lower Food Web Carbon Dynamics

Task Scientists. D. Scavia and G.A. Laird

Objectives.

(1) To assess the structure and significance of various pathways for carbon flow and cycling within the pelagic food web.

(2) To assess various alternative carbon pathways as sources for heterotrophic bacteria production.

Task 6.47. Fish Enclosure Experiments in a Profundal Area of the Great Lakes

Task Scientist. T.F. Nalepa

Objectives.

(1) Determine the impact of fish predation on benthic invertebrate abundance and composition.

(2) Obtain quantitative estimates of the transfer of secondary production into fish production.

Task 6.48. Food-Web Regulation of Water Quality

Task Scientists. J. F. Kitchell, D. Scavia, and G.A. Lang

Objectives.

The overall objective of this task is to evaluate the relative influences of "top-down" and "bottom-up" impacts on Great Lakes water quality. The immediate goals of the task are focused on Lake Michigan and will be addressed through models designed to explore the following hypotheses:

(1) Summer phytoplankton abundance is determined by epilimnetic phosphorus (P) remaining after the onset of stratification; stratification-period total P concentrations are controlled by the timing of the onset of stratification and thus the duration of spring diatom production.

(2) Summer phytoplankton composition is controlled by the balance between nutrient supply and zooplankton grazing, both of which are determined by the composition of zooplankton present.

(3) Variability in controls described in (2) is related to stochastic variation in planktivory (i.e., strong vs. weak fish year classes, etc.) and cascades through the food web in ways that regulate phytoplankton composition and water clarity.

(4) Variation in planktivory is controlled by piscivory and is therefore subject to regulation through fisheries management practices.

(5) By virtue of the relationship between $CaCO_3$ precipitation and primary production (i.e., pH influenced by primary production) and the potential relationship between fish-predation/zooplankton-structure and primary production, the historical record should offer evidence of correlation between planktivory and both the frequency and intensity of calcite whitings.

PROJECT 7. HYDROLOGIC PROPERTIES

PROJECT SCIENTISTS. F.H. QUINN AND T.E. CROLEY II

Objectives

(1) To develop improved water supply and lake level forecasting techniques for large lake basins and estuaries.

(2) To develop improved mathematical models for simulating the effect of past hydrologic conditions and future scenarios on the water supplies, levels, and flows of the Great Lakes and their connecting channels.

(3) To enhance our understanding of the impact of climatic variability and change on the water resources of the Great Lakes.

(4) To develop improved understanding of the hydrologic processes of the Great Lakes Basin.

(5) To develop and maintain a hydrologic data base of sufficient quality for both scientific and water resource studies of the Great Lakes.

(6) To assist in the solution of water quality management problems.

Background

An understanding of lake hydrology is fundamental for water resource and prediction studies of the Great Lakes Basin. The processes governing water depletion and replenishment are contained in the hydrologic cycle, which integrates the relationships between water supplies, water losses, and the resulting lake levels and flows in the connecting channels. A knowledge of the water supplies and flows is necessary for water quantity, water quality, shore erosion, hydropower, navigation, recreation, flooding, resource management, prediction, and simulation studies of the Great Lakes System. In addition, the knowledge gained from the precipitation, runoff, and groundwater studies can be applied to such highly diverse areas as agriculture, municipal water supplies, land use, tributary flooding, and basin recreation.

The project is conducted under NOAA's broad mission, given by Reorganization Plan No. 4, to conduct research relating to the water quantity of the Great Lakes. This includes research conducted as part of NOAA's support of interagency and international committees, such as the various boards of the International Joint Commission and the International Coordinating Committee for Great Lakes Basic Hydraulic and Hydrologic Data. The research from this project supports many users, ranging from the National Weather Service and the National Ocean Survey to marine resource decision makers and the general public. Also included among the primary users are the Corps of Engineers, the Environmental Protection Agency, and the various boards of the International Joint Commission.

The hydrologic properties research is primarily oriented toward the mathematical modeling of the individual processes comprising the hydrologic cycle. This research consists of the development, calibration, testing, and application of process response models to simulate the complex interrelationships that exist between the hydraulic and hydrologic processes within the Great Lakes and their immediate environment. Comprehensive data bases on pertinent hydrologic parameters, such as precipitation, runoff, evaporation, and temperatures, have been developed to support the models. Experimental programs are carried out as required to fill gaps in both theory and data.

A hydrologic response model of the Great Lakes Basin, the supporting GLERL large basin rainfall/runoff model, lake-level outlook packages, and unsteady flow models of the Detroit, St. Clair, and St. Lawrence Rivers have been developed to date. These models are currently being used in conjunction with the hydrologic data base to provide an advisory service on water levels and flows and to assess the value of new data collection programs. Typical users of this service are the general public, Federal agencies, international commissions, the Great Lakes States, and departments of Environment Canada.

It is expected that, as the base of scientific knowledge increases and as data acquisition in near real-time improves, Great Lakes system models will be developed. Increased hydrologic advisory services will provide a sound basis for systematic consideration of the more intensive multipurpose use of the lakes that is certain to develop with growth of the region's population and economy.

The following research tasks have been completed and final task reports are on file:

Task 7.1, Lake Precipitation.

Task 7.2, Lake Evaporation.

Task 7.3, Evaporation Synthesis.

Task 7.6, Great Lakes Beginning-of-Month Levels.

Task 7.8, Hydrologic Forecasting.

Task 7.9, Connecting Channels Transient Models.

Task 7.10, Lake Michigan Evaporation.

Task 7.11, Lake Superior Regulation Analysis.

Task 7.12, St. Lawrence River Hydraulic Transient Model.

Task 7.14, GLERL-SEA Cooperative Effort: Upland Erosion in the Great Lakes Basins.

Task 7.15, Development and Application of Climatic Water Balance Models for the Lake Erie, Lake Ontario, and Lake Superior Drainage Basins.

Task 7.16, Travel Time in the Great Lakes Channels for Operational Spill Applications.

Task 7.19, Lake Champlain Water Supply and Flood Forecasting.

The following task has been deleted:

Task 7.5, Great Lakes Shoreline Flooding.

Interrelationships With Other Projects

The energy balance at the water surface is the primary driving force for thermal structure forecasting (Project 1, Water Movements and Temperature). Shoreline damage caused by waves and water level fluctuations is governed by changes in the lake levels (Project 2, Prediction of Surface Waves, Water Level Fluctuations, and Overlake Winds). The data and models generated by this project will also provide input to Project 8, Lake Ice, and Project 10, Environmental System Studies and Applied Modeling.

Approach

Hydrologic data are being collected and analyzed on such variables as precipitation, runoff, air temperature, evaporation, and groundwater. The data are used to maintain the GLERL hydrologic data base for support of mathematical models, research on the hydrologic processes and a hydrologic advisory service. Hydrologic monographs and data reports containing the latest information on the Great Lakes will be compiled and published for use by Federal and state agencies, the general public, and the International Coordinating Committee for Great Lakes Basic Hydraulic and Hydrologic Data.

Research into the hydrologic processes will emphasize rainfall-runoff studies, evapotranspiration assessments, lake evaporation and precipitation, groundwater, snow melt and ablation studies, connecting channel hydraulics under ice conditions, and overland sedimentation processes. The main thrust of the project is the development and application of mathematical models of the various hydrologic processes for forecasting and simulation studies. Typical models include basin runoff models, overland erosion models, evaporation models, unsteady flow models of the connecting channels, and water supply prediction models. In the near term, the modeling effort will concentrate on the development of basin-runoff models for each of the Great Lakes Basins. Both conceptual and climatic water balance configurations will be used. These models will interface with the Great Lakes hydrologic response model as part of an integrated Great Lakes system model. The use of these models for forecasting will be supported in real time with the development and incorporation of near real-time data acquisition. Research effort will also continue on the modification of the unsteady flow models for ice conditions.

Experimental studies will be conducted as required, to fill in gaps knowledge or data. In the near term the experimental work will concentrate on connecting channels winter regime hydraulics and on erosion research.

Typical applications include connecting channel flow for the International Joint Commission, U.S. Geological Survey, and Great Lakes states water quality studies, determining causes of Great Lakes long-term water level fluctuations, Great Lakes river basin studies, and water supply forecasting. A major application currently underway is to develop, in conjunction with the International Technical Information Board of the International Joint Commission, an improved hydrometeorological forecast system for the Great Lakes.

Tasks and Task Objectives

Task 7.4. Water Levels and Flows Simulation

Task Scientist. F.H. Quinn

Objectives.

(1) To use the Great Lakes hydrologic response model for specific management problems involving the water quantity in the lakes, such as evaluation of the precipitation augmentation, determination of effects of diversions on the water levels, and determination of effects of ice retardation in the connecting channels.

(2) To use the hydraulic transient models for specific problems involving the water quantity in the lakes and connecting channels, such as water quality and pollution studies, lake inflow and outflow studies, and more accurate connecting channel flow determinations.

(3) To investigate and report on factors that impact upon the water levels and flows.

(4) To update the GLERL hydrologic data base.

Task 7.7. Great Lakes Basins Runoff Modeling

Task Scientist. T.E. Croley II

Objectives.

(1) To develop digital models that will:

a. Simulate runoff responses of each of the Great Lakes Basins to time series of climatological conditions.

b. Simulate the hydrologic response of individual watersheds in the Great Lakes Region reasonably accurately.

(2) To interface the lake basin watershed models with the Great Lakes Hydrologic Response Model so that the watershed models provide the runoff component to the response model.

Task 7.13. St. Clair and Detroit River Flow Regimes

Task Scientist. J.A. Derecki

Objectives.

(1) To determine the winter flow variability and characteristics of the St. Clair and Detroit Rivers.

(2) To use the measured data to verify and/or recalibrate the existing St. Clair and Detroit River mathematical transient models.

(3) To reassess the St. Clair and Detroit River 1959-78 winter monthly flows for international coordination by the River Flow Subcommittee of the International Coordinating Committee for Great Lakes Basic Hydraulic and Hydrologic Data.

(4) To measure the St. Clair and Detroit River flows in support of the Upper Great Lakes Connecting Channels Study.

Task 7.17. Great Lakes Hydrological Forecasting

Task Scientist. T.E. Croley II

Objectives.

(1) To develop digital models for making deterministic and probabilistic forecasts of soil moisture, runoff, net basin supply, and lake levels in near real-time for the Great Lakes Basins.

(2) To develop and maintain a hydrologic data base in a near real-time fashion of sufficient quality for scientific and water resource studies and for up-to-date forecasts and outlooks.

(3) To investigate use of system-wide forecasting in lake-level regulation determinations.

Task 7.18. Investigation of Large-Scale Short Period Variations in Detroit River Flows

Task Scientist. F.H. Quinn

Objective.

To investigate the magnitudes of large-scale flow variations in the Detroit River induced by Lake Erie wind setups and storm surges.

Task 7.20. Investigation of Changes of Lake Storage in Lakes Superior and Erie

Task Scientist. F.H. Quinn

Objective.

To investigate the roles of thermal expansion and computational procedures in computing the change-in-storage component of the water balance of Lakes Superior and Erie.

Task 7.21. The Water Supply and Levels of the Great Lakes: Past, Present, and Future

Task Scientists. F.H. Quinn, E.J. Aubert, and T.E. Croley II

Objective.

The objective of this task is to provide relevant background on perceived Great Lakes water supply, water supply problems, NOAA/GLERL role in hydrologic research, monitoring, and management.

Task 7.22. Unsteady Flow Model of Entire St. Clair River

Task Scientist. F.H. Quinn

Objective.

To develop an unsteady flow model of the St. Clair River from Lake St. Clair to Lake Huron, including tributary stream inputs, capable of simulating flows on hourly and daily time scales.

Task 7.23. Update the Great Lakes Hydrologic Data Base, 1981-85

Task Scientists. F.H. Quinn, and R.N. Kelley

Objective.

The objective of this task is to maintain a hydrologic data base of sufficient quality for both scientific and water resource studies of the Great Lakes.

PROJECT 8. LAKE ICE

PROJECT SCIENTIST. S.J. BOLSENGA

Objectives

(1) To develop improved climatological information on the formation, growth, and decay of the Great Lakes ice cover.

(2) To develop numerical models and techniques to simulate and forecast the freeze-up, breakup, areal extent, and thickness of the ice cover of the Great Lakes and their connecting channels.

(3) To define the natural distribution and variability of the physical and chemical characteristics of the Great Lakes ice cover.

Background

An understanding of the Great Lakes ice and snow cover is necessary for many water resource and engineering studies of the Great Lakes. Knowledge of the ice and snow cover and its properties is necessary for winter navigation, shoreline engineering, hydropower generation, water supply forecasts, and water quality studies. In addition, the knowledge gained from these studies can be applied to such highly diverse areas as ship and icebreaker design, monitoring of atmospheric pollution, and siting of nuclear and fossil fueled power plants.

The research results from this project support many users, ranging from NOAA operational elements, such as the National Weather Service (NWS), to marine resource decision makers, the Great Lake shipping industry, and the general public. Also included among the primary users are the Corps of Engineers, the St. Lawrence Seaway Development Corporation, and the Great Lakes power utilities.

The lake ice studies began in 1963 with initial work on lake ice concentration. These studies have resulted in a series of technical reports documenting each year's ice cover. In addition, an ice climatology report, the Great Lakes Ice Atlas, was compiled and published in 1969. As a corollary, an 81-yr air temperature data base for the nearshore areas of the Great Lakes has been developed. The data base has been used to evaluate the winter severity of the past 80 winters and to classify the winters on which the ice-cover climatology for a revised ice atlas, published in 1983, was based. A recently completed study requested by the International Niagara Board of Control analyzed the climatic impact of the Niagara River ice boom on the temperature regime of the Buffalo, NY, area.

As a part of the forecast studies, four ice forecasting techniques, for locations in the St. Marys and St. Lawrence Rivers, have been developed to date.

On the St. Lawrence River, a freeze-up forecasting technique was developed and tested which used an empirically-based algorithm which predicted the heat loss in the eastern end of Lake Ontario and the heat depletion in the river between Lake Ontario and the forecast area near Massena, NY. This technique has been used operationally by NWS since 1975. More recently, a model has been developed of the surface energy flux and heat transfer within a river ice cover for use in simulating ice cover growth and decay on the international section of the St. Lawrence River

On the St. Marys River, a forecast of ice cover in the Little Rapids Cut was developed in conjunction with a contractor to forecast ice backup which could clog a ferry crossing in the river. A more recent study using site-specific heat transfer coefficients and observed water temperatures at Sault Ste. Marie, MI, developed operational forecast techniques to predict ice formation, thickness, and breakup at several sites on the St. Marys River. The forecasts are conducted operationally by the Corps of Engineers and are part of an operational plan for controlling navigation.

Studies on the optical properties of ice began during the 1975-76 winter season with a field program using pyranometers (300-3000 nm) to investigate the diurnal and seasonal variation of the albedo of the various ice types common to the Great Lakes. The program was initiated in response to a need for an accurate definition of the albedo for ice prediction models and for use as basic ground signature input for remote sensing analysis of the ice cover.

Photosynthetically active range (400-700 nm) [illegible]ctors were subsequently acquired to study the transmittance of radiation through ice. A model was developed and the published results represent the most complete and accurate information source available on this subject. Finally, two scanning spectroradiometers were configured to simultaneously measure reflected and incident radiation over ice and snow in the 300-1100 nm range. Field studies using these instruments have provided the first measurements of spectral reflectance over ice and snow in the Great Lakes.

The results of the various studies are currently being used to provide an advisory service on Great Lakes ice. Typical users are international boards and commissions, Federal agencies, consulting engineers, and the general public.

The following tasks have been completed and final task reports are on file:

Task 8.1, Ice Distribution.

Task 8.2, Ice Forecasting.

Task 8.3, Nearshore Ice Thickness and Stratigraphy.

Task 8.4, Winter Navigation.

Task 8.5, Ice Information Archiving and Advisory Service.

Task 8.6, Water Temperature Observations.

Task 8.7, Optical Properties of Ice.

Task 8.8, Lake Superior Heat Storage.

Task 8.9, St. Lawrence River Ice Breakup Forecast.

Task 8.10, Revision of the Great Lakes Ice Atlas.

Task 8.11, St. Marys River Ice Forecasts.

Task 8.13, Great Lakes Ice Dynamics Modeling.

Task 8.14, Verification of Ice Transport Model.

Interrelationships With Other Projects

This project will provide input to other GLERL projects, such as Project 6, Eutrophication and Nutrient Cycling; Project 5, Planktonic Succession; Project 7, Hydrologic Properties; and Project 9, Environmental Information Services. It will receive input from Project 1, Water Movements and Temperatures.

Approach

The freshwater ice and snow research falls into three broad, interrelated program areas. These are ice and snow characteristics, ice distribution, and ice forecasting.

The ice and snow characteristics program is designed to define the natural distribution and variability of the characteristics of the Great Lakes ice and snow cover. This includes providing information useful in modeling the cycle of ice formation, growth, and decay and associated phenomena such as ice jams, forces on shore structures, ice movement, and ice effects on lake ecology. The program involves the collection and analysis of data on all aspects of the physical and chemical properties of ice and snow. Past studies have included analysis of ice and snow thickness, stratigraphy, surface features and optical properties. At the present time, an ice thickness and stratigraphy data collection program at 30 nearshore stations throughout the Great Lakes has been completed. The data analysis currently involves compilation of engineering statistics from the data base. Investigations of the optical properties of ice currently involve determination of the reflectance in the 300-1100 nm range using airborne pushbroom-scanner-type instrumentation. The information will be used to improve understanding of winter lake energy budgets and associated improvements in ice forecasting models; to develop an understanding of primary productivity under wintertime conditions; and to provide pertinent ground truth for remote sensing studies.

In the ice and snow distribution program, ice charts depicting the extent, concentration, and surface features of the Great Lakes ice cover have been collected for past winters by United States and Canadian government agencies. The data collection, which began about 1960, consists of both visually observed and remotely sensed observations and is used to document the ice cycle on the individual Great Lakes for each winter of record. The data have been digitized with a 5-km-grid resolution to establish a computerized data base of ice concentration and age. These data have been analyzed and published in a revision of the Great Lakes Ice Atlas and in a series of NOAA Technical Memoranda describing in greater detail the variation of ice concentrations in the individual lakes. The archiving of ice concentration data from ongoing programs has been accomplished at the National Snow and Ice Data Center at Boulder, CO. It is planned to review the additional data collected by other agencies in approximately 10 yr and to revise the Ice Atlas at that time, if warranted. If improved high resolution satellite imagery, such as LANDSAT, become available on a more frequent interval in the future, research may be undertaken to develop an automated program to delineate the concentrations and types of ice from the digital satellite tapes using the reflectance catalog from the GLERL ice characteristics field program.

The ice forecasting program encompasses studies designed to develop, test, and improve techniques for short- and long-range forecasts of ice formation, ice growth, ice decay, and ice transport. These include the development of mathematical models depicting the ice processes along with the collection of experimental data for the model calibration and verification. Current research is concentrated on studies to investigate the heat storage characteristics of Lake Superior using fall and winter expendable bathythermographic data collected during a 8-yr field program and on a pilot program to assess the relationships between ice cycle types and certain meteorological conditions. An interactive ice forecast program for the St. Marys River is currently being developed for NWS. Technical forecast development is also coupled with a continuing assessment of user needs, in particular NWS which, in many cases, issues the operational forecasts.

Tasks and Task Objectives

Task 8.12. Spectral Reflectance of Great Lakes Ice Cover

Task Scientist. G.A. Leshkevich

Objectives.

(1) To collect ground and airborne data on the visible and near-infrared spectral reflectance of snow and freshwater ice types and to evaluate the influence of atmospheric conditions and surface metamorphosis on those reflectances.

(2) To develop methods for estimating area-wide shortwave ice albedos and for identifying different ice types in the Great Lakes ice cover from remotely sensed data using the spectral reflectance field data.

Task 8.15. Under-Ice Ecology--Pilot Program

Task Scientists. S.J. Bolsenga, G.L. Fahnenstiel, M.A. Quigley, and H.A. Vanderploeg.

Objective.

To obtain a better understanding of phytoplankton, zooplankton, and benthic macroinvertebrate population dynamics under winter conditions.

Task 8.16. Lake Erie Ice Cycles--Pilot Program

Task Scientist. R.A. Assel

Objective.

Develop an improved ice forecasting procedure for the National Weather Service (NWS) for ice cover distribution and concentration in Lake Erie.

Task 8.17. Survey of Great Lakes Ice Research

Task Scientist. S.J. Bolsenga

Objective.

To compile a summary of scientific studies on the physics and chemistry of Great Lakes ice.

Task 8.19. Great Lakes Nearshore Ice Forecasts

Task Scientist. R.A. Assel

Objectives.

(1) To develop ice formation, growth, and breakup forecasts for selected bay and harbor sites on the Great Lakes.

(2) To develop computer algorithms to access GLERL's nearshore ice forecast techniques in an operational mode.

PROJECT 9. ENVIRONMENTAL INFORMATION SERVICES

PROJECT SCIENTIST. D.F. REID

Objectives

(1) To define the information needed for a broad range of environmental problems in coastal and estuarine waters, with special emphasis on the Great Lakes.

(2) To determine the environmental information needs of the Great Lakes and estuarine resource users, managers, and planners for their decision-making activities.

(3) To distribute GLERL products relevant to the information needs of the users, and to facilitate proper application of these products by the users.

(4) To provide an advisory service that is responsive to and meets the needs of the Great Lakes and estuarine communities.

Background

This project provides information and guidance to the GLERL research program to ensure that GLERL products are responsive to and of optimum use by the Great Lakes and estuarine communities, and provides coordination for the dissemination of GLERL products. Identification of the environmental information required in association with Great Lakes and estuarine use and development is vital to GLERL. This effort impacts GLERL's future programs of research and helps focus efforts within existing programs. The maintenance of an advisory service fulfills one of GLERL's mission objectives by providing a primary mechanism for distributing and facilitating the use of GLERL products.

The GLERL mission statement includes an environmental problems orientation, as follows:

> "Places special emphasis on a systems approach to problem oriented environmental research in order to develop environmental service tools. Provides assistance to resource managers and others in obtaining and applying the information and services developed by the laboratory."

In order to satisfactorily address these requirements, GLERL staff must identify and understand the problems and issues associated with the various forms of stress that man and nature place on the environment. Consideration must be given to what environmental factors are or should be included in the decision making processes concerned with use of Great Lakes and estuarine resources. GLERL must provide research products that are timely, and that can be understood and applied correctly to the solution of planning, management, and/or operational problems. Products that are misunderstood or misused will be of little value to environmental resource managers, planners, and other users, and will undermine the overall value of the GLERL research effort in providing tools to help resolve environmental problems and issues.

GLERL staff participation on boards, commissions, task forces, and committees is an essential part of this effort. Such participation provides a mechanism for defining user needs and guiding the development of usable products, and helps maintain staff interest and participation in programs concerned with Great Lakes environmental problems, such as water quality, water quantity, and ecosystem characteristics. It also maintains staff familiarity with water- and land-oriented resource development and management issues.

Interrelationships With Other Projects

This project relates to all projects and tasks within GLERL, providing both a basis for initiation of projects and a focus for the dissemination and application of project results.

Approach

The development and provision of environmental information services is approached through five interrelated activities:

(1) Responding to and analyzing information requests;

(2) Staff participation in commission, committee, interagency, and similar activities;

(3) Identification of users and their information/product needs;

(4) Coordination of staff-based advisory service; and

(5) Product development.

The advantage of this approach is in its flexibility. Any one or all of these five steps can be expanded, contracted, or focused, depending on user needs and in-house resources available to address such needs. It also spreads the information services responsibility throughout the staff while providing central coordination, and thus improves the reliability and responsiveness of GLERL as a unit.

GLERL develops short- and long-range program objectives that reflect and try to satisfy a maximum number of the most urgent user needs. Knowledge of user needs and information requirements provides a basis for the distribution of GLERL product information and operation of an advisory service. The advisory service promotes staff interaction with the users of GLERL products, and provides users with assistance in the application of these products. The maintenance of this link with the Great Lakes and estuarine community greatly enhances the practical use of GLERL products. This project provides the means for establishing and maintaining the communications link between GLERL and federal, state, and local government agencies, institutions, private organizations, and the general public. Individuals who require information related to environmental problems can be identified and interactions to determine their needs can be established. User contact is made through a variety of activities including direct responses to information requests and queries, membership on regional and international boards and commissions, participation in workshops, public appearances, and through interactions with federal, state, and local agencies. These activities provide information to GLERL concerning potential users, their problems, and their information and product needs. Such information is fundamental to the development of the GLERL research program, output of user-oriented products, and maintenance of responsive advisory services.

Publications such as environmental, professional, and government newsletters are routinely reviewed, and items of potential interest are flagged and routed to appropriate staff; Congressional activities are periodically surveyed to identify legislation that is pertinent to the GLERL mission and program. In addition, GLERL is often asked to provide background material and expert advice to lawmakers, as well as review draft bills. Management awareness of pending legislation and related issues is essential to GLERL's responsiveness to public needs. As new laws are enacted, related scientific issues and research needs are identified and incorporated, as appropriate, into the GLERL program, or are recommended as program development initiatives.

Tasks and Task Objectives

Task 9.1. Environmental Information Requirements

Task Scientist. D.F. Reid

Objectives.

(1) To identify Great Lakes and estuarine problems and issues requiring environmental information for their solutions.

(2) To determine the information types and forms of value to Great Lakes and estuarine resource managers and planners in their decision-making role.

Task 9.2. Advisory Service

Task Scientist. D.F. Reid

Objectives.

(1) To provide information in a form useful to the Great Lakes and estuarine community, particularly for planning, management, and development activities.

(2) To facilitate the application and interpretation of environmental information, analytical techniques, models, and other GLERL products, and disseminate such products in a timely and efficient manner.

PROJECT 10. ENVIRONMENTAL SYSTEMS STUDIES

PROJECT SCIENTIST. T.D. FONTAINE

Objectives

(1) To undertake studies of the effects of man-induced changes on the Great Lakes environment and the possible impact of these effects on uses of the lakes.

(2) To develop and apply system analysis methods, such as optimization analysis and risk assessment, to the solution of problems of importance to Great Lakes resource use and management.

(3) To develop scientific information useful to the determination of the pollution assimilative capability of the Great Lakes and marine coastal waters in an attempt to minimize costs and risks in pollution management.

(4) To develop and test simulation and prediction models for use in developing wise and cost-effective environmental management strategies.

Background

While one primary goal of GLERL is to conduct fundamental research on the Great Lakes ecosystem, another primary goal is to synthesize information from this research and develop models to assist in the solution of environmental problems and to help guide management decisions. Further, a long-term goal of NOAA's overall marine pollution program is to provide, through research on pollution-related or resource-use problems of the coastal United States, information that can be used in management decisions that balance acceptable risks with acceptable costs. Thus, by putting practical perspectives on pollution and environmental perturbations, this project addresses major responsibilities of GLERL, as well as NOAA and the Department of Commerce in general.

In meeting the above goals, integrated assessments of ecological and socioeconomic information will be conducted. System analysis techniques, such as risk assessment, cost-effectiveness analysis, optimization analysis, and cost-benefit analysis will be used, where appropriate, to aid in interpreting and communicating results. In using these techniques, it will be imperative to make their limitations and inherent assumptions clearly understood. The application of such techniques to establish an optimal blend of economic and environmental practices is a major objective of NOAA's marine pollution program.

The following research tasks have been completed and a final task report is on file:

Task 10.1, Maumee Bay Level B Study.

Task 10.2, Phosphorus Model.

Task 10.5, Atlas of Lake Ontario Physical Properties.

Task 10.6, Modeling of Spills in the Great Lakes.

Task 10.7, Study of Consumptive Uses of Great Lakes Waters.

Task 10.8, Phosphorus Model Refinements and Applications.

Task 10.10, Great Lakes Water Quality Alternatives.

Task 10.11, Application of the Phosphorus Loading Concept to Incompletely Mixed Systems.

Task 10.13, Great Lakes Environmental Planning Study.

Task 10.14, Toxic Substances Budget Model for the Great Lakes.

Task 10.15, Applications of Risk Assessment to Water Quality Management.

Task 10.17, WATERSHED--A Management Technique for Choosing Among Point and Nonpoint Control Strategies.

Task 10.19, Relative Importance of Pollutant Loadings.

The research of Task 10.3, Lake-Scale Water Quality Model, was transferred to Project 4, Aquatic Ecology Models, in November 1975. Task 10.4, Monitoring Water Characteristics, was transferred to Project 8, Lake Ice. Task 10.9, Atlas of Great Lakes Eutrophication, was incorporated in Task 10.13. Task 10.12, Thermal Characteristics of Lake Ontario, Task 10.16, Perspectives on Relative Risks of Chemical Contaminants Found in the Great Lakes, Task 10.18, Lake St. Clair Assessment, and Task 10.26, Optimization and Cost-Benefit Analyses of Ecosystem, Trace Contaminant, and Phosphorus Management Strategies in the Upper Great Lakes Connecting Channels were terminated due to changes in staffing or internal priorities.

Interrelationships With Other Projects

Because it is interdisciplinary and is designed to synthesize or interpret research results for practical implications, Project 10 relates to, and will use, the results of other GLERL research. Thus, it is intended that GLERL research will be collectively used in this project to help address environmental problems. Moreover, the results of Project 10 will be an input to the environmental information services of GLERL, outlined in Project 9.

Approach

Project 10 will focus its efforts on a variety of temporal and spatial scales depending on the question under investigation. An overriding theme, however, will be to consider questions in a holistic way so that the long-term economic and ecological consequences of environmental decisions are clearly understood. Targeted for investigation are the fate, transport, and behavior of nutrients and toxic substances in Great Lakes ecosystems. Also of interest are the effects that manipulations such as dredging, water diversions, introduction of exotic species, and habitat destruction have on the health of Great Lakes ecosystems and their surrounding regional economy. Of concern is defining how ecosystems may change in response to various perturbations and how such changes may in turn change (1) the fate, transport, and behavior of contaminants, and (2) economically and otherwise desirable food web relationships. Also of interest is the definition of ecological engineering methods that can be used to enhance desirable properties of the ecosystem. For instance, wetland areas can be created that might enhance fish and waterfowl productivity.

The research emphasis described above is integrative and synthesis-oriented. Research results from within and outside of GLERL will be drawn upon heavily. A by-product of this integrative approach will be enhanced research coordination among GLERL staff themselves, as well as with scientists and engineers from other organizations.

In putting practical perspectives on pollution and environmental perturbations, the following tools will be used to organize our thoughts and understanding of ecological-socioeconomic interactions in the Great Lakes region:

(1) ecosystem models;

(2) contaminant fate, transport, and behavior models;

(3) uncertainty, risk, cost-benefit, cost-effectiveness, and optimization analyses;

(4) combinations of (1), (2), or (3), above; and

(5) qualitative judgments such as those obtained through expert opinion.

Upper Great Lakes Connecting Channels Study (UGLCCS)

The UGLCCS is a multi-agency, multi-national research project that seeks to understand, predict, and recommend remedial actions concerning contaminant fate, behavior and effects in the ecosystems of the connecting channels (the St. Marys, St. Clair, and Detroit Rivers, and Lake St. Clair). Tasks 10.22 through 10.25 pertain to the connecting channels study and have been formulated based on available knowledge concerning the study area. Because the study has been underway for only 1 yr, the background information included in each of the task descriptions often contains educated guesses about the importance of various ecosystem processes.

For purposes of inter-GLERL coordination and long range planning, proposed interrelationships among Project 10 tasks and tasks from other Projects are shown in Figure 5. Models proposed in Task 10.22 and Task 1.13 (see Project 1) will be used to investigate and identify processes that are responsible for the observed physical, chemical, and biological characteristics of the study area. The models of these closely related tasks represent the foundation upon which models proposed in Tasks 10.23 through 10.25 can subsequently be built. Because there are many temporal and spatial scales in which a single question can be couched, more than one model could be developed in any of these tasks. In developing a strategy for UGLCCS models, the approach that will be taken is to start with simple (e.g., average annual flow and storage) models which can easily be elaborated upon when it becomes evident that the questions being asked require more detail. The dilemma of having questions quickly outstrip available data bases can to an extent be ameliorated by the application of uncertainty analysis techniques as proposed in Task 10.25.

Tasks and Task Objectives

Task 10.20. Lake Erie Area Environmental and Recreational Atlas

Task Scientists. S.J. Bolsenga and C.E. Herdendorf (Ohio State University Sea Grant)

Objective.

To prepare an atlas that is descriptive of conditions, processes, and both natural and man-developed features of the coastal and offshore waters of Lake Erie that will be of value to recreational users and developers of recreational facilities.

Task 10.21. A Stochastic Optimization Framework for Identifying Cost Effective Phosphorus Management Strategies for the Great Lakes

Task Scientists. T.D. Fontaine and B.M. Lesht (Argonne National Laboratory)

Objectives.

(1) To modify Chapra's (1983) steady-state phosphorus model and optimization program so that the effects of environmental variability on optimal phosphorus control strategies can be assessed.

(2) To determine if optimal phosphorus control strategies derived from models run with average conditions will be more or less cost effective than strategies derived from models which take into account environmental variability.

(3) To predict expected natural variability of phosphorus concentrations in the Great Lakes.

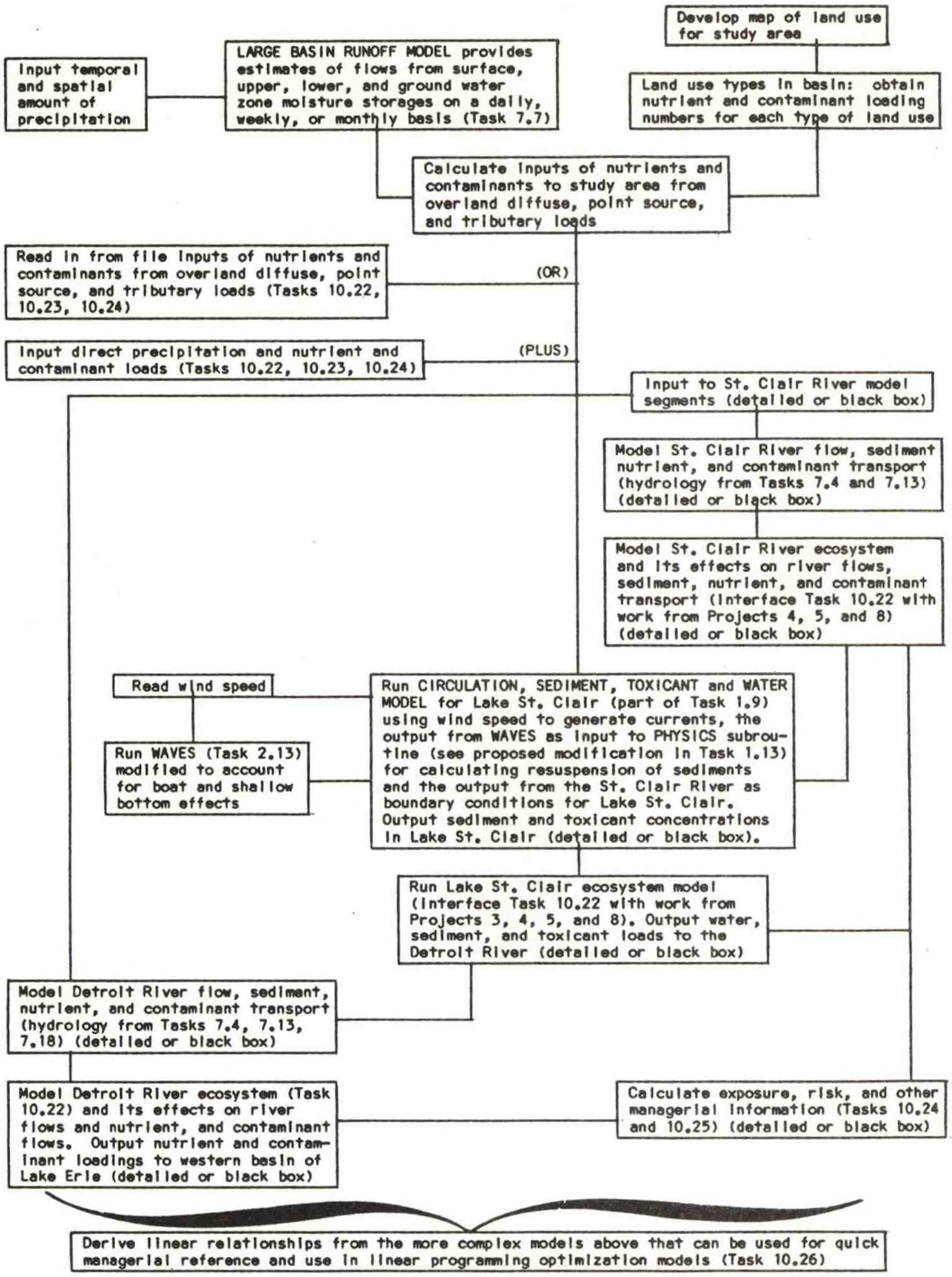

Figure 5.--Interrelationships among Project 10 Upper Great Lakes Connecting Channels Study tasks and the other tasks at GLERL. The top five boxes indicate studies that will be used to assess the effect of land use changes on the connecting channels study area.

Task 10.22. Ecosystem Model for Lake St. Clair (UGLCCS)

Task Scientist. T.D. Fontaine

Objectives.

(1) To develop a model which conceptually addresses major ecological processes in the Upper Great Lakes Connecting Channels Study (UGLCCS) area.

(2) To simulate the model developed in (1) in order to understand and explain observed patterns of system behavior.

(3) To develop ecological models of the UGLCC study area in such a way that they or their output can be used (a) to clarify our understanding of contaminant fate and behavior, and (b) in management oriented applications.

(4) To help focus and guide the course of data collection and process oriented research.

Task 10.23. Lake St. Clair Phosphorus Model (UGLCCS)

Task Scientists. T.D. Fontaine, G.A. Lang, and J.A. Morton

Objectives.

(1) To develop a data base which quantifies the major inputs, losses, and storages of Lake St. Clair phosphorus. To quantify the variability associated with these data.

(2) To develop and test models for simulating phosphorus dynamics in Lake St. Clair.

Task 10.24. Generic Contaminant Model for Lake St. Clair (UGLCCS)

Task Scientists. T.D. Fontaine, G.A. Lang, and B.J. Eadie

Objectives.

(1) To develop models for simulating contaminant transport, fate, exposure, and potential effects in Lake St. Clair.

(2) To develop or obtain a data base which quantifies the major inputs, losses, and storages of selected contaminants associated with the upper Great Lakes Connecting Channel Study (UGLCCS) area; to quantify the variability associated with these data; and to use such data in testing the generic contaminant model.

Task 10.25. Risk and Uncertainty Analysis of Ecosystem, Trace Contaminant, and Phosphorus Models for Lake St. Clair (UGLCCS)

Task Scientist. T.D. Fontaine

Objectives.

(1) To use ecosystem models developed in task 10.22 for evaluating risks and uncertainties associated with ecosystem management strategies.

(2) To use phosphorus models developed in task 10.23 for evaluating risks and uncertainties associated with phosphorus management strategies.

(3) To use contaminant models developed in task 10.24 for evaluating risks and uncertainties associated with contaminant management strategies.

Task 10.27. Multiobjective Basin-Wide Models for Great Lakes Water Quantity and Quality Management.

Task Scientists. T.E. Croley II, T.D. Fontaine, and H.C. Hartmann

Objectives.

(1) To develop the capability for basin-wide assessment of major new diversions, increased consumptive uses, lake-level regulations, and climatic change.

(2) To coordinate water quantity conceptual models of rainfall-runoff, lake evaporation and precipitation, ground water, and channel hydraulics with conceptual models of ecosystem function, contaminant transport, and lake economics.

(3) To develop simulation models from (2), above, for basin-wide simulations of water quantity and quality.

(4) To identify use objectives from basin-wide, state, national, and international Great Lakes perspectives.

(5) To identify views, attitudes, and value functions associated with the use objectives and to integrate them into the water quantity/quality models.

(6) To adapt optimization methodologies for identification of efficient management alternatives.

PROJECT 11. PROGRAM DEVELOPMENT

PROJECT SCIENTIST. F.H. QUINN

Objectives

(1) To facilitate the development of multidisciplinary research programs within the mission and objectives of GLERL and of significance to the Great Lakes and coastal regions.

(2) To define environmental issues and research needs of importance to marine resource management and environmental services pertinent to the GLERL mission and objectives and to develop preliminary program documentation (program development plans).

(3) To undertake pilot, feasibility, or other preliminary research studies, as pertinent, in order to refine problem definition and research approach.

(4) To achieve incremental support, either through channels or from other agencies, consistent with NOAA policies and good research management practice.

Background

Program development includes the preparation of a research proposal and the associated staff work to document and sell the proposed research through the NOAA budget channels and to other agencies. NOAA program documents include the Program Development Plan (PDP) and the Technical Development Plan (TDP); other agency program documents include the Proposal to Study (PTS) and Plan of Study (POS). Program development can also identify future research directions for our ongoing and evolving research program within available resources.

Program development may include exploratory research or convening of a workshop, as necessary, to assist in defining research problems or issues, research objectives, and approach. As an example of GLERL program definition, a workshop of future Great Lakes research initiatives was held at GLERL in October 1974, and subsequent analysis of this project identified Great Lakes nearshore problems and processes as a logical follow-on to IFYGL. This multidisciplinary research program has broad research objectives with both a scientific and a user orientation.

During 1979, program development in Task 2, Great Lakes Waves and Flooding, focused on participation with other ERL oceanographic laboratories in the development of research plans for improved Marine Prediction Services. In FY 1981, NOAA assigned this accelerated research on Great Lakes and ocean waves a low priority and it has not survived the budget process. No wave initiatives were undertaken since FY 1981 owing to low funding priority.

During 1979, program development continued to focus on Task 11.6, Long-Term Effects of Man-Induced Changes on the Ecosystem. A PDP "Great Lakes Long-Term Effects Research" was prepared in May 1978 and submitted as part of the NOAA FY 1980 improvement in Marine Ecosystem Investigations. Two critical Great Lakes pollution problems were identified: toxic organics and nutrient enrichment. This PDP addressed long-term research that would have resulted in significant expansion of the GLERL research program in physical processes, ecosystem dynamics, and environmental systems. This proposed research initiative identified a new comprehensive program in research and monitoring in response to Section 202 of the Marine Protection, Research and Sanctuaries Act (P192-532), and is a logical expansion and follow-on to major segments of the GLERL research program in Projects 1, 2, 4, 5, 6, and 10. An initiative was prepared for the FY 1981 Budget decision package Marine Ecosystem Investigations to investigate the complex Great Lakes ecosystem and the effects of human-introduced nutrients and toxic organics. In May 1979, a Technical Plan on Toxic Organic Cycling in the Great Lakes Ecosystem was prepared and submitted to NOAA-RD-OMPA; it was accepted and resulted in the initiation of this new long-term program in July 1979. It is as a result of this Program Development success that the GLERL research program in this Technical Plan was reoriented to initiate the three new projects P3--Particle Dynamics, P4--Toxic Organic Cycling, and P6--Eutrophication and Nutrient Cycling.

A proposed initiative entitled "Toxic Organics in the Coastal Region" was prepared for the FY 1982 budget line item Marine Ecosystem Investigations to expand upon this toxic organics cycling research initiated in FY 1979. The Toxic Organics PDP was later incorporated into the OMPA PDP Contaminant Assimilative Capacity that had partial success in the FY 1982 budget process, but was outside the NOAA OMB mark. We continued to support OMPA in developing a Contaminant Assimilative Capacity Initiative for FY 1983, although the degree of overlap of OMPA and GLERL interests and the possible expansion of GLERL Toxic Organics and numerical modeling research remains to be determined. Because of the expansion of the GLERL research program in Marine Pollution with no accompanying staff expansion, we have initiated a Cooperative Program with the University of Michigan.

A marine quality research proposal "Toxic Organics at the Sediment-Water Interface" was prepared and submitted for FY 1985 support under line item Ocean and Great Lakes Assessment and Research. This proposal was briefed to the Administrator and turned down by DOC; an updated version was prepared and submitted for FY 1986 as "Contaminant Sediment Dynamics," and for FY 1987 as "Toxic Organic Contaminants in Coastal Environments." While approved by OAR and NOAA this initiative was turned down each year by DOC. While OAR has solicited an FY 1988 resubmission, one may logically ask, "Why resubmit this research initiative?" There are various answers. The problem is of National importance. Good science is involved. It is a NOAA responsibility. There is a core of interested scientists and OAR is below critical mass. The FY 1988 initiative, "Toxic Chemicals in the Marine Environment," has been briefed to ERL and approved for submission to OAR. We propose a comprehensive experimental and theoretical/numerical prediction research program in coastal oceanography; to improve the capability to simulate, to predict, and to make assessments of toxic contaminant problems in coastal ecosystems. The proposed research focuses on: synthetic organic contaminants, key coastal and estuarine ecosystems, and the benthic food chain.

Three other project accomplishments in CY 1985, cited by title only, were:

(1) Action Plan for Federal Research and Monitoring in the Great Lakes;

(2) FY 1987 Water Resources Initiative; and

(3) Cooperative Agreement with EPA, "Modeling the Behavior and Fate of Nutrients and Trace Contaminants in the Upper Great Lakes Connecting Channels."

The following tasks have been completed:

Task 11.1, Nearshore Environmental Problems and Processes.

Task 11.3, Fox-Wolf River Basin Study.

Task 11.4, Great Lakes Ocean Color Application.

Task 11.5, Effects of Carbon Dioxide Increase on Large Lake Ecosystems.

Task 11.7, Effects of Calcite Whitings on the Lake Michigan Ecosystem.

Interrelationships With Other Projects

This project is potentially related to all other GLERL research projects. In addition, the project relates to other components of NOAA and other government agencies where the potential for joint research programs is explored and, if mutually advantageous, joint research plans are developed.

Approach

This project involves the problem and program definition phase for research projects or tasks that represent a significant change from the existing GLERL projects or tasks and that usually require augmented resources to carry out. Here the approach includes the definition of environmental issues and research needs pertinent to resource development, resource management, and environmental hazards. Activities include defining achievable research objectives, organizing the research program, developing viable technical and financial plans, defining feasibility and pilot studies, developing and testing required data acquisition systems, and developing and testing simulation and prediction models. These tasks frequently involve other units of NOAA and other agencies.

Tasks and Task Objectives

Task 11.6. Ocean and Great Lakes Prediction Research--Marine Ecosystems Assessment

Task Scientists. E.J. Aubert, B.J. Eadie, T.D. Fontaine, W.S. Gardner, F.H. Quinn, and others

Objective.

The overall objective of this task is to participate with the Office of Oceanic and Atmospheric Research (OAR), the National Ocean Service (e.g., OMS/OAD and NMPPO), the National Marine Fisheries Service (NMFS), and others in planning of NOAA research activities under the Ocean and Great Lakes Prediction Research--Marine Ecosystem Assessment Program. This program is directed toward improved understanding and prediction of natural marine ecosystems, physical phenomena, and the impact of man-induced stresses on the ecosystem; and developing a sound scientific basis for management decisions, pertinent to marine resources, marine pollution, and environmentally sensitive marine activities. The specific objectives of this (GLERL) Task are:

(1) To define the scientific program that should be pursued on the Great Lakes and key coastal and estuarine ecosystems.

(2) To develop detailed documentation for the budget process.

(3) To develop a budget (FY 1988) initiative and research proposal/plan as appropriate.

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