TECHNICAL PLAN

for the
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Dr. Eugene J. Aubert, Director

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

Ann Arbor, Michigan January 1976

TECHNICAL PLAN

FOR THE

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Dr. Eugene J. Aubert, Director

January 1976

Great Lakes Environmental Research Laboratory
Environmental Research Laboratories
National Oceanic and Atmospheric Administration
2300 Washtenaw Avenue
Ann Arbor, Michigan 48104

Telephones: FTS: 374-5253
Commercial: (313) 769-7100, Ext. 253
(313) 994-3374

NOTICE

The NOAA Environmental Research Laboratories do not approve, recommend, or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to the NOAA Environmental Research Laboratories, or to this publication furnished by the NOAA Environmental Research Laboratories, in any advertising or sales promotion which would indicate or imply that the NOAA Environmental Research Laboratories approve, recommend, or endorse any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this NOAA Environmental Research Laboratories publication.

PREFACE

The Great Lakes Environmental Research Laboratory (GLERL) was established on April 24, 1974 to provide a focus for NOAA's environmental research in the Great Lakes region. 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 mission is to conduct research directed toward an understanding of the environmental processes in the Great Lakes and their watersheds. Emphasis will be placed upon an interdisciplinary systems approach to the solving of problems in resource management and environmental services for that region. In support of this mission, the following central objectives have been established:

- To improve environmental information (e.g., statistical description, prediction, and simulation) concerning properties, processes, and phenomena of the Great Lakes and the Great Lakes watersheds;

- To develop improved environmental service tools, data, information, and consulting services to support the needs of users in government and private organizations; and

- To provide an environmental advisory service, as appropriate.

The scope of GLERL's research includes field, analytic, and laboratory investigations into the limnological, hydrological, meteorological, and limnogeological properties of the lakes, their basins, and the atmosphere.

This plan was prepared primarily for GLERL research management purposes. It will also facilitate coordination and information exchange with interdependent research agencies. This Technical Plan reflects GLERL research and does not replace the IFYGL Technical Plan. IFYGL is an international and interagency research program for which GLERL exercises the National Oceanic and Atmospheric Administration (NOAA) lead agency responsibility through the IFYGL Project Office (Project 11).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 Introduction. This Technical Plan documents the existing GLERL research program as of December 1975, organized in terms of Projects and Tasks. This document updates the GLERL Technical Plan dated January 1975. Projects are conceived as broad units of research with long term duration. Tasks are short term, more definitive, and identify products targeted for completion at a particular time.

Several changes have taken place in the GLERL Technical Plan during 1975. The IFYGL is now documented as a separate project (P-11.0) and a program development activity is also organized at the project level (P-12.0). At the task level, 5 tasks have been completed, 3 deleted, and 17 new tasks have been added to the plan.

2.0 Perspectives. This plan was prepared primarily for GLERL purposes. It represents a tool for managing the research program.

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

Our research mission includes both process oriented and problem oriented environmental research in support of Great Lakes resource management and environmental services. The concept is to develop a sound scientific basis for rational decisions associated with the development and utilization of our Great Lakes resources. Our comprehension of user needs for environmental information in conjunction with the match of our capabilities and understanding of the relative importance of environmental problems will influence the styling of the problem oriented research program. In addition, we must guard against undertaking too many unrelated projects and tasks, or our accomplishment will be small due to over commitment of limited resources.

A broad survey of environmental needs[1] identified some 25 Great Lakes activities and provided an initial basis for the problem oriented research program. An analysis of the numerical models necessary to provide information for rational decisions for 10 top-ranked activities indicates a high degree of similarity between the physical, chemical, and biological models required. This is perhaps not unexpected for, while the scales important to management decision differ between problems of a single Great Lake activity and between activities, the information is all related to the limnology, hydrology, limnogeology, and meteorology of the Great Lakes environment. Additional information on user needs comes from participation on various boards and commissions (e.g., International Joint Commission (IJC) Research Advisory Board, the Great Lakes Basin Commission and its Plan and Program

---

[1] C. F. Jenkins, "Requirements for Great Lakes Environmental Information," Working Document, Rockville: IFYGL Project Office, June 1973.

Formulation Committee, and Coastal Zone Management Committee), joint participation in interagency programs (e.g., program to extend the Navigation Season on the Great Lakes, Upper Lakes Reference, and the Maumee Bay Level B Study of the Great Lakes Basin Commission), and direct interaction with potential users (e.g., National Weather Service (NWS), Sea Grant, and Coastal Zone Management, all NOAA activities).

During 1975, the GLERL international and interagency involvement has been significantly strengthened and ideas for future program have resulted (e.g., Task 12.2 Great Lakes Waves and Flooding, and Task 12.3 Fox-Wolf River Basin Study). The October 1974 Workshop[2] provided guidance of importance to process research from leading researchers. This guidance is influencing the styling of Projects 1, 4, and 6 and resulted in the initiation of Task 12.1 Nearshore Environmental Problems. Perspectives of the GLBC in Limnological Systems Analysis and the associated environmental engineering models of importance to water resource planning have had a strong influence on the limnological modeling and prediction studies of Projects 1, 2, 4, 7, and 10.

While our initiatives in environmental information services (Project 9) have been few due to our degree of commitment elsewhere, we are moving toward a balance between process and problem oriented research. An association has been developed with the Sea Grant Advisory Service which will be mutually beneficial.

While the ideas are not new, the research sequence of Figure 1 portrays the GLERL overall research approach. Problems for research investigation originate from either a scientific motivation or a user need. After suitable problem definition, an interdependent approach sequence includes data collection, analysis, modeling, and evaluation with various feedback loops. The research products of GLERL 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).

User needs involve the definition of the environmental problems (the issues and research needs) of importance to the user and an identification of the sensitivity of the user's activity to the environment. Relevant questions and management alternatives need definition pertinent to the environmental sensitivities. These considerations are then translated into environmental service requirements.

In the scientific approach, project objectives likewise must be defined. Here the definition of objectives, products, and scientific questions are concerned with the state-of-the-art in description, understanding,

---

[2] E. J. Aubert and A. P. Pinsak, Proceedings of Workshop on Priority Great Lakes Environmental Research Initiatives, April 1975.

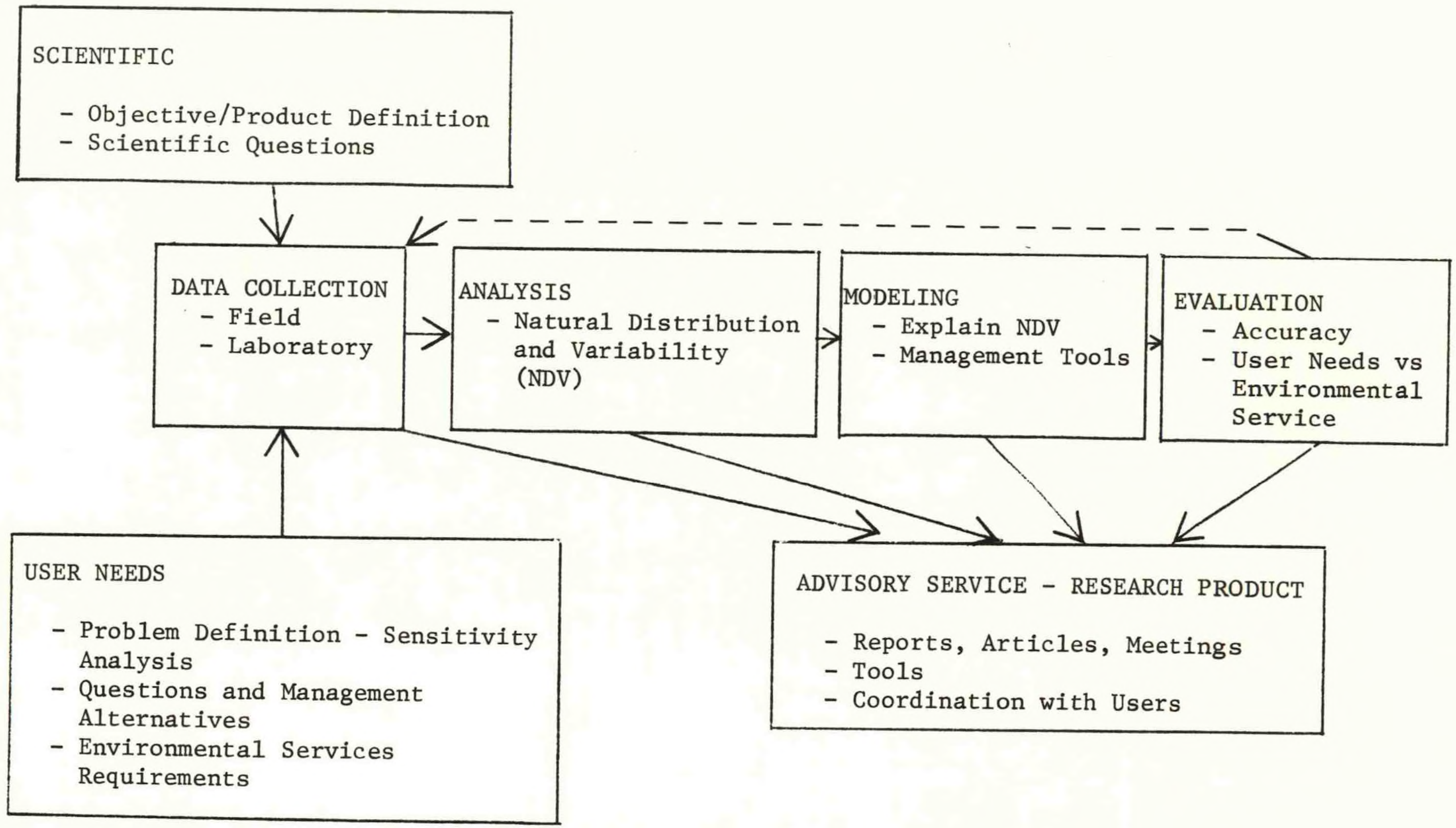

Figure 1. Research sequence.

and prediction of dependent variables of theoretical importance and significance to the natural distribution and variability of the Great Lakes and the Great Lakes Watersheds. Studies to improve prediction require improved understanding of relevant phenomena and processes.

Data collections involve both field observations of the physical, chemical, and biological quantities, using various facilities (e.g., ships, buoys, water chemistry laboratory, marine instrumentation laboratory, biology laboratory) and laboratory experiments or studies which utilize facilities to collect data in a controlled environment.

Analysis and modeling studies involve experimental and theoretical approaches. Analysis studies define the environmental variations and variability in space and time and organize data to improve understanding of phenomena and processes. Mathematical models are developed to predict and simulate the environment to explain the natural distributions and variability. Prediction and simulation models must be evaluated in terms of accuracy and in terms pertinent to the user's decision process.

All of these research activities support the GLERL advisory service function to provide environmental coordination and consulting services within the scope of the Laboratory to individuals and institutions - both government and private organizations. The problem oriented research will develop improved tools to support the environmental services provided by GLERL and by other NOAA components, e.g., NWS.

Some perspective of the project structure, its relationship to organizational research groups within GLERL and the group interdependencies, is relevant. Projects 1 and 2 are primarily the function of the Physical Limnology and Meteorology Group (see Table 1) although in Project 2 a supporting interdependency exists with Lake Hydrology. Project 3 is primarily the responsibility of both the Environmental Systems Engineering and Physical Limnology and Meteorology Groups. Projects 4, 5, and 6 are primarily the function of the Chemistry and Biology Group, with supporting interdependencies of the Physical Limnology and Meteorology Group, and Projects 7 and 8 are the primary function of the Lake Hydrology Group, with supporting interdependencies of the Physical Limnology and Meteorology Group. Projects 9, 10, and 11 are the primary function of the small Environmental Systems Engineering Group, but are also the primary function of the other three groups due to the multidisciplinary, interactive nature of these projects. The first eight projects are more disciplinary oriented in comparison with Projects 9, 10, 11, and 12.

Table 1. Projects as Related to Organizational Group

		PL&M	C&B	LH	ESE
P-1	Water Circulation, Transport, & Diffusion	P			
P-2	Surface Waves & Oscillations	P		S	
P-3	Lake Ontario Energy Budget (IFYGL)	P			P
P-4	Aquatic Ecology Models & Related Studies	S	P		
P-5	Planktonic Succession		P		
P-6	Natural Distribution & Variability of Lake Properties	S	P		
P-7	Hydrologic Properties	S		P	
P-8	Lake Ice	S		P	
P-9	Environmental Information Services	P	P	P	P
P-10	Environmental Engineering Models & Applications	P	P	P	P
P-11	International Field Year for the Great Lakes	P	P	P	P
P-12	Program Development	P	P	P	P

LEGEND:
- PL&M - Physical Limnology and Meteorology Group
- C&B - Chemistry and Biology Group
- LH - Lake Hydrology Group
- ESE - Environmental Systems Engineering Group
- P - Primary
- S - Supporting Interdependency

3.0 Project 1 Water Circulation, Transport, and Diffusion

Project Scientist. D. B. Rao

Objectives. The objectives of this project are:

(1) To improve climatological information on the distribution and variability of physical lake variables (e.g., current, temperature, level) and interdependent meteorological and hydrological variables.

(2) To develop improved numerical models to simulate and predict the current, temperature, transport, diffusion and decay in the lakes, bays, harbors, and rivers of the Great Lakes on scales determined in objective (1). These models should also be able to display impacts of alternate decisions for Great Lakes managers.

(3) To improve the understanding of physical processes important in objective (2).

Background. An understanding of the physical properties and processes of the Great Lakes is fundamental to the management of Great Lakes activities sensitive to the environment. Judging from requirements for Great Lakes environmental information, the top 10 user activities (e.g., waste management, power generation, fishery management, water supply management, etc.) all need information on the physical environment. Also transport and diffusion due to lake currents and eddies are important to the analysis and prediction of chemical and biological properties.

Past information on Great Lakes circulation, transport, and diffusion has been largely descriptive. IFYGL efforts in water movement represented a turning point from descriptive studies with fragmentary information to quantitative studies covering an entire lake. The massive data base acquired during the IFYGL collection period (1972-73) is a primary basis for the analysis and modeling tasks in the project.

Several tasks in the project (e.g., Tasks 1.1, 1.2, 1.3, and 1.7 are part of IFYGL. Other tasks (e.g., Task 1.4) are GLERL contributions to the IJC studies under the Upper Lakes Reference Program of the IJC.

Important scientific problems pursued in the project include the coupling process between wind and water, thermal effects, the nearshore jet, transport and diffusion processes, mechanisms of exchange between the inshore and open lake regions, and upwelling and downwelling. Additional physical phenomena which have been identified as important in other projects (e.g., Projects 4 and 5) include the thermocline seasonal progression and the thermal bar.

Interrelationships with Other Projects. This project is related to GLERL Projects 2, 4, 5, 8, 9 and 10. The interdependencies are in the form of data collection, data base, analysis techniques, and numerical models.

Approach. The approach in this project consists first of identification of a valid scientific objective based on either recognized gaps in the knowledge of lake processes or on problems of immediate concern to the users. Once an objective is established, its accomplishment proceeds through a combination of field and theoretical work. Analysis of field data helps in assessing the impact of meteorological and hydrological processes on the circulation and thermal characteristics of lakes and in developing and verifying numerical models. These models will predice currents, temperatures and diffusion, advection and decay of pollutants. The research is of an iterative type in that numerical models provide vital information on modification of future field data gathering.

3.1 Task 1.1 Distribution and Variability of Temperatures and Currents in Lake Ontario

Task Scientist. R. L. Pickett

Objectives. The general objective is to identify and explain the distribution and variability of Lake Ontario's temperatures and currents using the 1972 IFYGL data.

Specific objectives of this task are:

(1) To examine the temporal and spatial variations of the measured variables; e.g., current, water and air temperature, and wind.

(2) To examine the temporal and spatial variations of derived variables, such as thermocline depth, kinetic and potential energy, heat, and transport.

(3) To explain these observed variations.

(4) To provide products for an atlas of Lake Ontario properties and for the Water Movements scientific report.

Background. One of the major systems deployed in the 1972 IFYGL program in Lake Ontario was a network of buoys and towers that recorded physical properties of the lake. This lake-scale network was designed to provide data on a fine time and space scale to describe the physical properties of Lake Ontario.

Interrelationships with Other Tasks. The results of this task will be useful for Task 1.3, 1.4, and 1.5. Projects 2, 3, and 6 will probably also use either derived techniques or results.

Approach. First a 1-month data sample for July 1972 was processed to demonstrate that the objectives of this task could be met. United States and Canadian buoy, tower, and meteorological data were investigated via:

(1) Time series analyses - editing, t and z graphic plots, histograms, numerical filters, statistics, power spectrum analyses, and contingency distributions.

(2) Spatial analyses - editing xy and xz plots, numerical filters, manual analyses, two- and three-dimensional objective analyses, and analyses of variance.

(3) Special analyses - geostrophic analyses, kinetic and potential energy calculations, and heat content analyses.

These same techniques used on the July sample are now systematically being applied to the data for the whole year.

Products. To date, the following products have been completed:

(1) A library of computer programs for editing and analysis - in computer library.

(2) Lake Ontario mean temperature and currents in July 1972 - given at 17th IAGLR.

(3) Editing procedures for analysis of buoy and tower data - in IFYGL Bulletin 11.

(4) Comparison of July temperature statistics from adjacent buoys at Station 13 - in Bulletin 11.

(5) Comparison of July currents from adjacent United States and Canadian buoys - in Bulletin 11.

(6) Comparison of airborne radiation thermometer and buoy temperature measurements - in Bulletin 14.

(7) Intercomparison of Canadian and U. S. automatic data buoys - accepted by Journal of the Marine Technology Society.

(8) Lake Ontario mean temperature and currents in July 1972 - Journal of Physical Oceanography, October, 1975.

(9) Lake-averaged temperatures and currents in Lake Ontario in 1972 - in Bulletin 15.

Monthly analysis similar to that in (8) above will be prepared for each month. If esepcially interesting or unique results are found, they will be reported in the open literature. After the monthly analysis, a technical report will be written covering the total results. After January 1977, the analysis may be extended to seasonal or episodic studies depending upon what is found in the monthly analysis and in numerous outside contracts employing the same data set.

Schedule.

Activity	Completion Date
Edit whole data set.	Complete
Analysis programs.	Complete
Inputs for the atlas.	Complete
Completion of monthly mean analysis.	July 1976
Technical report on monthly data.	December 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
R. L. Pickett	100	100	100	100
S. Bermick	100	100	100	100
F. C. Rodante	1	1	1	1
Computer Hours	5	5	5	5

3.2 Task 1.2 Lake Ontario Lagrangian Current Observations and Analysis (IFYGL)

Task Scientist. J. H. Saylor

Objectives. The objectives of this investigation are to measure Lagrangian current flows in Lake Ontario during the 1972 IFYGL field observation season, to analyze the measured current flows, to compare the results with other data sets, such as current meters on moored buoys and coastal chain measurements, and to report the findings in scientific papers.

Background. Lagrangian current flows were measured in Lake Ontario during 1972 by tracking a system of 8 to 10 drogues from a small vessel equipped with precise navigation gear. In late spring, the investigations were conducted along the south shore of the lake to describe currents associated with the formation and lakeward growth of the thermal bar, especially the horizontal velocity shear across the thermal front. During the season of density stratification, the investigations were conducted in midlake regions to determine spatial coherency of the current flows and to describe mean circulations in the presence of oscillatory flows induced by the propagation of long interval waves.

Interrelationships with Other Tasks. These studies are related to Task 1.1 in requiring data from the IFYGL buoy network for intercomparison, with Task 1.3 in that results of the investigation will be summarized for inclusion in the IFYGL water movements scientific report, and with Task 10.5, which will incorporate in the IFYGL atlas some of the Lagrangian current observations representative of the coastal areas.

Approach. Flow measurements from current meters suspended from moored buoys provide the basic data set for IFYGL circulation studies. However, as the length scales of the mean flows dominant in Lake Ontario are not known with precision, it is highly desirable to measure Lagrangian current patterns to investigate spatial coherency. These measurements are also useful in interpreting volume transports from current meter data which, during the density stratified season, exhibit strong oscillatory flows resulting from long interval waves, if in fact the volume transports are significant enough to be determined from the current meter data during such conditions.

Products. A technical report describing the measurement techniques and program, and presenting the observed Lagrangian currents will be prepared. Interpretation and analyses of the observations will be included in the report.

Schedule.

Activity	Beginning Date	Completion Date
Collection of field data.	May 1972	October 1972
Reduction of raw data to current charts.	June 1972	March 1973
Intercomparison with other measurements.	October 1974	April 1976
Analyses and report writing.	July 1974	August 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. H. Saylor	30	30	30	
Student Aids	30	90	30	

3.3 Task 1.3 Lake Ontario Water Movements Scientific Report (IFYGL)

Task Scientist. J. H. Saylor

Objectives. The objective of the IFYGL water movements scientific report is to summarize and synthesize the significant results of all water movements related research conducted on Lake Ontario as part of IFYGL. This summary effort will present in one document the major achievements accomplished to advance the knowledge of the physical limnology of Lake Ontario through research investigations of the IFYGL program.

Background. The IFYGL water movements research program focused the investigative efforts of many government and university scientists from both the United States and Canada on the physical limnology of Lake Ontario. Studies were made during the 1972 field season of lake-wide circulation patterns; of the interdependent water temperature structure, coastal currents, the generation and distribution of surface wind waves, and diffusion; and of the interactions of these physical processes with the driving forces which are mainly meteorological. There were also notable efforts to numerically model many of these processes.

Interrelationships with Other Tasks. Summaries of reports and data developed in Tasks 1.1 and 1.2 and in Project 2 will be required as input to the scientific report. There must also be coordination with Task 10.5, the IFYGL atlas, concerning quantities and types of material to be presented in that publication.

Approach. The report will address all aspects of the IFYGL water movements research. The principal authors are the Water Movements Panel Co-Chairmen, E. B. Bennett of CCIW and J. H. Saylor of GLERL. The assistance of CCIW and GLERL scientists participating in Lake Ontario physical studies will be solicited by the Panel Co-Chairmen for the summary effort.

Products. The IFYGL water movements scientific report will be the product of this activity.

Schedule.

Activity	Beginning Date	Completion Date
Principal authors prepare report outline and report preparation schedule, coordinate with participating authors, Technical Editor, and IFYGL Scientific Editors.	March 1974	January 1976
First draft scientific report prepared by principal and participating authors.	January 1976	September 1976

Review by Principal Investigators in Water Movements studies.	September 1976	December 1976
Submission of draft manuscript to IFYGL Scientific Editors.		January 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. H. Saylor		30	75	30	15			
P. C. Liu		30	30					
R. L. Pickett		30	30					

3.4 Task 1.4 Lake Huron and Saginaw Bay Current Studies

Task Scientist. J. H. Saylor

Objectives. The main objective of the studies is delineation of the natural distribution and variability of currents in Saginaw Bay and Lake Huron during both density stratified and unstratified seasons of the year. Steady-state currents related to prevailing and persistent forcing by wind stress acting on the water surface and interdependent distributions of water density will be determined.

Background. During the middle 1960's, the Federal Water Pollution Control Administration (FWPCA), which later became part of the Environmental Protection Agency (EPA) in a government reorganization, conducted an extensive current measurement program in Lake Huron. Data collected in this program have not been analyzed or reported. Interest in this data was regenerated by the U.S.-Canada Water Quality Agreement and the subsequent IJC Upper Lakes Reference Study. The physical limnology of Lake Huron is an integral part of this study and with EPA financial support, GLERL has undertaken analysis of the earlier current measurements. Recognizing certain shortcomings of the earlier data collection efforts, GLERL also performed data collections to describe the circulation of Lake Huron and Saginaw Bay, again with financial and equipment support from EPA.

Interrelationships with Other Tasks. This task is related to Task 1.5, in which similar analyses of existing data collected in Lake Superior were performed.

Approach. Currents in Saginaw Bay and Lake Huron will be determined by analyzing current meter data collected by EPA during 1965-66 and by GLERL in two separate projects during 1974-75. The first of these projects consisted of mooring 18 current meters at 9 stations in Saginaw Bay during the period of May through October 1974. Additionally, three 2-week long Lagrangian current surveys were conducted, while the moorings were in place, to determine current characteristics in shallow water reaches of the bay where fixed, moored meters were impractical. The second GLERL project consisted of a cooperative study with EPA and Canada Centre for Inland Waters (CCIW) to measure the winter circulation of Lake Huron. Twenty-one moorings utilizing a total of 60 current meters were placed in the southern two-thirds of the lake basin during late November 1974. Retrieval was made in May 1975. This program represents the first serious attempt to measure lake scale currents during the winter months in the Great Lakes. Other existing data, such as that collected by CCIW in prior years, will be examined for relevance to present investigations. Analyses will include steady-state flow determinations and spectra to determine significant periodicities.

Products.

(1) A Technical Report describing the current structure of Lake Huron as developed from earlier EPA and CCIW data will be written. It will contain results of observations taken mainly in the summer and fall periods of density stratified lake water and will present persistent flow characteristics to the extent possible from the limited amount of available data.

(2) A report describing the data collection program by GLERL in 1974 in Saginaw Bay will be written. Results of the circulation studies will permit mapping of currents during prevailing wind directions and will compare these studies with previously published results, independently generated numerical circulation models, and chemical tracer studies.

(3) A Technical Report describing the current observations in Lake Huron during the winter of 1974-75 and presenting a first look at winter water mass transport will be written. This first iteration of the winter data will simply present the observed current vectors, analyze the dominant flow characteristics, and examine in detail a few unusual meteorological events.

(4) Papers presenting significant results of the studies will be written and submitted for publication in scientific journals. Data utilized in the study will constitute a permanent GLERL edited data base archived for Lake Huron.

(5) A data archive will be generated.

Schedule.

Activity	Beginning Date	Completion Date
Analyses of EPA collected data.		Complete
Field studies in Saginaw Bay.		Complete
Lake Huron circulation report (summer currents only and excluding Saginaw Bay).		Complete
Saginaw Bay circulation report.		Complete
Lake Huron winter current measurements.		Complete
Lake Huron winter studies data analyses.	June 1974	December 1976
Lake Huron winter studies Technical Report (first look at data for IJC).	June 1974	December 1975
International Association for Great Lakes Research (IAGLR) paper on summer circulation of Lake Huron.		Complete

Paper for oceanographic journal on the summer circulation of Lake Huron.		Complete
Paper for oceanographic journal on the circulation of Saginaw Bay.		Complete
Papers on the winter circulations of Lake Huron.	January 1976	June 1977

Resources.

	CY 1976 (Quarters)				CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. H. Saylor	45			30	30	30		
L. J. Danek	75	45	75	45				
G. S. Miller	75	45	60	45				
P. W. Sloss	45	45	45	45	45			
Student Aids	30	30	30	30				
Computer Hours	3	3	2	2				

3.5 Task 1.5 Lake Superior Current Studies

Task Scientist. J. H. Saylor

This task is complete. A final report is on file.

3.6 Task 1.6 Flux Between Lake Michigan and Lake Huron

Task Scientist. A. P. Pinsak and J. H. Saylor

Objectives. Net exchange of water and its contained dissolved constituents and suspended material between Lakes Michigan and Huron and the factors that are responsible for the exchange will be systematically investigated during a single open-water season to determine the impact of Lake Michigan on the water quality of Lake Huron.

Background. As a part of the United States and Canada Great Lakes Water Quality Agreement, IJC undertook to study the pollution problems of Lakes Huron and Superior, especially as they concern the boundary waters, and to make recommendations based on their findings. As a contribution to that study, a determination of input from Lake Michigan through the Straits of Mackinac as it affects the water quality of Lake Huron will be made.

Approach. The *R/V Shenehon* was utilized to systematically characterize water masses in northern Lakes Michigan and Huron, their short term and seasonal variations, and the exchange between the two lakes. Time critical chemical and physical measurements of the water and suspended solids were made aboard the boat and samples were sent to GLERL in Ann Arbor for further analysis. In addition to the basic geochemical composition, temperature, and transparency of the water column, pH, specific conductance, Eh, dissolved oxygen, chloride, COD, phosphate, nitrate, sulphate, silica, total organic carbon, volume of organic and inorganic suspended material, and coliform bacteria were determined. Standard meteorologic parameters that can be related to mass movement were continuously monitored with an onboard automatic recording system. Two towers were deployed about 3/4 and 1 mile offshore between May and November 1973 on the north and south sides of the straits in about 20 meters water depth to continuously record current direction and velocity. The south tower was also instrumented to measure wind speed and direction. Two submerged buoys with six self-recording current meters furnished by EPA and deployed and maintained by NOAA monitored current speed and directions during July to December 1973. One buoy had current meters at 10-meter and 20-meter depths and the other buoy string had current meters at 10-meter, 20-meter, and 50-meter depths. Drogues were tracked to establish velocity distribution across the straits and to determine areal extent of mass movements. The existing water level gage network is considered adequate to define surface longwave characteristics driving oscillatory flows. In addition to the data collected in the field, the project will utilize all existing data and analyses in the Straits of Mackinac area.

The method outlined for the investigation of mass exchange between the two lakes will provide quantitative determinations of the net flux of contained water quality constituents and only limited information on a short term basis of temporal variations. Through deployment of current meters, mass exchange will be defined on a short term basis relating to lake oscillations and transient environmental stresses. Measured transport will be related to oscillations in lake levels in the two lakes.

GLERL will coordinate with EPA, CCIW, and the University of Michigan.

Products. Data will be programmed for computer analysis at GLERL. Time and spatial relationships will be established and related to volume exchange of water masses. Short term variations as well as short and long term net exchange will be determined. A paper entitled "Material Transfer Through the Straits of Mackinac" was presented at the IAGLR Conference. A paper entitled "Water Volume Transport and Oscillations" has been submitted for publication in the Journal of Physical Oceanography. A draft report will be submitted to the Upper Lakes Reference Committee. Sections of the ULR report and recommendations to IJC will then be prepared.

Schedule. This task became operational in May 1973 and is scheduled for completion by April 1976.

Activity	Beginning Date	Completion Date
Execute field operations; deploy off-shore towers and buoyed current meters, investigate physical-chemical properties of water masses, prepare drogue studies (5/73-11/73).		Complete
Remove towers and buoyed current meters.		Complete
Prepare laboratory analyses.		Complete
Process water characteristics data.		Complete
Process current meter data.		Complete
Characterize water masses, determine composition changes, estimate loadings.		Complete
Determine daily flows and water mass movement.		Complete
Present paper at IAGLR Conference (5/75).		Complete
Submit paper to Journal.	June 1975	
Determine net exchange of water and contained constituents.		Complete
Prepare draft report.	June 1975	December 1975
Prepare input to IJC recommendations.	September 1975	April 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
A. P. Pinsak	40			
J. H. Saylor	40			
R. L. Chambers	30			

3.7 Task 1.7 Current Study-Oswego Harbor

Task Scientist. G. S. Miller

This task is complete. A final report is on file.

3.8 Task 1.8 Lake Scale Circulation Model

Task Scientist. J. C. K. Huang

Objectives. The general objective of this task, under the overall GLERL missions and objectives, is to develop a flexible large-scale lake circulation model based on hydrodynamic equations for the simulation of temporal and spatial variations of the mean circulation patterns and mean density distributions in the lake.

Specific objectives are as follows:

(1) To put special priority and emphasis on the development of a Lake Ontario general circulation model (the basic lake model should, however, be easily applied to any other Great Lake with minor alterations).

(2) To make intercomparisons between field observations, especially the IFYGL data and simulated results from the numerical model for verification and tuning.

(3) To provide time-dependent climatology for other lakes based on simulated output from similarly developed lake models with the incorporation of all essential physical processes included in the Lake Ontario model.

Background. The rapid advance of modern computing technology has made possible numerical simulation of large-scale, organized phenomena in the atmosphere and ocean as well as in the lakes. Recent progress in hydrodynamic models has yielded quite realistic and detailed results. Lake scaled general circulation models, if properly tuned to observational field data, will provide reliable, time-dependent climatology of major physical variables, such as the barotropic and baroclinic velocity, the density field, the upwelling, and others, over the entire lake. These simulated gross features in the lake will provide not only a physically sound basis for intercomparisons and verifications with field observations but also very valuable background information for resource management and environmental services as well as for scientific studies for other disciplines. Such a model will also be a powerful tool that can be used for the understanding of lake dynamics and response under atmospheric forcing. Following the methodology and technology advanced in the hydrodynamical and thermodynamical models in the atmospheric and oceanic sciences, we are planning to develop the lake simulation model to achieve the objectives set in this task.

Interrelationships with Other Tasks. The results of this task will be instrumental to Projects 3, 4, and 9. It will also provide valuable information to Projects 10 and 11. On the other hand, products of Tasks 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 will be very useful for model verification and tuning. This task is also the fundamental basis of Task 1.9.

Approach. A three-dimensional numerical dynamic model based on governing equations for a closed geophysical hydrothermodynamic system will be developed, aimed at the statistical mean state in the lake as contrasted to the eddy state. The model will include all major physical processes in nature, namely Coriolis forces, the pressure gradient forces, diffusion and advection effects, radiation processes, etc.

The numerical scheme to be used in the lake general circulation model has to conserve the total mass, the total momentum, and the total energy to ensure longtime integration. A numerical scheme developed for the University of California at Los Angeles atmospheric model (which is also widely used in ocean models) will be adopted in our future lake scale general circulation model.

Assuming the probable future commitment to studies of different lakes, the lake model is planned to be programmed in such a flexible manner that it can be used for simulations of any lake with only a minor change in dimensional and mesh grid indexes. However, the development of the Lake Ontario model is emphasized in the immediate future.

Parallel with the development of the lake model and preparation and compilation of input atmospheric data, such as wind stresses, all meteorological parameters involved in the heat calculation should be conducted simultaneously at the same pace. Topographic and lateral boundary configuration data also need to be compiled and transformed into grid indexes.

Immediate follow-up work to this task includes intercomparisons between the model outputs and the observational IFYGL data for mutual verification and realistic tuning of the model.

Products. The final product of this task will be a sound physical model whose results will be valuable for resource management and environmental services as well as for biological, chemical, and interdisciplinary modeling studies. The simulated model output will serve as the ideal basis for intercomparisons and verifications between theoretical studies and field observations. The model itself will also be a powerful tool for lake dynamic studies to be used by other scientists. The model and its output will be presented at scientific meetings and documented in reports.

Schedule.

Activity	Completion Date
Literature research and model formulation.	Complete
Strategic planning.	Complete
Programming.	Complete
Supplementary programming.	Complete
Debugging and testing of program.	September 1975

Preparation for boundary conditions (Lake Ontario model).	October 1975
Production runs (Lake Ontario model).	December 1975
Output analyses and displays (Lake Ontario model).	March 1976
Comparisons and verification (Lake Ontario model).	March 1977
Documentation.	June 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. C. K. Huang	75	75	50	50	50	25	25	25
P. W. Sloss	50	50	50	50	50	50	50	50
B. C. Doughty	100	100	100	100	50	50	50	50
Computer Hours	10	10	10	10	5	5	5	5

3.9 Task 1.9 Nearshore Circulation Model

Task Scientist. J. C. K. Huang

Objectives. The present task is mainly concerned with understanding fundamental aspects of nearshore processes and phenomena in the shallow water of the Great Lakes region. Physical processes in the nearshore zone are closely integrated with the overall processes in the lake basin. The major objective of this task is, therefore, to develop a fine mesh, limited area model to couple to the large scale general circulation model of the lake for the understanding of small scale physical processes and natural phenomena in a limited area, especially in the nearshore zone along the lake. By using the limited area model as the service tool, emphasis will be put upon studies of mixing, dispersion, and diffusion phenomena along the shallow perimeter of the lake from certain independent sources and/or sinks containing conservative properties, such as the estuary discharges and power plant effluents. The limited area model will also be ideal for close intercomparisons with well-designed field observations, such as those carried out during IFYGL. This provides a powerful tool for the realistic tuning of the numerical model to be developed for Task 1.8.

Background. The nearshore zone along the lake is the area in the Great Lakes most intimately related to human activity. It is in this shallow water perimeter of the lake where most recreational activities and fishing occur, where most water supplies are obtained, and where most pollutants are introduced. It is also the most active area for air-lake-bottom interactions. As a result, the characteristics of the shallow water in the nearshore zone are rather different from those of the offshore water and thus deserve special attention. Detailed information concerning the movement and degradation of chemical and thermal pollutants through advection, convection, and diffusion processes in the nearshore zone is vitally important to resource management and environmental services.

Interrelationships with Other Tasks. The results of this task will be very valuable to Projects 3, 4, 9, and 10. It will also be used as a vital tool for tuning to realistic observations the model in Task 1.8. On the other hand, this task depends heavily on the results of Task 1.8. It also takes advantage of the services provided from the results of all other tasks in Project 1 and, later, Project 2.

Approach. The development of a very fine mesh model (less than 1 km in horizontal separation) for certain portions of the lake (for example, along the perimeter of the lake) is based on the same hydrodynamic and thermodynamic principles as the preparation of a model for the entire lake. Since the characteristic behavior of the limited area model is dominantly affected by the imposed boundary conditions, it is preferable that these boundary values be coupled with the lake scale model. However, for close comparisons with a well-designed field monitoring system, boundary conditions imposed on the limited area model can also be obtained from observational data. At the preliminary stage, the general approach and numerical scheme to be used in the limited area model will follow the development of the lake scale general circulation model. At later stages, surface wave effects should be incorporated into the limited area model for the nearshore zone because the surface waves play a very important role in shallow water processes. Furthermore, the feasibility of the finite element approach in the numerical model study for boundary value problems of irregular domain is worth looking into.

Products. The final products of this task will provide detailed information concerning nearshore physical processes and natural phenomena which will be very useful for resource management and environmental and geological sutdies. The model itself will be a powerful tool for realistic tuning of the parameterizations of physical processes into the numerical model. The simulated model output will provide an ideal basis for intercomparisons and verifications between theoretical studies and field observations.

Schedule.

Activity	Completion Date
Literature research and model formulation.	Complete
Programming.	October 1975
Supplementary programming.	February 1976
Debugging and testing of program.	June 1976
Preparation for boundary conditions.	June 1976
Production runs.	July 1976
Output analyses and displays.	October 1976
Comparisons and verification.	October 1977
Documentation.	November 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. C. K. Huang	25	25	50	50	50	75	75	75
Associate Investigator			25	25	75	75	75	75
Associate					50	50	50	50
Computer Hours			5	5	15	15	10	10

3.10 Task 1.10 Current Flow Through the Straits of Mackinac

Task Scientist. J. H. Saylor

Objectives. The objectives of this investigation are to determine the periods of significant oscillatory current flows through the Straits of Mackinac and to correlate the observed periods with oscillations of the water surfaces of Lakes Huron and Michigan. The data set of approximately twelve months duration to be collected in this experiment will be sufficient to examine with good statistical confidence waves as long as 4 days in period. Waves of interest in this study range from periods of 96 to 12 hours.

Background. For the IJC Upper Lakes Reference Study, GLERL conducted an investigation of water volume and dissolved materials transport through the Straits of Mackinac (Task 1.4). In this investigation, current flow was monitored for a period of nearly 100 days, from August through November, 1973. Eleven current meters were installed and for the purposes of the flux project, they were successfully operated to compute the volume transport. During analysis of the measured Straits currents, periodic components were identified in the current records which were not expected prior to project inception. The analyses revealed a bi-lake seiche with period between 50 and 60 hours, which was anticipated from the work of earlier investigators, as well as semidiurnal tides and the seiches of Lakes Michigan and Huron. However, present between the period range bounded by the tidal and bi-lake seiche components are periodic oscillations unexplored in existing literature. Thorough investigation of these newly found phenomena is constrained by (1) the shortness of the current records for statistical confidence in spectral analyses of the current records with sufficient low frequency resolution, and (2) inherent timing inaccuracies of the current meter clocks used in the 1973 study which preclude precise phase determinations.

Interrelationships with Other Tasks. The free oscillations of Lake Michigan are being studied in Task 2.2. One class of waves with periods longer than the normal mode seiches are the rotational modes which are being investigated in Task 2.2. Thus, there is a coupling of theoretical and observational programs for scientific analysis.

Approach. The investigations conducted for the IJC Upper Lakes Reference Study revealed that the oscillatory flow through the Straits of Mackinac was in phase for all current meter locations. Therefore, placement of current meters is not cirtical for this study, but they will be installed near mid-channel to record peak flows. Two current meters will be placed on one mooring at depths of 15 and 25 m, near the center of the cross section instrumented in 1973. The mooring will be set from the EPA vessel R. Simons during its Straits passage en route to winter layover in Lake Michigan, and retrieval will be accomplished from the R. V. Limnos operated by the Canada Centre for Inland Waters during the fall of 1976. Water level data is collected by the Lake Survey Center of NOAA. They will be advised of the need for continuous records at key gaging sites during the course of this investigation.

Products. A technical report presenting scientific results of this investigation will be prepared for publication in an oceanographic journal. Then existing theoretical work will be examined for applicability and, if necessary, new theories developed for data interpretation.

Schedule.

Activity	Beginning Date	Completion Date
Hardware preparation for deployment.		Complete
Mooring installation and retrieval.	October 1975	November 1976
Data analysis.	December 1976	June 1977
Technical report.	January 1977	June 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. H. Saylor					30	45		
Technician				30				
Student Aids					60			
Computer Hours					2	2		

3.11 Task 1.11 Circulations in a Homogeneous Lake

Task Scientist. D. B. Rao

Objectives. The general objectives of the task are to understand the dynamics of wind-driven long term and transient circulations in a homogeneous lake.

Specific objectives are:

(1) To examine the effects of different frictional parameterizations and weak nonlinearities on the steady-state circulation induced in a lake by a constant (time-independent) wind stress.

(2) To examine the influence of impulsive application of wind stresses on the patterns of circulations.

(3) Comparison of the results to data from Lakes Huron and Ontario.

Background. Steady-state circulations for all the Great Lakes of North America were previously calculated using homogeneous (unstratified) lakes, some ideal wind fields and linear bottom friction (e.g., Rao and Murty 1970: Murty and Rao 1971). In Lake Ontario, these studies produced a double gyre pattern for the circulation, a feature subsequently also found in simple analytical studies. Similar behavior is also apparent in Lake Erie. In both of these lakes, the bottom topography is not very complicated and the orientation of the axes of the lakes is more or less along the direction of the prevailing mean winds. The other lakes have more complicated bottom topography and the corresponding circulation patterns are also very complicated.

As far as Lake Ontario is concerned, the steady circulation model was tested for the months of May and November 1972, during which time the lake appeared to be homogeneous. Mean monthly winds were used to calculate the circulation patterns. The calculated pattern for November gives two gyres - a large cyclonic one and a small anticyclonic one. The observations seem to fit well with the large cyclonic cell but do not appear to indicate the presence of the amaller anticyclonic cell.

In view of the above, it appears worthwhile to reexamine certain aspects of the simple steady-state circulation models - such as different friction parameterizations and effects of nonlinearities. In addition, the wind stress is always unsteady and stress impulses are applied to the lake at intervals. It is possible that these unsteady winds will give contributions to the time-averaged circulations through nonlinear processes. Such an investigation is warranted since a lake circulation model using only mean winds may not be adequate to explain the mean (steady) circulations.

Interrelationships with Other Tasks. Results of this task will be useful in interpretation of those from Task 1.1 and 1.8.

Approach. For the steady-state problem, the depth integrated equations of a homogeneous lake will be solved by application of Liebman's point-over-relaxation procedure. The equations will be developed using a Rossby number (assumed small) expansion so that the effects of first order nonlinearities may be considered. The behavior of solutions for high and low friction coefficients and linear and quadratic friction laws will be considered for different steady wind regimes.

The time-dependent circulation problem will be considered from a spectral expansion procedure in space and finite-difference integration in time. The spectrum functions are the topographic modes of the lake. Such a procedure is advantageous since it provides an insight into the excitation of these topographic modes, whose presence is evident from the model integrations of both Simons and Bennett. The spectrum of topographic modes are already computed for Lake Ontario by Rao and Schwab. Some experiments may also be conducted using a single lattice finite-difference mesh. Also, a few experiments will be made on ideal shaped basins with analytical topographies to gain some insight into the different mechanisms responsible for generating the circulation patterns.

Products. Products consist of two reports and a talk at a scientific meeting.

Schedule.

Activity	Completion Date
Studies on simple models.	June 1976
Report.	December 1976
Application to Lake Ontario.	June 1977
Report.	December 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
D. B. Rao	40	25	30	30	30	30	30	30
D. J. Schwab	25	25	25	25	25	25	25	25
Computer Hours	3	3	3	3	3	3	3	3

3.12 Task 1.12 The Currents of Southern Lake Michigan

Task Scientist. J. H. Saylor

Objectives. Objectives of the experiment are to define the spatial scale of coherent coastal currents in the southern basin of Lake Michigan, both in longitudinal length along the lake shore and in transverse width toward the center of the lake, to monitor and record episodes of upwelling and its effects on current structure, and to delineate circulation of the southern basin across a transverse cross section. Data will be analyzed and reported for its own scientific merit and will be used for further planning of continuing Lake Michigan investigations in succeeding years.

Background. There have been two significant attempts to measure the currents of southern Lake Michigan. The first of these was by Ayers et al. in the latter part of the 1950's. Synoptic ship surveys were used to measure temperature structures during summer and from the temperature field geostrophic currents were computed. However, only three surveys of two day duration were performed so that the data give little indication of the persistence or variability of the flow field, or of the scale of coherent motions. The Public Health Service moored a large array of current meters in Lake Michigan during the early 1960's. Due to inherent limitations of the instruments used and innumerable difficulties in data processing, results of these studies were not very successful in determining characteristics of the large scale flow field. They did provide, however, a first look at the remarkable prominence of near inertial period internal waves in the lake during the season of summer stratification. With much improved instrumentation, the measurements to be accomplished in this study will provide valuable input to the determination of the distribution and persistence of lake scale characteristic circulations and the first really intensive investigation concerning the generation and propagation of long interval waves on the thermocline.

Interrelationships with Other Tasks. Concomitant with the current studies, field investigations of the biology and chemistry of southern Lake Michigan are being accomplished in Projects 5 and 6. The physical data to be collected here will provide essential background for interpretation of observed processes and distributions. The measurement program will also supplement modeling efforts addressed in Project 1 and provide basic data for long period wave studies included in Project 2.

Approach. Sixteen current meter moorings will be deployed in southern Lake Michigan as shown in Figure 2. Ten moorings will be placed in the inshore strip of the coastal current maxima, at distances of 7.5 and 15 km offshore. Four of these coastal traverses will be spaced at nearly 35 km intervals along the eastern shore of the lake from Benton Harbor to Muskegon. One traverse off Holland will have two other moorings at distances of 3.75 and 11.25 km offshore. The fifth nearshore traverse will be placed off Racine.

Current meters will be suspended from subsurface floats at depths of 12.5 and 25 m. Four additional moorings will be spaced across the transverse basin section extending from Racine, Wisconsin to Holland, Michigan. The end moorings will be 30 km offshore and the remaining two equally spaced between them. Current meters on the four deep water moorings will be placed at 12.5, 25, and 50 m depth. A total of 35 current meters are deployed in the Lake Michigan array; most have an integral temperature recorder.

A meteorological buoy designed to measure wind speed and direction and air and water temperature will be moored at the center of the Lake Michigan cross section.

Products.

(1) Edited data set for southern Lake Michigan currents and water temperatures.

(2) Technical report describing the program, successes and failures, and circulation characteristics of the southern basin.

(3) Scientific papers describing nearshore long wave processes, the stability and persistence of coastal currents, and generation and propagation of long transverse internal waves, and upwelling-downwelling processes are envisaged.

Schedule.

Activity	Beginning Date	Completion Date
Planning and preparations.	July 1975	May 1976
Installation of instruments.	May 1976	June 1976
Retrieval of instruments.	November 1976	December 1976
Data processing and editing.	January 1977	April 1977
Project and circulation report.	April 1977	September 1977
Scientific analyses and reports.	April 1977	Indefinite

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. H. Saylor	*	*	*	*	*	*	75	75
L. J. Danek		30		30	75	75	75	75
G. S. Miller		30		30	75	75	75	75
P. W. Sloss						45	45	45
J. E. Dungan	75	75	15	75				
Student Aids	75	150	30	90	60	60	60	60
Computer Hours				2	20	5	5	5

*Planning and supervisory role.

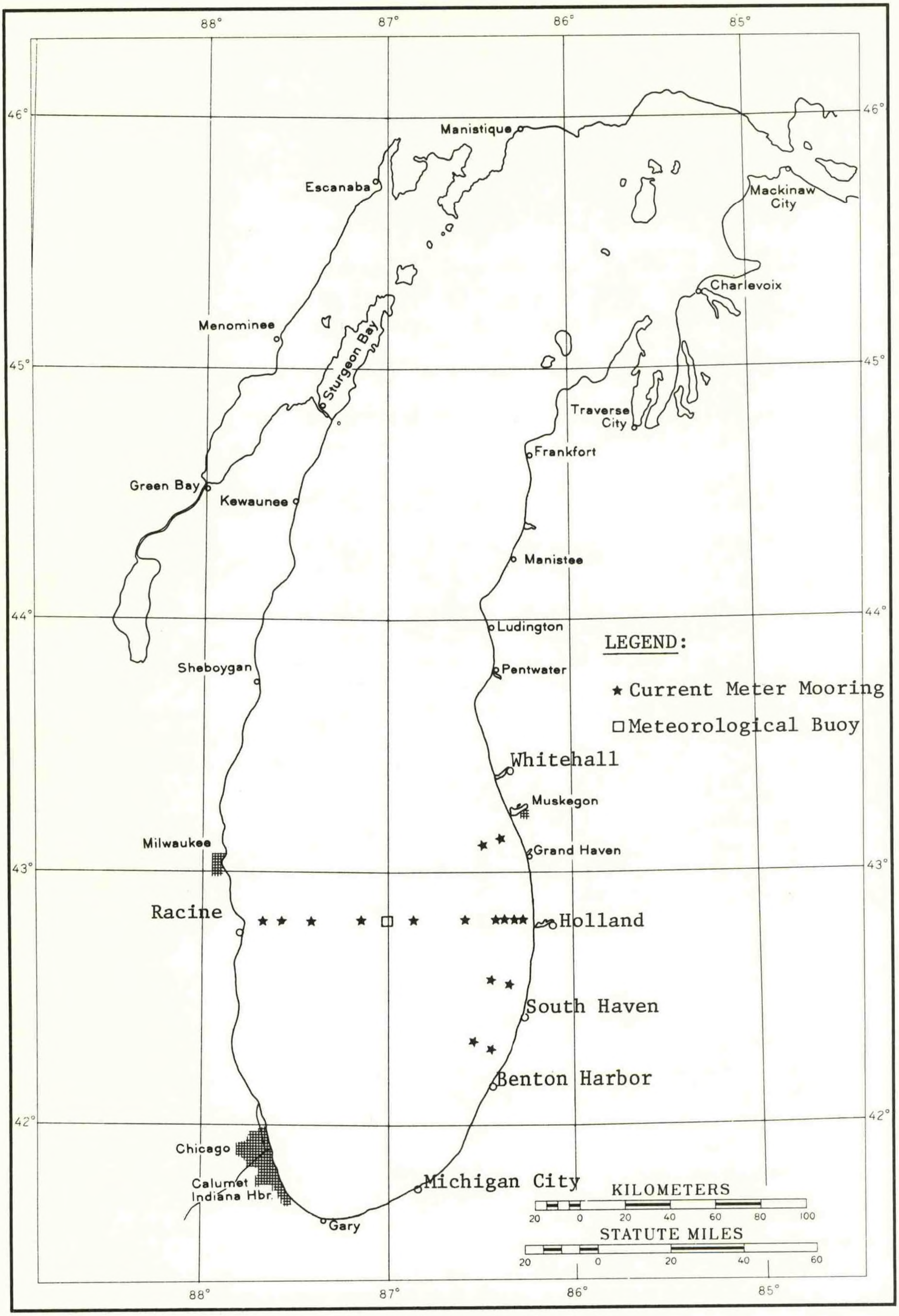

Figure 2. Planned observation sites.

4.0 Project 2 Waves and Oscillations

Project Scientist. D. B. Rao

Objectives. The objectives of this project are:

(1) To improve climatological information on the distribution and variability of surface waves, wind setup, and seiches (external and internal).

(2) To improve numerical models, both theoretical and empirical, to predict surface waves, wind setup, and seiches in order:

(a) To explain major scales defined in the observational studies.

(b) To extend the limited climatological information derived from direct observations to all regions of the Great Lakes.

(c) To provide tools for operational forecasters.

(3) To improve understanding of the physical processes involved so that numerical prediction models can be improved.

Background. This research project is important because the phenomena under investigation are environmental hazards in many Great Lakes activities. While studies of waves and oscillations (surface and internal) have scientific interest in their own right, the need for improved information to support public information services, commercial and sport fishing, beach erosion and flooding, shipping, coastal zone management, recreational boating, shoreline construction and public works, and ship design is the main justification.

Theory is well understood for surface waves in deep water. In the Great Lakes, however, these waves are not as well understood due to limited fetch, short wind duration, shallow depth, and boundary effects. Theoretical and empirical models need further development and testing in conjunction with well conceived field data collection studies.

Large water level oscillations occur in the Great Lakes as a result of atmospheric forcing. The horizontal scale of this response is large as opposed to the comparatively small horizontal extent of surface waves. In magnitude this response may exceed both breaking waves and hydrological changes, making it an important factor in lakeshore erosion, shipping and land use management.

Interrelationships with Other Projects. The physical variables of importance to other GLERL projects include water levels with measurements of sufficient frequency to resolve the high frequency surface waves and the longer frequency wind setup and seiche phenomena. This project will utilize some of the same hydrologic data useful to Project 7. Lake and atmospheric boundary layer data bases and observations are common with Project 1. Interdependencies exist with Projects 9 and 11, and Task 12.2.

Approach. The approach in this project includes field data collection, analysis, model development, testing and evaluation. For surface waves, special data acquisition systems will be deployed along with other data acquisition systems to measure lake and atmospheric boundary layer variables. Analyses of data will examine 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 tested and evaluated utilizing data bases developed from field data collections.

4.1 Task 2.1 Surface Wave Observations and Analysis

Task Scientist. P. C. Liu

Objectives. The objectives of this task are as follows:

(1) To investigate the processes of generation, growth, and decay of wind-generated waves in the Great Lakes, their interactions with the atmospheric boundary layer, their linear and non-linear properties, and their correlations with various theoretical models.

(2) To provide seasonal, annual, and long term wave statistics that are of fundamental importance to the design of lake vessels, shoreline structures, beach erosion protection, and coastal sediment transport processes.

Background. GLERL and its predecessors, the Limnology Division of LSC, NOAA and the Research Division of the U.S. Army Corps of Engineers, Lake Survey District, have engaged in long term recording of surface waves in the Great Lakes since 1964. Because of a lack of appropriate analysis facilities, they have analyzed only small samples of recorded data from the large volume of wave measurements. Efforts have also been made to hindcast Great Lakes wave statistics by using empirical methods. The results have been generally lacking in accuracy and unreliable for practical application. An ideal wave prediction model should be based on physical understanding of how waves are actually generated and dissipated and should allow provisions for further testing and modification. The achievement of the objectives of this task will provide such understandings and thereby facilitate the subsequent efforts of developing an improved model for surface wave predictions in the Great Lakes.

Interrelationships with Other Tasks. This task will utilize the data base developed by Task 1.1 and provide information and analysis results to Task 9.2.

Approach. Surface wave observations will be accomplished by making field measurements in southern Lake Michigan. Between Muskegon, Michigan and Milwaukee, Wisconsin four Datawell waveriders, two on each side of the lake, will be deployed at 10 and 20 km respectively offshore. A research tower will also be installed 2 km offshore from Muskegon, Michigan in 15 km of water. The instruments to be installed on the tower include two wind-speed sensors, two air-temperature sensors, one wind-direction sensor, one surface water temperature sensor, and an array of four wave staffs to measure directional wave spectra. The waverider data will be recorded continuously on analog magnetic tapes. The data from the research tower will be recorded digitally at alternate 10-minute intervals with a sampling rate of two data points per second.

A data analysis system that includes the utilization of data acquisition equipment with analog-to-digital conversion capability in connection with GLERL's computing facility will be developed. Prior to the procurement of GLERL's own data acquisition equipment, the analog-to-digital conversion is presently conducted on the PDP-11/45 of CEDDA of EDS in Rockville, Maryland. The data analysis system consists of the presently operating statistical and spectral analysis programs and the yet to be developed directional spectral analysis program.

<u>Products</u>. Two technical reports will be generated from this task:

(1) A report on the experimental understanding of the physical processes of wind-generated waves in the Great Lakes.

(2) A report on the measurement and analysis of directional spectrum of wind-generated waves in Lake Michigan.

In addition, a series of data reports resulting from analysis of previously recorded wave data will also be prepared. In the interim of developing these final products, significant results, interesting notes, or research progress will be documented or presented, as appropriate.

<u>Schedule</u>.

Activity	Beginning Date	Completion Date
Develop data analysis system.		December 1976
Analysis and prepare technical report on physical processes of waves.		December 1976
Collect field data for directional wave studies.	June 1976	December 1976
Generating wave data reports.	June 1976	December 1977
Analysis and prepare directional wave spectrum report.	January 1977	December 1977

<u>Resources</u>.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
P. C. Liu	90	90	90	100
T. A. Kessenich	100	100	100	
Scientist			100	100
WAE		50	50	50
Computer Programming	10	10	10	10
Instrumentation	75	100	50	
Field Installation	50	75	25	25
Additional Field Installation	50	75	25	25
Computer Hours	5	5	10	10

4.2 Task 2.2 Free Oscillations of Lake Michigan

Task Scientist. D. B. Rao

Objectives. The objectives of the task are to determine the periods and structures of the two-dimensional free oscillations of Lake Michigan when the lake is homogeneous. The irregular shape and depth variations of the lake and earth's rotation will be considered. Some of the theoretical calculations will be verified against available analyses of water level data around the lake.

Background. Knowledge of the characteristics of free oscillations of a lake is very useful in understanding the dynamics of a lake and interpretation of data. Only the homogeneous (or the barotropic oscillations) will be considered here. When topography of the lake and the earth's rotation are taken into account, the spectrum of free oscillations consists of two distinct species - the short period gravitational modes and the long period topographic (or rotational) modes. The gravitational modes play an important role in determining the short term response of a lake to transient disturbances; e.g., storm surges, resurgences, etc. On the other hand, the role of rotational modes will be important in the determination of the mean circulation patterns.

Interrelationships with Other Tasks. This task will be useful in interpretation of some of the results of Task 1.6. It will also be useful for interpretation of large scale numerical simulation model results from Task 1.8 when it is applied to Lake Michigan.

Approach. The method of calculation is based upon a Galerkin method used by Rao and Schwab (1974). It essentially proceeds by expansion of the eigen-functions on an orthogonal basis. The basis functions are chosen as eigen-functions of two self-adjoint elliptic operators that are simpler than the tidal operator but together suffice to generate a complete functional basis. The eigen values and eigen functions obtained from the preceding procedure give the periods and structures of the gravitational and the topographic modes. The features of the gravitational modes will then be compared with spectral analysis of water level data done by Professor C. H. Mortimer of the Center for Great Lakes Studies, University of Wisconsin, Milwaukee.

Products. A scientific paper on the free oscillations of Lake Michigan. A final report is on file.

Schedule.

Activity	Beginning Date	Completion Date
Write program for computer.		Complete
Run on computer.		Complete
Interpretation of results.		Complete
Report.		Complete

4.3 Task 2.3 Oscillations of Lake Huron

Task Scientist. D. B. Rao

Objectives. The objective of this task is to theoretically examine the oscillations of Lake Huron to explain some of the observed oscillations found, for example, in Task 1.4. In the calculations the lake will be considered homogeneous. The irregular shape and bathymetry of the lake will be taken into account along with the earth's rotation.

Background. Lake Huron is perhaps the most complicated shaped basin among the Great Lakes with Saginaw Bay in the southwestern corner and Georgian Bay in the northeastern corner. It is connected to Lake Michigan through the Mackinac Straits and to Lake Superior through the St. Mary's River. It is known that Lake Huron exhibits a mode of oscillation with Lake Michigan with a long period (50-60 hours). Lake Huron also has its own periods of oscillation and the same is true of Saginaw Bay and Georgian Bay. Periods of some of the lower gravitational modes of Lake Huron and Saginaw Bay have been in the past calculated using one-dimensional channel theory. Even though observations seem to substantiate a few of these, the structures of the modes will not be well determined. In addition, spectral analyses of currents from Mackinac Straits and Saginaw Bay seem to indicate the existence of several modes with much higher periods than the lowest Huron or Saginaw Bay modes. In order to identify at least some of these modes, as well as to make a more precise determination of the lower gravitational modes of the complete Lake Huron basin, a two-dimensional calculation with the inclusion of earth's rotation is needed.

Interrelationships with Other Tasks. This task will be useful in the interpretation of results from Tasks 1.4, 1.6, and 1.10.

Approach. The normal mode calculations use Galerkin procedure. It essentially proceeds by expansion of the eigen-functions on an orthogonal basis. The basis functions are chosen as eigen-functions of two self-adjoined elliptic operators that are simpler than the tidal operator but together suffice to generate a complete functional basis. The eigen values and eigen functions obtained from the preceding procedure give the periods and structures of the gravitational and the topographic modes. Results of spectral analyses of currents in Lake Huron, Saginaw Bay and Mackinac Straits will be used for comparison with theoretical calculations. Some additional spectral analyses will be done with water level records since the signature of the gravitational modes is normally more conspicuous in the water level fluctuations.

Products. The product of this investigation will be a scientific paper.

Schedule.

Activity	Beginning Date	Completion Date
Programming for normal modes.		December 1975
Computer runs.		January 1976
Spectral analyses of water levels at some stations.		July 1976
Analysis of results.		August 1976
Report.		September 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
D. B. Rao	15	25	10	
D. J. Schwab	50	50		
Computer Hours	3	1		

4.4 Task 2.4 Wind-Induced Changes in Water Levels on the Great Lakes

Task Scientist. D. J. Schwab and D. B. Rao

Objectives. The objective of this task is to develop methodology for prediction of wind-induced changes in Great Lakes water levels associated with severe weather conditions.

Background. Large water level fluctuations in the Great Lakes occur as a result of atmospheric forcing of the lake as a whole. The horizontal scale of this response is large compared to water depth as opposed to the comparatively small horizontal extent of breaking waves. In magnitude of water level displacement, this response may exceed both breaking waves and hydrological changes, making it an important factor in lakeshore erosion, shipping and land use management.

Statistical methods are currently in use by the National Weather Service to predict the maximum water level fluctuation during a severe storm. These methods involve regression techniques using predicted winds and atmospheric pressures as the independent variables. A set of regression coefficients must be determined for each station at which a prediction is to be made. At present only a few of these sets exist. If water level predictions for extended shoreline regions are to be made, these methods are inadequate.

The dynamics of wind-induced water level fluctuations are now understood well enough to develop prediction models based on dynamical theory. Several dynamical methods have already been tried with varying degrees of success. Most of these, however, tend to become too complicated for routine prediction.

Interrelationships with Other Tasks. This task will provide the technique to predict wind-induced water level fluctuations required to develop a climatology of Great Lakes shoreline flooding from wind climatology. The results of this task will be a valuable product for dissemination through Task 9.2, Advisory Service.

Approach. A thorough review will be made of existing statistical and dynamical forecasting techniques. The efficacy of NWS statistical methods will be investigated. The best way to attack the objective of storm surge forecasting will be determined. Because of its conspicuous response to wind, Lake Erie will be used as a test case. Methodology will then be documented and made available to potential users.

Products. The results will be presented in scientific papers and/or technical reports.

Schedule.

Activity	Beginning Date	Completion Date
Review and test existing techniques.	July 1976	December 1976
Develop methodology for routine predictions.	January 1977	December 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
D. J. Schwab		25	75	75	50	50	50	50
D. B. Rao			10	10	10	10	10	10
Computer Hours			1.5	1.5	1.5	1.5	1.5	1.5

5.0 Project 3 Lake Ontario Energy Budget (IFYGL)

Project Scientist. A. P. Pinsak

Objectives. The objectives of the IFYGL Energy Budget Panel are as follows:

(1) To establish effects of each element on the total energy budget.

(2) To establish the general and specific properties of the energy budgets of individual lakes.

(3) To determine effects of stored energy on characteristics and motions of lake water.

(4) To provide input to forecasts of ice formation and decay, evaporation, water balance, and dissipation of heat entering the lakes as these relate to navigation, power generation, lake regulation, weather forecasts, and projected trends of cultural stresses.

Background. The Energy Budget Panel is one of the core components of IFYGL. Numerous Canadian and U. S. scientists investigated the individual terms of the energy budget of Lake Ontario expressed as

$$Q_s - Q_r - Q_b - Q_h - Q_e + Q_v - Q_t = 0$$

where Q_s is incident solar radiation,

Q_r is reflected solar radiation,

Q_b is net longwave radiation exchange,

Q_h is sensible heat transfer,

Q_e is evaporative heat,

Q_v is advected heat,

Q_t is heat content of the lake.

Q_b is composed of three parts $Q_b = Q_a - e\,\sigma\,T_o^4 - Q_{ar}$

where Q_a is incident longwave radiation; e is emissivity, σ is Stefan-Boltzmann constant, T_o is skin temperature in ^oK, and Q_{ar} is reflected longwave radiation.

The above provides an assessment and input to an energy balance of Lake

Ontario. Field investigations were conducted during April 1972 - April 1973.

The energy budget is a fundamental factor in understanding the climatic effect of a water body on the atmosphere and surrounding area and, conversely, the effect of the atmosphere on the water body itself. The magnitude of certain components in the energy balance can greatly affect the agricultural potential in terms of crop season in the basin. Heat content of the lake is controlled in large part by the magnitude of both incoming and outgoing radiation. The balance thus affects both ice and snow amounts and the recreational season. Despite the significance of the energy budget, most current calculations are based on estimates and generalizations.

Results will provide data to better understand ice and snow characteristics and to form a basis for possible prediction of time of ice formation and decay on the lakes, evaporation from the lakes, water balance, and disposition of natural heat and thermal discharges into the lakes.

Interrelationships with Other Projects. This project requires output from and provides input to Projects 1, 6, 7, 8, 9, 10 and constitutes a portion of Project 11.

Approach. The energy budget program as it has been defined for IFYGL is actually an attempt to evaluate all the terms within the framework of a lake-scale energy balance. Changes in heat content of the lake will be compared with all the factors that affect heat storage. Relative precision of measurement or estimation of each of the terms then becomes critical in an evaluation. One advantage of the situation where each budget term is being measured is that any one of them can be tested against the others. One problem with the energy budget technique is that it is not completely independent of other techniques. The sum of evaporative or latent heat and sensible heat exchange is a residual that is then partitioned by means of the Bowen Ratio, the elements of which are indigenous to the mass transfer technique. This ratio is generally expressed as $R = 6.4 \times 10^{-4} P(T_1 - T_2/e_1 - e_2)$ in which P is atmospheric pressure (mb), T_1 T_2 are temperatures (°C) at the surface and some height, and e_1, e_2 are vapor pressures (mb) at T_1 T_2.

Measurement of energy budget terms is accomplished by instrumented ships and by instruments and sensors on buoys, towers, aircraft, and land and island stations. Ship operations are designed to coincide with annual cyclical variations of thermal structure and lake heat storage. Heat content variation is determined by temperature profiles to total depth. Aerial reconnaissance of ice conditions is supplemented by ground ice control. Systematic radiation measurements and cloud cover height and thickness observations are obtained from all available sources. Net advected heat is calculated from measurements of the water volume and temperature flowing from the next upper lake, tributary runoff, surface runoff, precipitation, cultural inputs, groundwater flux, and outflow from the lake.

5.1 Task 3.1 Heat Storage in Lake Ontario

Task Scientist. A. P. Pinsak

Objectives. Heat storage is a major factor in the energy budget equation and must be measured in any sort of an objective analysis because thermal structure is so complex and variable in the Great Lakes.

The objectives of this task are as follows:

(1) To test and correlate various methods that can be used to measure and estimate heat storage.

(2) To calculate lake heat storage in terms of volume averaged temperature surveys and change in storage as expressed by the relationship $V_2 T_2 - V_1 T_1$.

(3) To apply output to computation of the energy budget of Lake Ontario as a part of IFYGL.

Background. Inasmuch as heat storage is the algebraic sum of all other energy inputs and is large, measurement in evaluation of a balance is important. Despite the significance of this storage term, most estimates are based on sketchy or surficial and peripheral measurements. An obvious way to determine heat content of a lake is to obtain temperature profiles during vessel surveys. However, timing is critical, lakes are not always accessible, and vessel surveys may be unwieldy. Other techniques are available, but they need to be evaluated in terms of cost and generation of usable data.

Interrelationships with Other Tasks. Output of this task will be used in Task 3.2, Thermal Characteristics of Lake Ontario; Task 3.3, Advective Heat Exchange; Task 3.4, Energy Budget Analysis; Task 7.3, IFYGL Evaporation Synthesis; and Project 11, International Field Year for the Great Lakes (IFYGL).

Approach. Various methodologies that can be used for measuring and estimating seasonal variations in heat content of Lake Ontario will be compared. These include such things as periodic surveys, *in situ* sensors, remote sensors, or combinations of these. Sensors were placed on buoys, on off-shore towers, and at inshore sites to measure temperature profiles from the surface to lake bottom, and remote platforms were used for synoptic surface temperature measurements.

Periodic coordinated ship surveys keyed to temporal-spatial thermal variations were conducted. Time intervals between surveys were keyed to periods that include no greater change in storage than 10 percent of the annual estimate. Another objective in survey frequency was to coordinate time intervals for change in storage with frequencies used in other IFYGL programs.

Temperature accuracy of the order of 0.1°C is necessary to resolve the heat storage factor. Bathythermograph profiles were taken at 93 stations encompassing the entire lake. These stations were occupied by two ships during each of a total of 40 cruises rated in four priority classes planned during the period of field observations. Highest priority surveys are keyed to provide data on major vertical heat transfers between layers in the lake. Second priority surveys provide data for a regular 2-week estimate of heat content. Lower priority surveys are used to augment the higher priority surveys. In addition to fulfilling energy budget objectives, these cruises satisfy needs of other IFYGL programs.

Products.

(1) A report on the temporal changes in heat storage in Lake Ontario for input to the calculation of the energy budget of Lake Ontario.

(2) A report on evaluation of large lake heat storage estimates reflecting the findings in this analysis and investigation.

(3) Paper entitled "Heat Storage in Lake Ontario" presented at IAGLR, McMaster University, 1974.

Schedule.

Activity	Beginning Date	Completion Date
Compute daily mean water temperature for segments of the lake for thermal characteristics investigation.	July 1973	February 1976
Compute daily mean water temperatures at inshore thermograph stations.		Complete
Compute mean water temperature of subdivisions in the lake during each cruise.	November 1975	March 1976
Integrate temperature of each cell into an estimate of heat storage during each lake-wide cruise.	November 1975	March 1976
Compute biweekly changes in heat storage in Lake Ontario.	November 1975	March 1976
Evaluate and report on the various heat storage estimates.	February 1976	October 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
A. P. Pinsak	5	5	20	10
J. Simonson (PT)	90	60	50	10
Computer Services	10	10		
Computer Hours	6	2	1	

5.2 Task 3.2 Thermal Characteristics of Lake Ontario

Task Scientist. A. P. Pinsak

Objectives. Movement of water in lakes is mostly turbulent, and convection and wind mixing are generally regarded as major forces in heat transfer. However, differences exist concerning the relative significance of these energy sources.

Objectives of this task are as follows:

(1) To analyze temporal-spatial variations in the thermal structure within Lake Ontario.

(2) To correlate variations with forces acting on the lake.

(3) To define the natural distribution and variability of heat within the lake.

(4) To determine the relative significance of heat transfer mechanisms on a temporal-spatial basis.

Background. Mechanics of heating and cooling are generally understood and reasonable estimates can be made, especially for surface layers or for shallow lakes. But definition and refinement of the thermal structure in deep lakes is difficult because the large volume is normally difficult to measure on a time-spatial basis and also because the thermal structure of a deep lake is complex and irregular in a temperate climatic zone.

Interrelationships with Other Tasks. This task will provide input to Project 1, is intimately related to Task 1.1, Distribution and Variability of Temperatures and Currents in Lake Ontario; Task 3.1, Heat Storage in Lake Ontario; Task 3.3, Advective Heat Exchange; Task 3.4, Energy Budget Analysis; and Task 10.4, Monitoring Water Characteristics. Horizontal movement of heat within the lake will be used in conjunction with water movement investigations to define circulation patterns in Lake Ontario.

Approach. Lake Ontario will be arbitrarily divided into 24 cells and multiple layers. Thickness of the layers relates to the degree of turbulence within the water column. Horizontal dimensions of cells relate to the density of the sample network, bathymetry, and the time interval between measurements. Change in heat storage within cells will be computed and the magnitude and direction of intercell heat transfer will be determined. Canadian and U.S. buoy, tower, shipboard, inshore thermograph, tributary, outfall, and remote observations obtained during IFYGL will be utilized. Lake circulation patterns and wind field analyses will also be incorporated into the analysis.

Products. The intensive coordinated surveys and the sensing systems that were incorporated into IFYGL will provide a basis for determination of the thermal characteristics of Lake Ontario during a complete annual cycle.

A report entitled "Thermal Characteristics of Lake Ontario" will quantitatively define the thermal regime over an annual cycle within the lake, will evaluate methods that can be employed as well as observational frequencies, will establish correlation coefficients with baseline stations, and will evaluate the temporal significance of causative forces.

Schedule.

Activity	Beginning Date	Completion Date
Compute daily values of heat content for layers within each included cell (output from Task 3.1).	July 1973	April 1976
Compute heat content for each cell for each cruise (output from Task 3.1).	November 1975	April 1976
Compute change in storage in cells between ship cruises.	May 1974	July 1976
Determine magnitude and direction of change between cells.	July 1976	October 1976
Define the natural distribution and variability of heat within the lake.	October 1976	March 1977
Report for publication.		June 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
A. P. Pinsak		10	5	5	10	30		
J. H. Simonson (PT)		30	50	90	60	20		
Technician (PT)			50	50	50	10		
Computer Services		5	5	5				
Computer Hours		.5	4	1	1			

5.3 Task 3.3 Advective Heat Exchange

Task Scientist. J. L. Grumblatt

Objectives. The advective heat exchange is quantitatively a minor term in heat budget studies in the Great Lakes. Its significance lies in the fact that it is one of the terms of the energy budget that may be manipulated by man with relative ease. Examination of advective heat exchange in the Great Lakes should be at those points of inflow and outflow that are critical to water balance estimates, but cultural and tributary inputs need to be evaluated.

Background. In May 1972, water temperature monitoring stations were installed in the lower Niagara River at Lewiston, New York and in December 1972 at Clayton, New York. These stations are in addition to existing stations operated as part of an ongoing Great Lakes water temperature monitoring system and are used in conjunction with inflow-outflow volume data supplied by IFYGL terrestrial water balance investigators to determine inflow-outflow heat advection. Investigation of the velocity and thermal structure at the head of the St. Lawrence River in 1972 was conducted before, during, and after lake stratification. Lake Ontario outflow was found to remain thermally stratified well down into the river until mixing is complete in the vicinity of the Clayton-Gananoque transect. Fluxes in local tributary inflow were well under 10 percent of the Niagara River inflow volume. Estimates were also made of heat advected by overlake precipitation and direct industrial discharge into Lake Ontario.

Interrelationships with Other Tasks. This task relates to Project 11 and Task 8.2, Ice Forecasting.

Approach. Niagara River heat flow into Lake Ontario is a function of inflow water temperature and inflow water volume. Short term variations of heat flow due to outflow regulation of the Niagara River by hydroelectric power plants are calculated. Short term variations in Niagara River heat flow due to wind setups on Lake Erie and placement of ice boom at Buffalo, New York are also examined. Heat flow from tributary streams is estimated from data supplied by other principal investigators.

Lake Ontario outflow through the St. Lawrence River is regulated, and river flow is computed from flow through structures at Massena, New York. Storage in the river between the regulating structures and Lake Ontario is calculated to compute daily Lake Ontario outflow. Computed Lake Ontario outflow and water temperature in the upper river are used to compute Lake Ontario heat outflow. Short term and seasonal changes in the advective term due to regulation of Lake Ontario outflow are described.

Products.

(1) A technical memorandum to the Energy Budget Committee containing a

tabulation of daily heat advection during the IFYGL.

(2) A report entitled "Some Aspects of Lake Ontario Heat Advection."

(3) A card file of hourly Niagara River outflow volume and daily Lake Ontario outflow volume.

(4) A disk file of hourly mean water temperature in the lower Niagara River and upper St. Lawrence River.

Schedule.

Activity	Beginning Date	Completion Date
Prepare disk file of daily inflow-outflow water temperatures.		Complete
Prepare card file of Niagara River hourly outflow volume and adjusted Lake Ontario outflow volume.		Complete
Paper entitled "Some Aspects of Lake Ontario Heat Advection" delivered at 17th IAGLR Conference, 8/74.		Complete
Assemble data for report to Energy Budget Committee.	June 1974	January 1976
Compute heat flow estimation for tributary streams.	January 1976	February 1976
Submit technical memorandum to Energy Budget Committee.	June 1974	March 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. L. Grumblatt	30			
Computer Programmer	2			
Computer Hours	4			

5.4 Task 3.4 Energy Budget Analysis

Task Scientist. A. P. Pinsak

Objectives. Measurements and determinations of solar radiation, net radiation exchange, heat storage, sensible heat transfer, latent heat exchange, advective transfer, and ice and snow obtained in Lake Ontario during IFYGL will be utilized to establish an energy budget of the lake. These parameters vary significantly in both time and space.

Objectives of this task are as follows:

(1) To define the general and specific properties of the energy budget of a large dimictic lake.

(2) To evaluate all terms of the energy balance equation.

(3) To develop an annual energy balance of the lake. This description, while referring specifically to Lake Ontario in 1972, will be examined in the general sense as it may apply to the energy budget of any large dimictic lake.

(4) To provide an estimate of evaporation as a residual of the energy balance equation and to contribute these estimates for comparison with evaporation estimates obtained by utilizing mass transfer and water budget techniques.

Background. In a general energy balance study, the two types of transfer that can be considered are momentum and sensible heat transfer between atmosphere, hydrosphere, and lithosphere. In the first type, kinetic energy derives from turbulent friction at any interface that might exist. This might typically be wind action at the air-water interface, internal waves, tides, seiches, or currents. However, solar radiation is the primary heat source and is about three orders of magnitude greater than levels of kinetic energy. Kinetic energy, therefore, can reasonably be neglected.

Radiation from the sun is the primary heat source and consequently the prime factor in the heat budget; and cloudiness over and around the lake strongly affects insolation. Because the concept of solar radiation is so complex, it is critical that the differentiation and relation of components be clearly established in order to establish the significance of each.

Thermal structure of large lakes in a temperate climate is complex with marked variations in time and space; therefore, heat storage estimates are largely conjectural. Because it is a major factor, storage needs to be measured in detail.

Presence of ice and snow on a lake in a temperate climatic zone during portions of the year represents complicating factors in budget estimates. Effect on albedo as well as the latent heat of formation and melting need to be included.

Energy budget calculations provide one of a number of ways to estimate evaporation of water from the lake surface. Intercomparison is one way to assess the relative accuracy of the various techniques.

Interrelationships with Other Tasks. This task interrelates with Task 1.1, Distribution and Variability of Temperatures and Currents in Lake Ontario; Task 1.3, Lake Ontario Water Movements Scientific Report (IFYGL); Task 1.8, Lake Scale Circulation Model; Task 3.1, Heat Storage in Lake Ontario; Task 3.2, Thermal Characteristics of Lake Ontario; Task 3.3, Advective Heat Exchange; Task 7.3, IFYGL Evaporation Synthesis; Task 8.1, Lake Ice Distribution; Task 8.2, Ice Forecasting; Task 9.2, Advisory Service; Task 10.4, Monitoring Water Characteristics; Task 10.5, Atlas of Lake Ontario Physical Properties; and Project 11, International Field Year for the Great Lakes (IFYGL).

Approach. Measurement of the energy budget terms was accomplished by instrumented ships and by instruments placed on buoys, offshore towers, and lake and island stations. Forty ship cruises were completed at irregular intervals during the year to coincide with annual cyclical variations of structure and storage within the lake. Heat content variation within the lake was determined by temperature profiles to all depths. Cloud cover, height, and thickness were also measured. Aerial reconnaissance of ice conditions was supplemented by ground ice thickness measurements. Shore stations operating in conjunction with the lake meteorology network provided systematic radiation measurements and cloud observations, and rawinsonde observations helped define radiation components.

Products. Investigations and analyses by the U. S. and Canadian IFYGL Energy Budget Panel members will aim at establishing effects of various terms in the energy budget equation and in developing daily averages for Lake Ontario for each of these. Inputs from each panel member will then be synthesized into an energy budget of Lake Ontario. An IFYGL Scientific Report, "The Energy Balance of Lake Ontario," will be produced as a joint effort by the U. S. and Canadian panel co-chairmen.

With real or near real time inputs of critical terms to drive the basic model, timely energy budgets can be produced for use in temperature distribution problems, heat assimilation and diffusion problems, energy transport, determination of evaporation as related to lake level forecasts and regulation plans, and forecasts of ice formation and decay.

Schedule.

Activity	Beginning Date	Completion Date
Evaluate the Bowen Ratio and apply to estimates of latent and	February 1973	April 1976

sensible heat transfer across the surface of Lake Ontario.		
Development of daily averages for all the terms in the energy budget equation by the Canadian and U. S. panel members.	July 1972	April 1976
Synthesis of all of the terms into an energy budget for Lake Ontario and preparation of a draft scientific report by U. S. and Canadian panel co-chairmen.	April 1976	December 1976
Draft report to editors.	January 1977	March 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
A. P. Pinsak	10	10	20	30	20			
J. H. Simonson (PT)	10	30						
B. D. Landay			50	50				
S. Bermick	30							
Computer Services	5	5	5					

6.0 Project 4 Aquatic Ecology Models and Related Studies

Project Scientist. A. Robertson

Objectives. The objectives of this project are as follows:

(1) To develop a series of models, at several levels of complexity, that realistically simulate the fluctuations in quantity in ecologically meaningful components of the Great Lakes ecosystems.

(2) To use these models to evaluate the present status of our knowledge and to identify areas of weakness that require further study.

(3) To carry out programs of data analysis and interpretation directed at answering questions about how to treat certain aspects of the modeling effort.

Background. A great many of the problems that have been identified in the Great Lakes in recent years are closely related to the ecology of the lakes. The solution of such problems as conserving and increasing the fisheries, protecting the lakes from toxic materials, and abating overenrichment by plant nutrients calls for a thorough knowledge of the ecological relations within the lakes. A substantial amount of this knowledge is already available. However, the Great Lakes ecosystems are so complex that there is a need for much more and better understanding before the resource managers really have the ability to predict the most efficient and beneficial manner in which to handle such problems.

A primary goal of GLERL's biology-chemistry program is to help provide the information that will allow managers to evaluate in a more rational and efficient manner the ecological consequences of proposed actions. To determine what research should be conducted to meet this goal, it is necessary to evaluate the present status of knowledge and to identify the major stumbling blocks to increasing our understanding of the Great Lakes ecosystems.

Project 4 has been set up in an attempt to evaluate the present status and to identify the major stumbling blocks. We will attempt to develop mathematical models of the Great Lakes ecology at several levels of complexity, based on available knowledge. These models will be systematic representations of our present status at the level of complexity under consideration.

We hope, then, through comparison of model output to real data, sensitivity analysis, and other techniques to identify the major inadequacies in the model and thus the areas most in need of active research efforts.

Our modeling efforts will initially be quite similar to those conducted by several other workers; e.g., Thomann and DiToro at Manhattan College, Canale et al. at the University of Michigan, and Chen at Tetra Tech., Inc. Instead of developing our models independently, we will draw on the existing models to bring our work up to state-of-the-art status as quickly as possible. However, as the other models are primarily being developed to solve immediate problems rather than to evaluate present status and future research priorities, we will have to proceed on our own path and diverge more and more from these other efforts as time goes on.

Interrelationships with Other Projects. This project relates to other projects as follows:

(1) The models developed for planktonic competition and succession in Project 5 will be used to improve these aspects of the models in this project.

(2) Models of circulation and temperature developed by the Physical Limnology and Meteorology Group will be used as the basis for modeling those aspects of this project.

(3) The studies on natural distribution and variability of lake properties conducted in Project 6 will provide assistance for conceptualization and verification in this project.

Approach. Using the information available in the literature, the subdivisions appropriate for the level of complexity under consideration and the interrelations among these components will be conceptualized. Each functional relationship will then be developed from existing Great Lakes data bases. The models will be tested, tuned, and then verified using all available data, especially those from IFYGL.

As stated previously, a hierarchy of models at various levels of complexity is visualized. The first and simpliest of these is outlined in Task 4.1, and other models with greater complexity in space and/or ecological subdivisions will be developed as the means and needs for these are identified.

The ecological aspects of these models will be coupled with models of circulation and temperature developed by the Physical Limnology and Meteorology Group. The emphasis in the modeling will be on models with one or more dimensions in space, as ecological consequences will be much easier to detect and interpret at these levels than in a three-dimensional model.

Supplementary studies to develop better values for the coefficients needed by the models will be conducted as necessary as will certain studies designed to improve our conceptualization of the Great Lakes system. These efforts will use data already available from IFYGL and other field studies.

6.1 Task 4.1 Level 1 Ecological Model

Task Scientist. B. J. Eadie

Objectives.

(1) To develop an in-house chemical/biological/physical model, of 1 spatial dimension, for the purpose of improving and testing hypotheses underlying the functional relationships in the ecological system of Lake Ontario.

(2) To provide a tool to focus research attention on the processes least well understood.

(3) To stimulate the movement of carbon and other important elements.

Background. The background for this work has been broadly defined in the Project 4 outline. In the late 1940's, Riley and co-workers began the development of mechanistic phytoplankton growth relationships. After a period of limited activity, this approach was adopted and refined by a multitude of investigators in the 1960's and 1970's. Recent results from the more sophisticated models indicate an ability to simulate many important environmental parameters in a gross way. In the area of chemistry, the theoretical framework is more well developed (i.e., classical thermodynamics) for the equilibrium are not well understood.

Interrelationships with Other Tasks. This task is related to Task 4.4 (Ecological Modeling), Task 6.2 (Analysis of Lake Ontario Oxygen Profiles), Task 6.3 (Chemical Dynamics), and Project 5 (Planktonic Succession).

Approach. The theory of the model is based on conservation of mass around each ecological component; i.e.,

$$V\frac{dc}{dt} = AC + S + W$$

where

C = component of interest
V = volume under investigation
A = advection and diffusion terms
S = in situ alteration of C
W = external sources and/or sinks

The ecological model is driven by a physical model (Sundaram & Rehm) which provides the temperature and eddy diffusivity regime and by light which is taken from IFYGL data. The model, being one-dimensional in space, can represent either a square unit area or a horizontally homogeneous approximation of Lake Ontario. There are currently two versions: one with twelve vertical sections primarily for examining the near-surface chemical phenomena, and a second more generalized three-level model with a variable thermocline, the levels representing epi, meta and hypolimnion.

In the time scale, the model is generally run to simulate a one-year cycle on a daily basis, with internal time steps ranging from an hour to a day. Currently, it is composed of a system of eighteen coupled non-linear differential equations:

- 4 phytoplankton types
- 5 herbivorous zooplankton types
- 1 carnivorous zooplankter
- 1 phosphorus form
- 3 nitrogen forms
- 1 ditritus
- 1 inorganic carbon
- 1 sediment
- 1 benthic community

As it will exist at the completion of this task, the model is not unique; rather it is somewhat of a bridge between the engineering models being developed under contract and the scientific type model being developed at Oak Ridge.

Products.

(1) A report describing the model and its operations.

(2) Paper for EPA Modeling Conference, 4/76.

(3) Documented computer program of the model.

Schedule.

Activity	Beginning Date	Completion Date
Resolve current problems.		Complete
Develop nitrogen subroutine.		Complete
Develop sediment kinetics.		Complete
Develop benthos subroutine.		Complete
Develop carnivorous zooplankton subroutine.		Complete
Evaluate atmospheric source and sink.		Complete
Evaluate sedimentary sink.		Complete
Verification of output.	November 1974	January 1976
Write technical report.	June 1975	March 1976
Write paper.	January 1976	April 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
B. J. Eadie	10	5		
D. Scavia	5	5		
A. Robertson	2	1		
Computer Assistant	5			
Consultants: Pickett, R. L.				
Tarapchak, S. J.				
Vanderploeg, H. A.				
Computer Hours	1			

6.2 Task 4.2 Assessment of Lake Ontario Invertebrate Community

Task Scientist. A. Robertson

Objectives. The objectives of this task are as follows:

(1) To determine what invertebrate species have been reported in Lake Ontario.

(2) To update and correct the scientific names applied to these according to modern taxonomic opinion.

(3) To determine which of the species are of sufficient importance to the lake ecosystem to be considered in modeling the ecological processes within the lake.

Background. The first step in understanding the ecological relations in a lake is to determine what organisms are present and which of these are the more important. Yet at the time of the initiation of IFYGL, such information was not available for Lake Ontario. Limited studies of the organisms at certain places and at certain times had been reported for Ontario, but the various reports had not been pulled together and synthesized into an overall summary. This project is designed to fill this lack for the invertebrate animals. Another IFYGL project (not under GLERL's direction) is attempting to provide a similar summary for the fish.

Interrelationships with Other Tasks. The results from this task will provide guidance to Tasks 4.1 and 4.4 as to what invertebrates should be considered as part of that model at a specified level of complexity.

Approach. The literature will be reviewed to compile a list of the species reported from the lake. This list will be revised using standard taxonomic references in an attempt to update and correct the names reported. Wherever available, the information on the Lake Ontario forms will be combined in an attempt to estimate the abundance of the various forms. For each of the more abundant forms, a rough estimate of its biomass in the lake will then be obtained, if possible, by combining the abundance estimate with weight or size estimates from the literature. The biomass estimates will be compared in an attempt to obtain a rough measure of the relative ecological significance of the various forms.

Products.

(1) An ERL Technical Report detailing the species found in the lake, their distribution, and their abundance.

(2) A scientific paper summarizing the biomass estimates and their ecological significance.

(3) A presentation at a scientific meeting summarizing results.

Schedule.

Activity	Beginning Date	Completion Date
Develop plan.		Complete
Develop provisional benthic list.		Complete
Correct provisional benthic list.		Complete
Develop provisional zooplankton list.		Complete
Correct provisional zooplankton list.		Complete
Develop distribution summaries.	May 1974	March 1976
Write ERL report.	April 1976	August 1976
Present paper.	April 1976	April 1976
Estimate abundance.	January 1976	July 1976
Estimate biomass.	July 1976	November 1976
Write report.	December 1976	May 1977

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
A. Robertson	10	10	10	10	10	10		

6.3 Task 4.3 Three-Dimensional Ecological Model

Task Scientist. D. Scavia

Objectives. The overall objective of this task is to develop an operational, three-dimensional, ecological model for the Great Lakes. This model will give us the capability for addressing problems in water quality, land use, fisheries, and other management aspects of the Great Lakes Watershed. More specifically, the immediate objectives are:

(1) Compare Tetra Tech. model constructs with those developed in Tasks 4.1 and 4.4 and select the best descriptions of the chemical and ecological processes.

(2) Estimate and evaluate model coefficients and calibrate the model to Lake Ontario IFYGL data.

Background. Tetra Tech. conceptualized and implemented a three-dimensional water quality model applicable to the Great Lakes (see Chen et al., 1975, A Comprehensive Water Quality Ecological Model for Lake Ontario, Tetra Tech. Report No. TC-435). The model is based on mass conservation and is driven by a hydrodynamic model developed by Dr. John Bennett for Lake Ontario. After implementation, the model was functionally tested by running it for one month using "best guess" coefficients.

Interrelationships with Other Tasks. This task will be intimately linked with Task 4.4, where the mechanisms of this model will be compared to those in GLERL's in-house ecological model. Other interactions will be with Projects 4 and 5, and Tasks 6.2 and 6.3.

Approach. This task will be carried out concomitantly with Tetra Tech's continuation contract "Comprehensive Water Quality Ecological Model for Lake Ontario." That contract encompasses four basic areas:

(1) Formulation Review - Tetra Tech. will take the initiative for soliciting comments on the existing mechanisms used in the ecological formulation of the model. This task will provide our comments and evaluate the results of the overall review.

(2) Hydrodynamic Program - Tetra Tech. has evaluated the hydrodynamic program presently used and suggested areas of weakness and possible modifications. This task will review the results of their refinements.

(3) Rate Coefficients - This phase will be carried out primarily through this task. By utilizing our in-house scientific expertise (e.g., Projects 4 and 5, Tasks 6.2 and 6.3) and other local groups (Fisheries, U. of M.), we will estimate values for the various coefficients in the ecological model. Most values will be tested initially in the one-dimensional model (Task 4.4) once the two have

been merged. Tetra Tech. will assist GLERL in this phase.

(4) Model Calibration - This will be carried out primarily at GLERL by varying coefficient values within the ranges compiled in phase 3 of this task. Model output will be compared to IFYGL time/space profiles for Lake Ontario. Preliminary sensitivity analysis will be carried out by Tetra Tech. and GLERL.

Products. The products of this task will be:

(1) Computer program of the three-dimensional model.

(2) Documentation of computer program and user's guide.

(3) Scientific paper co-authored by participating members of GLERL and Tetra Tech.

Schedule.

Activity	Beginning Date	Completion Date
Comparison of model constructs.	January 1975	May 1976
Estimation of model coefficients.	January 1975	August 1976
Calibration of model to Lake Ontario.	July 1976	January 1977
Prepare paper with Tetra Tech.	December 1976	January 1977

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
D. Scavia	45	45	45	45
A. Robertson	8	8	8	8
Consultants: Eadie, B. J.				
Chapra, S. C.				
Computer Hours	.5	1	2	1.5

Travel to Tetra Tech., Inc., Lafayette, California will probably be necessary. Approximately four man-trips are expected.

6.4 Task 4.4 Ecological Modeling

Task Scientist. D. Scavia

Objectives. The objectives of this task are as follows:

(1) To maintain a one-dimensional ecological model encompassing state-of-the-art mechanisms describing the more important biological and chemical processes of the Great Lakes. Expand the framework of the model to include additional compartments of interest (i.e., O_2, Si, fish).

(2) Test and evaluate the overall model responses to various input stresses.

(3) Develop more refined formulations for phytoplankton growth limitation and particulate sedimentation.

Background. The groundwork for this task has been laid by previous work (Task 4.1). A model involving four phytoplankton types, 5 herbivorous and one carnivorous zooplankton, phosphorus, 3 forms of nitrogen, detritus, inorganic carbon, sediment formation and benthos has been conceptualized, implemented and calibrated (Scavia, Eadie, and Robertson in preparation). Its potential utility as a general Great Lakes model has also been explored (Eadie, Scavia, and Robertson in preparation). The model presently incorporates most of the current theories of food web ecology.

Interrelationships with Other Tasks. This task relates to the following:

(1) Project 5 - Planktonic Succession: The results coming forth from Project 5 will guide in the further development of the model described herein, while results from the model will also describe areas needing further description by Project 5. Interactions started between Project 5 and Task 4.1 will continue and become more intense.

(2) Task 6.2 - Analysis of Lake Ontario Oxygen Profiles: Verification.

(3) Task 6.3 - Chemical Dynamics: Verification.

(4) Task 4.3 - Ecological Model: The mechanisms of this model will be compared with those developed under contract for a three-dimensional model (Tetra Tech., Inc.) to develop the management model described in Task 4.3.

Approach. The model produced in Task 4.1 should not be considered a final product, but rather the core from which we shall expand. Since it embodies what we consider the more important lower trophic levels, it can become the focal point for more detailed submodels. These submodels, while developed apart from the full ecological model and based on more detailed analyses performed both in-house and outside GLERL, will add further documentable realism to the model.

The model produced by Task 4.1 lacks some important aspects of the aquatic ecosystem. The incorporation of oxygen and silica cycling, blue green algae, and fish compartments will produce a more complete description of the system. These compartments and phenomena will be included as part of this task.

The effects of simultaneous limitation of phytoplankton growth by nutrients and light will be one area of investigation. The literature will be searched for applicable bioassay data and statistical methods will be used to evaluate possible models. Interaction with Task 5.1 will provide information necessary for describing individual limitation terms.

Sedimentation has been found critical to phytoplankton dynamics. The proposed dynamic simulation of settling effects in the model will be investigated. Many citations in the literature provide information regarding species-specific settling velocities. The proposed mechanism will be documented and verified using this information.

Products. The products of this task will include:

(1) Current documentation of the overall ecological model as well as the documented computer program.

(2) Presentation of model of scientific meetings.

(3) Publication of multiple-limitation submodel in technical journal.

(4) Publication of sedimentation submodel in technical journal.

Schedule.

Activity	Beginning Date	Completion Date
Develop and incorporate refinements as they occur (w/Task 4.3) (O_2, Si, Blue greens, fish).	December 1975	October 1976
Reduce computational costs and employ most efficient numerical methods.	December 1975	January 1976
Gather data and begin analysis of limitation data.	January 1976	April 1976
Prepare paper.	April 1976	April 1976
Gather data and begin analysis of sedimentation.	May 1976	August 1976
Prepare paper.	August 1976	August 1976

Evaluate present position of model with respect to state-of-the-art, identify and outline weak parts as areas for development.	September 1976	October 1976
Prepare report and assessment.	October 1976	October 1976
Prepare documentation.	November 1976	November 1976

Resources.

Staff (% of time):		CY 1976 (Quarters) 1	2	3	4
D. Scavia		40	40	45	45
B. J. Eadie		12.5	12.5	12.5	12.5
A. Robertson		12.5	12.5	12.5	12.5
Consultants:	Tarapchak, S. J.				
	Vanderploeg, H. A.				
	Chapra, S. C.				
Computer Hours		10.75	11.75	6	5

7.0 Project 5 Planktonic Succession

Project Scientist. A. Robertson

Objectives. The objectives of this project are as follows:

(1) To describe the process of succession in the plankton of the Great Lakes.

(2) To determine the mechanisms that control succession and the quantitative relationship of these mechanisms to that process.

(3) To develop an improved model of succession.

(4) To integrate the results from this study into the ecosystem model being developed under Project 4.

Background. The modeling of the ecology of the Great Lakes being conducted by ourselves (Task 4.1) and by others has so far been limited to including all the phytoplankton species under one or occasionally a couple of groupings. The same approach of combining a variety of species under one or a few headings is also being used for the zooplankton. It is already obvious, however, that modeling at such a gross level will not be able to simulate a number of the processes of immediate practical concern. For example, different types of algae vary greatly in their potential to clog water intakes and to cause taste and odor problems. Also, the different types of plankton vary greatly in their ability to serve as food to higher levels in the food chain. Thus, treating all types alike obscures many of the processes and allows simulation of only the least complex relationships. This project attempts to take a closer look at the control of the fluctuations of the different types of plankton through investigation of the succession of planktonic types in space and time and the mechanisms that control this process.

Interrelationships with Other Projects. As pointed out above, the results from this project will be used to improve the treatment of the planktonic components in the ecosystem models of Project 4. Also, the results from that project will be used to provide insight as to the studies that should be carried out as part of this one.

Approach. Two aspects seem to be of major significance in controlling phytoplankton succession, nutrient competition, and zooplankton grazing. Laboratory studies using selected Great Lakes species will be conducted to determine the rates of nutrient uptake under various conditions. These results will be generalized and the hypotheses developed tested in the field. This type of research will include radioactive tracer studies and autoradiographic techniques. Zooplankton grazing studies will be conducted using various foods to determine food selectivity under a variety of conditions. Again attempts will be made to generalize the results and test the hypotheses in the field. Besides contributing to an understanding of phytoplankton succession, the grazing experiments will increase our knowledge of the competition of zooplankters for food and how this affects their succession. Further studies will be conducted with zooplankton in an attempt to increase our knowledge of their population dynamics and the way in which this affects succession. This work will include investigation of reproductive and growth rates. In the long term, the results from these studies will be coordinated in an attempt to develop an improved model of the relationship between the phytoplankton and herbivorous zooplankton and of the succession within these two groups. The results from this project will be used to improve our handling of phytoplankton and zooplankton and the relationship of these two in the models of Project 4.

7.1 Task 5.1 Phytoplankton Nutrient Competition

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

Objectives. The objectives of this task are as follows:

(1) To investigate nutrient competition among phytoplankton populations in order to explain some of the more important aspects of seasonal succession in Great Lakes phytoplankton communities, especially in Lake Michigan.

(2) To investigate phytoplankton succession in conjunction with zooplankton grazing and selectivity in the Great Lakes (see Task 5.2).

Background. The factors that regulate seasonal succession of different species and groups of phytoplankton in the Great Lakes and in other bodies of water are poorly understood. The proposed research is designed to elucidate basic mechanisms underlying the general phenomenon of seasonal succession, especially those mechanisms operating in the formation and maintenance of phytoplankton blooms. We will place particular emphasis on Lake Michigan, where competition for phosphorus, carbon, nitrogen, and silica is undoubtedly a key factor in succession. This research is important for the following reasons:

(1) It will provide information on cause and effect relationships between species succession and the physical and chemical environment, and it will lead to a more precise understanding of nutrient competition and related interactions among phytoplankton populations. Portions of these data have application to lake management schemes, especially from the standpoint of predicting the effects of nutrient enrichment.

(2) It will result in the development of modified or new experimental methodology and information on the systematics of Great Lakes phytoplankton.

(3) It will provide improved mathematical expressions for phytoplankton-nutrient relationships for modeling purposes.

Interrelationships with Other Tasks. This task is integrally related to Task 4.4, Task 5.3, Task 10.2, and especially to Task 5.2. Field investigations on nutrient competition will be carried out in conjunction with studies on zooplankton grazing. The results will provide improved mathematical expressions for the ecological model of Task 4.4 and will also provide background data for Task 6.3.

Approach. The investigation is designed to assess and evaluate nutrient competition among phytoplankton populations by utilizing model systems in the laboratory and by conducting field studies. Field operations in 1976 will be carried out at weekly intervals during

June-October at one station in southern Lake Michigan. The principal objectives are:

(1) To determine if major changes in phytoplankton species composition are coupled with variations in the concentrations and uptake kinetics of inorganic carbon and dissolved phosphorus.

(2) To investigate species-specific assimilation rates of carbon and phosphorus by the application of autoradiographic techniques. Experimental and observational data from the field will be used to evaluate the hypothesis that phosphorus and carbon limitation lead to the development of green and ultimately to communities dominated by blue green algae. Seasonal variations in dissolved inorganic carbon, dissolved silica, nitrate, phosphorus concentrations, and primary productivity also will be used as background data in these interpretations. Autoradiographic analyses will be utilized to determine which species are more efficient in assimilating carbcn and phosphorus as concentrations of these nutrients fluctuate during the course of the growing season. Such isotope techniques provide direct measurements on nutrient assimilation under natural conditions.

Laboratory investigations, under controlled conditions of light and temperature, will be designed initially to evaluate phosphorus as a primary factor controlling species succession. Representative species from the Great Lakes will be used in experiments to determine a species' ability to compete for available pools of phosphorus. Once a data base is generated and growth kinetics are defined for representative species under standard conditions, the effects of light and temperature on the outcome of phytoplankton competition will be investigated.

Products. The results will be presented at scientific meetings and published in reports and appropriate journals. The schedule and sequence of products is tentative since the tasks involve development of techniques and require adequate technical assistance. Major products are as follows:

A. Field Studies

(1) The results of FY 76 studies evaluating patterns in species succession and their relationship to variations in nutrient concentrations and community uptake kinetics.

(2) The results of FY 76 analyses on species-specific conpetition for phosphorus and carbon under natural conditions.

(3) The results of syntheses between phytoplankton (Task 5.1) and zooplankton (Task 5.2) studies from FY 76 field studies.

B. Laboratory Studies

(1) The results of studies on phosphorus competition based on population growth kinetics.

(2) The results of studies on phosphorus competition based on population growth kinetics as affected by interactions of light and temperature.

(3) The results of experiments on competition for phosphorus and other nutrients based on short term nutrient uptake kinetics.

Schedule.

Activity	Beginning Date	Completion Date
Field Studies:		
Order equipment.		Complete
Set up laboratory.		Complete
Conduct preliminary field experiments, 1975.		Complete
Design field equipment, order supplies, and plan 1976 experiments.	November 1975	April 1976
Test and modify experimental and analytical methodology.	November 1975	May 1976
Conduct field experiments in Lake Michigan.	June 1976	October 1976
Analyze phytoplankton and nutrient samples, summarize and evaluate data.	June 1976	December 1977
Papers on methodology.	December 1976	December 1978
Papers on phytoplankton succession and species-specific assimilation rates of carbon and phosphorus.	June 1977	December 1978
Papers on synthesis of Tasks 5.1 and 5.2.	December 1977	December 1978
Laboratory Studies:		
Obtain cultures of algae and set up facilities.		Complete
Conduct experiments.	June 1976	December 1978
Papers on phosphorus limitation and growth kinetics.	December 1976	December 1977
Papers on phosphorus-carbon limitation and nutrient uptake kinetics.	October 1977	December 1978

Resources.

Staff (% of time):*	CY 1976 (Quarters) 1	2	3	4	CY 1977 (Quarters) 1	2	3	4
S. J. Tarapchak	75	75	75	75	75	75	75	75
H. A. Vanderploeg	20	20	20	20	25	25	25	25
Field Assistant		40	40	40				
Chemistry Lab Assistance	10	15	15	10				
Biology Technical Assistant (vice Arnold)	100	100	100	100	100	100	100	100
Marine Instrumentation Laboratory	3-4 man-days during CY 1976, Quarters 1 and 2							
Consultants: Robertson, A.; Eadie, B. J.; Scavia, D.								
Computer Hours			.25	.25	.50	.50	.50	.50
SHENEHON**	June thru October							

*Minimum manpower needs to accomplish objectives of field and laboratory programs, November 1975-November 1976.
** Weekly experiments with Task 5.2.

Major Equipment and Supply Needs:

		Cost
Field Items:	Deck-top incubator (see Task 5.2) equipped for phytoplankton incubation, and primary production and isotope equipment/supplies.	.6k
	Service contract for isotope removal.	.5k
	On-board light incubator cabinet.	.3k
	General supplies.	.5k
Laboratory Items:	Three shake tables.	1.5k
	Photographic adapter attachment.	.6k
	Percival incubation cabinet.	1.5k
	General supplies.	1.0k

7.2 Task 5.2 Zooplankton Grazing

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

Objectives. Our overall purpose is to develop an adequate general expression for food selection by individual zooplankton species and to determine the effect of grazing by the entire zooplankton assemblage on summer succession of phytoplankton species in Lake Michigan.

Background. Predicting the seasonal succession of phytoplankton and zooplankton is one of the most important theoretical and applied problems in biological limnology. Requisite for solving this problem is an adequate dynamic expression of zooplankton grazing.

Some data are available on filtering and ingestion rates of Great Lakes zooplankton as a function of different concentrations of phytoplankton. However; these results are based on feeding rates determined on monospecific cultures of phytoplankton in the laboratory and are not directly applicable to understanding grazing in the Great Lakes. Both marine and fresh water experiments have shown that the response of the feeding rate to the concentration of mixed species of phytoplankton is very different from that of a monospecific culture. Both the magnitude and functional form of the response may be very different. In addition to the uncertainty of the feeding rate-concentration response, we can only guess what phytoplankton are being selectively grazed in the Great Lakes. Further, a general expression for food selection is poorly developed.

Interrelationships with Other Tasks. The general feeding expression or a modified version of it will be incorporated into the ecological model of Task 4.4. The specific parameters derived from laboratory and field studies also will be included in the model. The zooplankton grazing rates on different sizes and species of phytoplankton when combined with the species-specific growth rates of phytoplankton derived from Task 5.1 will explain most of the more important functional aspects of the successional pattern of phytoplankton in Lake Michigan.

Approach. The objectives of this task require examination of the grazing phenomenon at two levels of complexity. The effect of the entire zooplankton assemblage on phytoplankton mortality will be directly measured *in situ* at an offshore station in Lake Michigan at weekly intervals throughout the summer and early fall. To do this, we are developing a method similar to that of Gliwicz (1968) to observe grazing rates in large *in situ* plexiglass chambers. We are attempting to develop an improved radioisotopic method which will allow us to determine unbiased grazing rates of dominant zooplankton species. The general expression for food selection (grazing rates on individual food items available in an assemblage) will be derived from laboratory experiments where combinations of concentrations, sizes, and palatabilities of algae will be offered to a single species of *Diaptomus*.

Products.

(1) Papers on methodology for measuring zooplankton grazing in the field.

(2) Papers reporting grazing rates of entire zooplankton assemblage on different sizes and species of phytoplankton.

(3) Paper(s) reporting grazing rates of individual zooplankton species.

(4) Paper(s) on seasonal succession of phytoplankton - synthesis of Tasks 5.1 and 5.2.

(5) Papers on selective grazing observed in laboratory.

Schedule.

Activity	Beginning Date	Completion Date
Order basic equipment.		Complete
Set up basic laboratory.		Complete
Work out field methods.	March 1975	May 1976
Conduct field experiments.	June 1976	December 1977
Conduct laboratory experiments.	December 1975	December 1977
Papers on methodology.	May 1976	December 1976
First paper on grazing of entire zooplankton assemblage.	December 1976	June 1977
First paper on grazing rates of individual zooplankton species in the field.	December 1976	June 1977
First papers on selective grazing observed in laboratory.	June 1977	June 1978
Paper on seasonal succession of phytoplankton - synthesis of Tasks 5.1 and 5.2.	December 1977	December 1978

Resources.

Staff (% of time):	CY 76 (Quarters)				CY 77 (Quarters)			
H. A. Vanderploeg	80	80	80	80	75	75	75	75
S. J. Tarapchak	25	25	25	25	25	25	25	25
T. F. Nalepa	33	33	33	33	33	33	33	33
P. A. Szymusiak (or replacement)	33	33	33	33	33	33	33	33
Biological Technician (vice Rheaume)	100	100	100	100	100	100	100	100
Computer Programmer	5	5	5	5	5	5	5	5
MIL	10	10	10	10	10	10	10	10
Consultants: Robertson, A. Eadie, B. J. Scavia, D.								
Computer Hours	.10	.10	.10	.10	.20	.20	.20	.20

Major Equipment Needs.

Item	Cost
Large deck-top incubator.	$2,000.
Four in situ grazing chambers.	$2,200.
Miscellaneous equipment.	$2,900.
Service contract for multi-channel Coulter Counter.	$1,000.
Lab and field supplies.	$4,000.

Time requirements for *R/V Shenehon*. In spring 1976, two two-day shakedown cruises on Lake Erie and two two-day shakedown cruises on Lake Michigan. During June 1976-October 1976, one two-day cruise per week. During fall 1976 and spring 1977, two-day cruises at biweekly intervals.

Literature Cited.

Gliwicz, Z. M., 1968. The use of anaesthetizing substance in studies on the food habits of zooplankton communities. Ekologia Polska - Seria A16: 279-295.

7.3 Task 5.3 Culturing of Great Lakes Zooplanktonic Crustaceans

Task Scientist. A. Robertson

Objectives. The objective of this task is to develop methods for continuous culturing in the laboratory of several of the more important species of crustacean zooplankton in the Great Lakes.

Background. In order to study species of Great Lakes zooplanktonic crustaceans (primarily cladocerans and copepods) under controlled laboratory conditions, populations of these forms must be maintained in a healthy condition in laboratory cultures. At present, this is possible for only a few forms, mostly cladocerans. The present task has been set up in an attempt to remedy this situation, especially for copepods. If successful, it will allow the grazing experiments in Task 5.2 to be carried out with a more representative assemblage of species than is now possible. The ability to maintain cultures of those forms in the laboratory will also allow studies that will provide improved coefficients for the ecosystem modeling in Project 4.

Interrelationships with Other Tasks. The ability to culture Great Lakes zooplankters will allow these forms to be used for experimentation as outlined in Tasks 5.2 and 5.4.

Approach. Initially, the attempts to culture Great Lakes crustaceans will concentrate on the calanoid copepods. These forms are very important in the ecosystems of the upper lakes and, at present, cannot be cultured. The approach used by Robertson et al. (1974), who have developed culturing methods for certain fresh water calanoids, will be followed. This involves sets of identical copepod populations in which each member of the set is exposed to a different level of a single environmental factor with all other conditions being constant. The best level of each factor is judged from these experiments, and these are combined to give the most likely conditions for culturing success. This combination is then tested and modifications developed, if necessary.

Products.

(1) The main product of this task will be the ability to obtain healthy animals at will for further experimentation.

(2) A short paper describing the culturing techniques.

Schedule.

Activity	Beginning Date	Completion Date
Order equipment.		Complete
Set up equipment and break in.		Complete
Culture *Diaptomus siciloides*.		Complete
Culture *Diaptomus oregonensis*.	August 1975	August 1976

Culture Cyclops vernalis.		Complete
Culture Cyclops bicuspidatus.		Complete
Document results and write paper.	July 1976	December 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
A. Robertson	5	5	15	15
T. F. Nalepa	8	8	8	8
P. A. Szymusiak	8	8	8	8

Literature Cited.

Robertson, A., C. W. Gehrs, B. D. Hardin, and G. W. Hunt, 1974, "Culturing and Ecology of Diaptomus clavipes and Cyclops vernalis," EPA, *Ecological Research Service*, EPA-669/3-74-006, 226 pp.

7.4 Task 5.4 Feeding of a Cyclopoid Copepod

Task Scientist. A. Robertson and T. F. Nalepa

Objectives. The objective of this task is to determine the feeding rate of *Cyclops vernalis* on prey of various sizes.

Background. One component of the ecological model being developed under Project 4 is predacious zooplankton. In the Great Lakes, this component is probably predominantly represented by the cyclopoid copepods, although predacious cladocerans are undoubtedly important at times. When this component was being added to the model, it was found that very little information was available on the feeding rate for these animals and on the factors affecting this rate. This task attempts to obtain such information for one of the important Great Lakes cyclopoids.

Interrelationships with Other Tasks. As explained above, this task is very closely related to Project 4 and specifically to Tasks 4.1 and 4.4. It also studies zooplankton feeding as does Task 5.2.

Approach. Known numbers of prey will be added to a container containing one adult cyclopoid. After a specified period of time, the prey that remain will be counted. Appropriate controls will be included. This procedure will be carried out for prey of several sizes and the density of prey will be varied at each size level. Estimates of the weight of the various sizes of prey will be made and the hypothesis that the animals have a maximum amount of food intake after which they stop feeding will be checked.

Products.

(1) A scientific talk presenting the results of this study.

(2) A paper describing the results of this study.

Schedule.

Activity	Beginning Date	Completion Date
Conduct preliminary experiments to shake down methods.		Complete
Study feeding on small cyclopoid nauplii.	August 1975	March 1976
Study feeding on large cyclopoid nauplii.	September 1975	June 1976
Study feeding on cyclopoid copepodites.	October 1975	August 1976
Write paper.	August 1976	December 1976
Make presentation.	April 1976	April 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
A. Robertson	10	10	10	10
T. F. Nalepa	25	25	25	25
P. A. Szymusiak	25	25	25	25

8.0 Project 6 Natural Distribution and Variability of Lake Properties

Project Scientist. A. Robertson

Objectives. The objectives of this project are as follows:

(1) To increase our understanding of the distribution in space and time of selected limnological variables in the Great Lakes.

(2) To summarize the distributions of the variables in certain lakes or even in the entire Great Lakes system.

(3) To relate the distributions observed to other factors in an attempt to determine causative relations.

(4) To develop guidelines for the amount and location of sampling needed to monitor long term trends in the Great Lakes.

Background. Great amounts of data have been collected from the Great Lakes specifying the levels of certain properties at specific places and times. Many of the data sets have not been analyzed at all, while others have only been analyzed in a cursory fashion. More detailed examination of the data for individual properties would undoubtedly increase our knowledge of the lakes by revealing spatial and temporal patterns in the distribution of these properties. It would also aid the design of a monitoring system to detect long term trends in the Great Lakes. A better knowledge of the scales of variability of important limnological parameters would provide a better basis for this design by helping identify where, when, and how often to monitor conditions in order to obtain a representative view of the trend of conditions in each lake.

Interrelationships with Other Projects. This project will provide information on the natural distribution and variability of a number of the parameters modeled in Project 4. Thus, the results from this study will aid in conceptualization and verification in that project.

Approach. Data sets from IFYGL and/or other sources will be analyzed with statistical methods to determine whether significant patterns are discernible. For certain parameters, atlas-type presentations of distribution in space and time will be constructed. Correlation and regression techniques will be used in an attempt to relate the distributional patterns observed to the distribution of other factors. Certain of the relationships found during the studies in this project will be quantitized and used to improve the models being developed in Project 4. The parameters to be studied in this way will be determined, in part, by the needs of the modeling effort. The patterns and variability observed in these studies will be used to form the basis for planning a continuous monitoring system to detect trends in water quality in the Great Lakes.

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

Task Scientist. A. P. Pinsak

Objectives. A systematic field investigation will be undertaken in which vertical and lateral distribution as well as variations with respect to time of the chemical and physical properties of water in the St. Clair and Detroit Rivers and Lake St. Clair and of their immediate environment will be measured and analyzed. The program will define temporal-spatial relationships of significant characteristics and their relation to the immediate environment. This type of systematic analysis is essential in forecasting water quality and estimating nature and magnitude of past events as an aid in optimum management of the lakes for multiple competing uses. The project was designed to complement existing data and continuing programs in this connecting waterway between Lakes Huron and Erie.

Background. As part of the 1972 International Great Lakes Water Quality Agreement between the United States and Canada, a reference was made to the IJC to study the pollution problems of Lakes Superior and Huron, especially as they relate to the boundary waters, and to make recommendations based on the findings. Discharge through the St. Clair River represents the product in a mass balance of the system. As a contribution to that study, discharge from those lakes through the waterway into the lower lakes will be assessed and a report will be submitted to EPA for inclusion in the recommendations to IJC.

Interrelationships with Other Tasks. This task relates to Project 1 objectives, can incorporate principles from Task 6.3, will provide data for Tasks 7.2, 9.2, and 10.2, will use output from Task 7.4, and will provide input to Project 10. Tested techniques can be applied to Project 12.

Approach. Measurement of temporal-spatial variations will be made at a series of predetermined reference stations which are occupied during each cruise to monitor characteristics of the water and its immediate environment. Each station then forms a datum that can be used to measure magnitude and rate of change. Through these time-rate determinations, any station can reasonably be correlated with any other.

Channels in the two rivers and in the St. Clair Delta will be sampled at those locations where the standard hydraulic sections have been established in order to develop volume estimates of dissolved and solid constituents.

The *R/V Shenehon*, supported by a 21-foot launch to sample in the shallow water that is encountered in Lake St. Clair and peripheral channel sections, will be used in the field program. Time-critical chemical and physical measurements of the water and sediment will be made aboard the boat and samples will be sent to the LSC laboratory in Detroit for further analysis. In addition to the basic geochemical composition and temperature and transparency of the water column, pH, specific conductance, Eh, dissolved oxygen, chloride, COD, phosphate, nitrate, sulphate, silica, total organic carbon, volume of organic and inorganic suspended material, and coliform bacteria will be determined. Standard meteorologic parameters that can be related to mass movement will be continually monitored with an onboard automatic recording system.

Data will be programmed for computer analysis and temporal-spatial relationships will be established and related to volume transport. Weighted composition of river water at hydraulic sections will be combined with flow estimates to determine loadings and their variations. Statistical analyses will be used to establish principal components and interrelationships and significance of all constituents in time and space. Isopleth maps, graphs, and curves will display natural distribution and variability.

Coordination will be effected with EPA and the Michigan Department of Natural Resources.

Products.

(1) A report on physical and chemical characteristics of flow and chemical loadings through the St. Clair and Detroit Rivers will be prepared for the Upper Lakes Reference Group. These results will also be provided to the IJC and to the Corps of Engineers Lake Erie Wastewater Management Study.

(2) Project results will be used as input to the study of the natural distribution and variability of the Great Lakes. Natural distribution and variability of properties of Lake St. Clair, a most heavily stressed lake, will be documented and related to the Great Lakes system.

(3) A report will be prepared for publication.

Schedule.

Activity	Beginning Date	Completion Date
Conduct field operations, data collection.		Complete
Conduct laboratory analyses.		Complete
Conduct data reduction and analysis.	June 1974	January 1976
Report on river loading.	June 1975	February 1976
Analyze and report on natural distribution and variability of river and lake properties.	January 1976	June 1977

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4	CY 1977 (Quarters) 1	2	3	4
A. P. Pinsak	10	10			20	10		
D. A. Dossett	100	100	100	100	100	100		
G. L. Bell	10	10						
B. D. Landay (PT)	50	50						
Physical Science Technician			40	50				
Computer Services	5	5						
Computer Hours	1	.5		1				

8.2 Task 6.2 Analysis of Lake Ontario Oxygen Profiles

Task Scientist. B. J. Eadie

Objectives.

(1) To improve our understanding of the natural distribution and variability of O_2 in Lake Ontario.

(2) To evaluate the extent of O_2 depletion and its relation to biological productivity.

(3) To evaluate any long term trends in hypolimnion O_2 depletion.

Background. Oxygen has been defined as the best single parameter to identify the state of a water body (Huchinson 1957). It is the by-product of photosynthesis required to drive the remainder of the biosphere.

Considerable effort has gone into analysis of O_2 in the Great Lakes, the most comprehensive and recent being Lee's (1972) analyses of 1960-69 Lake Ontario data. Dobson (1967) approached O_2 in a more quantitative manner but did not have the quantity of data that was collected during IFYGL. Nelson Thomas (EPA) has done some analysis of this data and we are in touch with his work.

Interrelationships with Other Tasks. This task will develop excellent verification data for the modeling effort, Task 4.4. It will also, hopefully, develop improved techniques for handling the modeling of O_2. This task will also provide information into the chemical dynamics task (6.3) through better approximations of gaseous exchange and in situ oxidation of organic matter.

Approach. An in situ O_2 probe was used aboard the *Researcher* during IFYGL. The resulting data will be analyzed with regard to temporal and spatial variations. Some of the software required was developed during analysis of the carbon budget.

Data will be edited, contoured, and analyzed through multivariant techniques with respect to chlorophyll, nutrients, temperature and trace metals. The rates of oxidation in the east and west basins of Lake Ontario will be compared. Results will be compared to CCIW's IFYGL O_2 data as well as other O_2 data in our data base.

Products. A paper describing the distribution of O_2 in the lake and the extent of O_2 depletion as well as the deduction of in situ oxidation rates.

Schedule.

Activity	Beginning Date	Completion Date
Inventory data.		Complete
Develop conversion and correction factors.		Complete
Edit data.		Complete
Analysis of spatial distribution.	November 1975	December 1975
Analysis of temporal distribution.	November 1975	January 1976
Analysis of O_2 depletion.	January 1976	February 1976
Analysis of *in situ* oxidation rate.	January 1976	February 1976
Analysis of air/water exchange rate.	February 1976	March 1976
Report/Paper.	March 1976	April 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. D. Boyd	90	25		
B. J. Eadie	10	20		
A. Robertson	5			
Computer Assistant	5	5		
Consultants: Tarapchak, S. J.; Chambers, R. L.				
Computer Hours	6	1.5		

8.3 Task 6.3 Chemical Dynamics

Task Scientist. B. J. Eadie

Objectives.

(1) To increase our understanding of the movement of carbon and the nutrients within the ecosystem for the purpose of developing the improved functional relationships necessary for modeling.

(2) To determine the time scales required to characterize various components of the lake's chemistry over the range of minutes to days.

(3) To attempt to evaluate the importance of the upper skin (micrometers to 1 meter) on the bulk chemistry of the epilimnion.

(4) To integrate the chemical dynamics program with the plankton dynamics of Project 5.

Background. The important time and space relationships involved in the representative collection of chemical data are completely lacking. Only in the Lake Erie Time Study (LETS) Project (1969) were data collected at a frequency which allowed analysis of signficant time variations. The location (Western Lake Erie) of that study relates poorly to the rest of the Great Lakes.

In this task we also will look at lake scale exchange of CO_2 and $CaCO_3$ dynamics.

Interrelationship with Other Tasks. The results of this effort will be of use to both the modeling effort (Task 4.4) and the biological programs in Project 5.

Approach. CO_2 gas exchange data collected during IFYGL and any other Great Lakes data sets will be analyzed by techniques developed under the carbon budget program. All of the theoretical approaches to gas transfer will be evaluated. Some experimental work will be done.

$CaCO_3$ precipitation - resolution dynamics: as above, all pertinent data will be analyzed. In addition, satellite imagery will be employed through Al Strong (NESS). A $CaCO_3$ saturometer has been developed with the MIL to measure in situ concentrations.

The following techniques will be developed for laboratory and field usage:

(1) Auto Analyzer
- Ortho P
- Total P
- Kjeldahl N
- SiO_2

(2) Specific ion probes
    NO_3
    PCO_2
    Conductivity
    O_2
    Temp
    pH

(3) Fluorometer
    Chlorophyll A

(4) $CaCO_3$ saturometer

(5) Gas Chromatograph
    O_2
    CO_2
    CO
    N
    Ar

(6) Carbon Analyzer
    Particulate organic carbon
    Particulate inorganic carbon

Items 1-4 and probably 5 will be under development this winter and will be aboard ship at the beginning of the 1976 field season. Data acquisition depends on a data logging system under development by H. K. Soo.

The auto analyzer, probe and gas chromotograph techniques discussed above will be used aboard ship. Samples will be pumped into the auto analyzer and fluorometer for high frequency measurements (minutes) and the probe string will be monitored in the same time frame. Discrete gas chromatography samples will be taken.

Data collection will be concentrated in the upper 1 meter with less emphasis on the remainder of the epilimnion.

Special screen samplers will be developed to collect samples from the upper 1 centimeter.

Data will be analyzed in the following fashion:

(1) The quality of data is to be evaluated both in-house and possibly with other laboratories.

(2) The data collected aboard ship will be analyzed by power spectrum techniques to determine the important frequencies in the range of minutes to days.

(3) Variability of nearshore and offshore data will be compared to determine feasibility and value of nearshore studies.

(4) Concentrated effort will be made to analyze all components of phosphorus due to its importance in the lake.

(5) Multivariant analysis will be applied to determine the effect of temperature, chlorophyll and other master variables on the system.

(6) $CaCO_3$ kinetics as a function of temperature will be evaluated as well as the importance of $CaCO_3$ on transparency and nutrient precipitation.

(7) Direct analysis of dissolved gases will give a more precise picture of biological dynamics (i.e., CO_2/Ar, N_2/Ar, O_2/Ar) where Ar assumed to be biologically unperturbed.

Products.

(1) Paper on $CaCO_3$ system in conjunction with Al Strong (NESS).

(2) Paper on saturometer information and analysis with Stoermer and Goad (UM) using Scanning Electron Microscopy and X-Ray spectroscopy to physically identify the $CaCO_3$ forms.

(3) ERP report on Saturometer design and operation with R. Kistler (MIL).

(4) ERL report on instrument array with MIL.

(5) Paper on results of high frequency study.

Schedule.

Activity	Beginning Date	Completion Date
Collect available data.	August 1975	
Edit and analyze above.	October 1975	
Develop saturometer and techniques.	January 1975	January 1976
Develop lab techniques.	December 1975	May 1976
Develop instrument array.	December 1975	May 1976
Paper on $CaCO_3$ system.		
ERL report on saturometer.	January 1976	June 1976
ERL report on instrument array.	June 1976	December 1976
Field data collection.	May 1976	November 1976
Data editing.	May 1976	December 1976
Data analysis.	June 1976	April 1977
Paper on saturometer data and X-Ray results.	April 1977	May 1977
Paper on high frequency data.	May 1977	July 1977

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
B. J. Eadie	60	60	75	75
J. M. Malczyk	95	90	90	95
A. L. Langston	95	95	95	95
J. P. Manor	25	40	40	
J. D. Boyd	10	10	10	10
Shipboard Technician	50	50	25	25
Computer Assistant	20	20	10	10
Marine Instrumentation Laboratory	Instrument Design & Development; Software Developing			
Computer Hours	2.5	2.5	2.5	2.5

8.4 Task 6.4 IFYGL Chemical Intercomparison

Task Scientist. A. Robertson

This task is complete. A final report is on file.

8.5 Task 6.5 Characteristics of Oswego River Plume

Task Scientist. G. L. Bell

Objectives. The objective is to define the chemical and physical characteristics of the Oswego River discharge in the harbor and the area of mixing in the adjacent portion of Lake Ontario on a time-spatial basis, to determine the effects of the water and sediment influx on the adjacent lake, to estimate the time for water-borne effects to be dissipated, to describe the areal distribution under varying conditions, and to relate distribution to causative forces.

Background. The Oswego is one of the four major tributaries discharging into Lake Ontario. Knowledge of the loadings, chemical and physical characteristics, and areal extent of the Oswego River water mixing zone is required to understand the impact of this water-mass on Lake Ontario. Flow during the 1972 water year was 4.7 percent of that of the Niagara. There were insufficient data available for the period prior to 1972 on which a study could be based. This work also provides detailed input into determinations of a mass balance of Lake Ontario and to advection estimates for an energy budget. The EPA stream sampling provides upstream loading data, and the majority of the other IFYGL studies were oriented toward lake scale monitoring rather than to the impact on the nearshore environment. C. R. Murthy had studied the Niagara River plume using a dye tracer in 1968. However, no extensive studies had been conducted on Great Lakes river plumes. The Oswego study was designed to complement the other programs.

Interrelationships with Other Tasks. This task is closely related to Task 1.7 (Current Study-Oswego Harbor) and is dependent upon data from IFYGL Task 7 (Materials Balance Studies - EPA). Results will provide input to Task 1.9 (Nearshore Circulation Model), Task 3.1 (Heat Storage in Lake Ontario), Task 3.2 (Thermal Characteristics of Lake Ontario), Task 3.3 (Advective Heat Exchange), Task 3.4 (Energy Budget Analysis), Task 10.2 (Phosphorus Model), and Task 10.5 (Atlas of Lake Ontario Physical Properties).

Approach. A sampling program was designed to systematically define the physical and chemical characteristics of the water and bottom sediment at the river mouth, in the harbor and in the area of mixing in the adjacent portion of the lake. An established station grid was occupied during each cruise so that the time-spatial relationships could be defined and thus provide a better understanding of the interrelationships with the total environment and the reasons for the variations. Sampling was conducted aboard the *R/V Shenehon* and 46 stations were occupied during 33 cruises in five periods between 1 May and 10 November 1972. Water from one to three levels was analyzed for PO_4, NO_3, SO_4, SiO_2, Ca, Na, Mg, K, Cl, pH, Eh, alkalinity, dissolved oxygen, specific conductance, suspended sediments, and total coliform.

Bathythermograph and transparency profiles, secchi disc, wave and meteorological observations were recorded. Bottom sediment samples were taken during four periods and analyzed for pH, Eh, percent solid and volatile material, oil and grease, and chemical oxygen demand. The physical, chemical, and flow data of the river, as well as temperature and volume input from the power plant and harbor current data from Task 1.7, will be integrated. Available data on diffusion patterns from overflights during the periods of investigation will also be utilized.

Products.

(1) Data file on magnetic tape for IFYGL Archive.

(2) Data file on magnetic tape for GLERL Archive, Boulder, Colorado.

(3) Hard copy with individual sample values, means weighted for depth variations, standard deviation and coefficient of variation for each station.

(4) Report "Diffusion at Oswego Harbor, N.Y." presented at 17th IAGLR Conference.

(5) GLERL Technical Report will include analysis of parameters, data summaries, cross-sections and contour maps showing selected parameters treated statistically and distribution related to causative forces.

Schedule.

Activity	Beginning Date	Completion Date
Field operations - data collection.		Complete
Laboratory analysis.		Complete
Data reduction, including programs for computer reduction and a program to compute percentage of river water present in each sample.		Complete
Data files on magnetic tape.		Complete
Paper presented at Seventeenth IAGLR Conference (8/74).		Complete
Description and analysis of chemical-physical properties, loading, mean distribution, mixing and relation to causative factors.	December 1974	January 1976
Final drafting and GLERL Technical Report.		February 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
G. L. Bell	66			
A. P. Pinsak	8			
B. D. Landay	17			
Computer Services, one man	5			
Computer Hours	.1			

8.6 Task 6.6 Chemical-Physical Variability in Southern Lake Michigan

Task Scientist. G. L. Bell and R. L. Chambers

Objective. To describe the broad aspects of the spatial and temporal variability of selected chemical-physical parameters in the nearshore environment at sites chosen to reflect a wide range of conditions, to compare the nearshore and open lake environment, and to establish gradients through the nearshore environment.

Results are expected to provide information useful in developing insights into the nearshore variability and to provide a basis for the design of new studies in this as well as other Great Lakes. The results could be used to identify the existence of, locating and describing plumes, thermocline development and decay, prominent areas of upwelling and downwelling, thermal bar and nearshore jets. The data generated will provide useful information relating to coastal zone management and the relative roles of inshore and open lake in the total system.

Background. Southern Lake Michigan is subject to a wide range of stresses imposed by municipal, industrial, and agricultural input as well as natural input from streams. An understanding of the variations within the nearshore area is essential to development and utilization of this resource.

Although a number of significant studies have been conducted in Lake Michigan by the Universities of Michigan, Wisconsin, and Illinois, Argonne National Laboratory, U. S. Department of Interior and U. S. Corps of Engineers, the majority of these have been generally limited to the open lake or to a specific area or problem, and were not designed to study the variability of different segments of the nearshore area and compare the areas with each other and the open lake. Changes in the nearshore on opposite sides of the lake during periods of upwelling and downwelling, are largely unknown or not well documented.

Interrelationships with Other Tasks: This task is closely related to Tasks 5.1, 5.2, 6.3, and 6.7, and will provide input to all projects with the possible exception of Project 8.

Approach. The program is designed to systematically study and define the nearshore variability of selected parameters, to relate observed variations and concentration to those within the open lake, and where possible to evaluate in terms of previous investigations. Sites selected are believed to represent the range of nearshore conditions expected in the southern half of the lake.

Surveys of two days each were conducted at Manitowoc, Port Washington, and Kenosha, Wisconsin; Michigan City, Indiana; St. Joseph, Grand Haven and Little Sable Point, Michigan. There were a total of 9 surveys at Michigan City, eleven at Port Washington and ten at the other ports. Five regional lake cruises were conducted at 37 stations (Figure 3) to connect the seven sites so that the characteristics of each area can be related. The lake station network includes stations at or in the vicinity of earlier surveys.

Two types of surveys were conducted. Samples were taken the first day at a given site and along all lake traverses at standard depths for analysis aboard the *R/V Shenehon* and at the GLERL Ann Arbor Laboratory. Samples collected at standard depths during the second day at a given site were for analysis aboard ship. In nearshore areas, specific conductance measurements were made every 6 minutes on near-surface samples collected at 1.5 m from the ship's intake system while underway along traverses from Manitowoc to Port Washington, St. Joseph to Grand Haven and Grand Haven to Pentwater.

Shipboard measurements were made for pH, Eh, specific conductance, alkalinity, dissolved oxygen, water temperature using reversing thermometers and EBT, transparency profiles using a transmissometer, secchi disc, suspended sediment and total coliform. Samples were analyzed in the Ann Arbor Laboratory for NO_3, PO_4, SiO_4, and Cl as received from the field. Analysis for Ca, Mg, Na, K and 2 cruises for total organic carbon will be made after the analyses above are completed. Suspended materials input were determined by filtering 1 to 2 liters of water at standard depths from the mouth of selected rivers and harbors. All Ann Arbor Laobratory samples were filtered and the amount of suspended materials determined.

Selections from the measured parameters will be made which will best serve as natural tracers and characterize a given area. These parameters vary from area to area.

Products.

(1) Lake Michigan data disc file.

(2) Hard copy data set for each parameter and station including means weighted for depth variations, standard deviation and coefficient of variation, R-mode and cluster analysis.

(3) Contour maps, cross-sections and tables developed for each of the seven sampling areas and for the open lake traverses showing means, standard deviation and coefficients of variation of the chemical and physical parameters with respect to areal distribution, depth and gradients from point sources along shore and from the nearshore environment into the open lake.

(4) R-mode principal components for each time period and depths to look for significant differences in the chemical interrelationships. This will aid in reducing a large data set to a more easily manageable set.

(5) Factor or cluster analysis in the Q-mode using the parameters determined from the principal component analysis to establish "chemical cells" within the nearshore and offshore areas.

(6) Discriminant function analysis will be used to test for significant differences between the "near" and "offshore" waters. The variables used in this analysis will be determined from principal components.

(7) Paper-IAGLR Conference (5/76).

(8) GLERL Technical Report describing the spatial and temporal variability of selected chemical-physical parameters in the nearshore environment as compared to the open lake environment and, where possible, to relate the variations to causative forces.

Schedule.

Activity	Beginning Date	Completion Date
Field operations - data collection (May to November 1975).		Complete
Laboratory analyses.	May 1975	March 1976
Data reduction.	June 1975	June 1976
Application of statistical programs.	January 1976	December 1976
Description and analysis of chemical-physical properties, construction of contour maps, cross-sections and tables.	December 1975	January 1977
Paper-IAGLR Conference.	December 1975	May 1976
GLERL Technical Report.		January 1977

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4	CY 1977 (Quarters) 1	2	3	4
G. L. Bell	30	66	66	100	30			
R. L. Chambers	10	15	25	25	20			
W. R. Lee	100	50	50	50	30			
J. M. Malczyk	30							
A. L. Langston	30							
J. P. Manor	5	5	5	5				
A. W. Hodson	50	30	20	20	10			
Consultants: J. L. Grumblatt								
B. C. Doughty								
Computer Hours	.3	.3	.4	.4	.5			

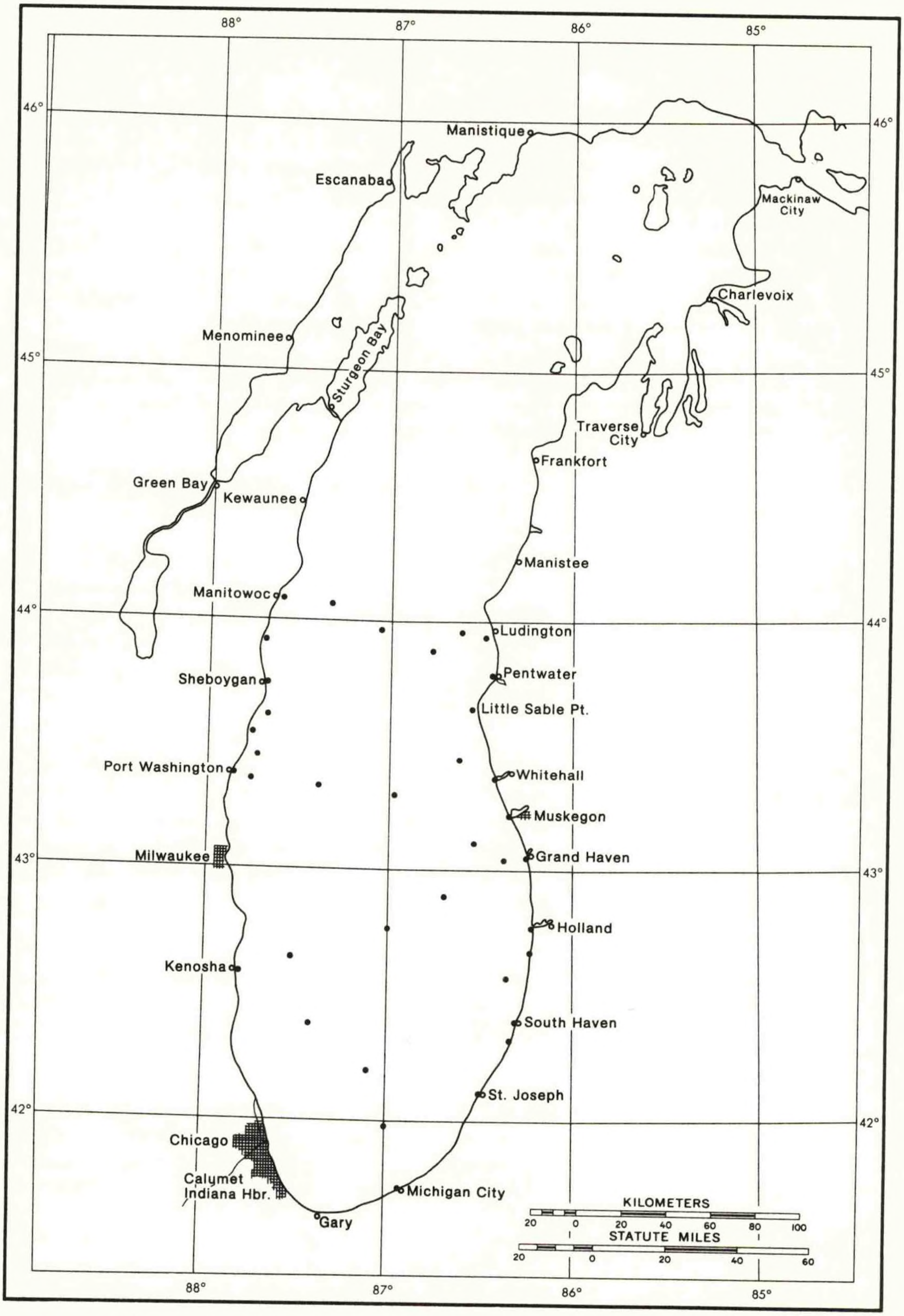

Figure 3. Stations along Lake Michigan traverses.

8.7 Task 6.7 Interstitial Water and Sediment Chemistry: Southern Lake Michigan

Task Scientist. R. L. Chambers

Objectives. A continuation of the FY 75 task with major emphasis placed on the surface "microzone" floc.

(1) To improve our understanding of the chemical relationships between the phosphorus species, Fe, Mn, organic carbon and nitrogen in order to determine the mechanism and magnitude of P release at the sediment-water interface.

(2) To determine the forms of phosphorus in the total suspended solids introduced into the study area (mainly from the Grand River) partitioned with respect to grain-size.

(3) To determine the forms of phosphorus associated with resuspended material, again partitioned with respect to grain-size.

Background. The degree to which sediments release dissolved inorganic P to the overlying water column is of major concern in attempts to retard or reverse lake eutrophication. Since phosphorus is also an element of major importance to the growth of aquatic organisms, it is essential to have accurate measurements of the cycling of this element at the sediment-water interface.

Although there is considerable information on the phosphorus content in the Great Lakes sediments, the nature and mobility of sediment P in the Great Lakes has received little attention. Kramer (1974) and Bannerman et al. (1975) performed laboratory experiments on the cycling of phosphorus in Lake Ontario sediments; however, to my knowledge little or no work has been conducted on in situ measurements of the "microzone" floc occurring at the sediment-water interface. This research is important for the following reasons:

(1) It will improve our understanding of the mechanisms responsible for the release of P from the sediment and provide information of the magnitude of P released under normal sedimentation and resuspension events.

(2) It will provide some of the first information of the relationship between phosphorus and specific grain-size fraction in suspended and bottom sediment, providing an evaluation of the dispersion of phosphorus from a river mouth into the nearshore environment.

Interrelationships with Other Tasks. This task will provide input into Tasks 5.1, 6.8, and 10.2. The results will also provide improved mathematical terms for the modeling efforts of Tasks 4.1 and 6.3. This study will also supplement the Rivers Impact Contract supported by EPA to begin in mid-March 1976.

Approach. Iron and probably manganese and organic carbon control to a great extent the release of phosphorus into the water column, therefore this task has been modified to determine the chemical relationships between these elements within the flocculent "microzone" occurring at the sediment-water interface. This "microzone" was observed in the summer of 1975 at depths greater than 12 meters.

Field operations in 1976 will be carried out at monthly intervals from May-November at 9 stations near the mouth of the Grand River, Michigan. The first task will be the emplacement of buoyed stations in May and setting up suspended solids collecting vessels at one meter above the bottom and 5 meters below the surface at each station. The upper vessel will collect mainly total suspended solids, while the lower vessel will collect resuspended and suspended material. The stations will be placed to monitor the river plume as well as the near open-lake conditions. Sediment-water interface samples will be collected at stations ranging in depth from 12 meters to 30 meters using SCUBA to avoid sample disturbance. Eh of the "microzone" floc will be measured *in situ* using a battery powered portable probe. Parameters to be measured in the field are pH, DO, temperature, ortho P, and alkalinity. Pore water from the surface floc will be removed in the field with a pore water extractor in an N_2 purged system. All samples will be stored at 4°C until further analyses are possible at the GLERL chemistry laboratory.

Parameters to be measured at the GLERL chemistry laboratory include:

(1) organic carbon (Dohrman carbon analyzer)

(2) total P, after acid extractions (auto analyzer or Spec 88)

(3) total and dissolved Fe, Mn (automic absorption)

(4) grain-size (settling tube and Coulter Counter)

(5) organic nitrogen (auto analyzer)

Partitioning of the "microzone" floc will be done as follows:

(1) filter floc through a set of nested nylon mesh screens of sizes 63μ, 5μ and .45μ

(2) dry and weigh each fraction

(3) extract total P, Mn and Fe using hot conc HCl and HNO_3

(4) determine concentrations in each fraction

Laboratory investigations are now underway on the 1975 samples to provide baseline values and optimal extraction techniques for the 1976 field season.

The relationships between each of the parameters will be determined using a multiple correlation or variance-covariance matrix in a principal-components analysis. Multivariate analysis of variance (MANOVA) will be used to test for significant differences between the suspended and resuspended (± suspended) sediment. MANOVA will also be used to test for significant differences between the stations at different depths (12, 20, and 30 meters). The depth relations should be related to grain-size which reflects sediment dispersion and the hydrodynamics in the environment.

The data will also be used to begin modeling of diffusion rates at the sediment water interface with respect to the fate of the phosphorus species in the environment and will be built around an existing Mn, Fe model developed by Dr. John Robbins at GLRD, Ann Arbor.

This task will also provide ground truth data of river plumes for remote imagery for the River Input Study contracted to GLERL by the EPA which begins in mid-March 1976.

Products. The results will be presented at scientific meetings and published in appropriate journals. Major products are as follows:

(1) Paper on the partitioning of P, Fe, Mn and organic carbon and nitrogen with respect to grain-size

(2) Paper on diffusion and fate of phosphorus at the sediment-water interface

(3) Paper on the effects of resuspension and correlation with remote imagery.

Schedule.

Activity	Beginning Date	Completion Date
FY 75 instrumentation development and procedure shakedown.		Complete
FY 75 sample collection.		Complete
Lab analysis.	July 1975	March 1976
Data reduction/analysis.	July 1975	May 1976
Development of extraction techniques for FY 76.	December 1975	May 1976
FY 76 sample collection.	May 1976	November 1976
Shipboard analysis.	May 1976	November 1976
Lab analysis.	May 1976	December 1976
Data reduction/analysis.	October 1976	May 1977
Partitioning paper (IAGLR).		May 1977
Diffusion paper.		Early 1978
Resuspension paper.		Early 1978

Resources.

Staff (% of time):		CY 76 (Quarters) 1	2	3	4	CY 77 (Quarters) 1	2	3	4
R. L. Chambers		80	80	75	75	75	50	15	15
Lab Technician		5	10	10	10	10			
Field Technician			.5	1	1				
Consultants:	Robertson, A.								
	Eadie, B. J.								
	Nalepa, T. F.								
	Tarapchak, S. J.								
	Chapra, S. C.								
Computer Hours		.2	.2	.3	.3	.7	.7	.2	.2

Ship time (SHENEHON):
- May - 1½ weeks.
- 3 day block per month from June to November.

Special Requirements:
- Refrigeration for sample storage.
- 9 buoys to mark stations for this task and task 6.8 (we have 6 at Monroe).
- Suspended solids collecting columns.
- Collecting rack for sediment and water samples (on hand).
- N_2 purged pore water extractor ($1000 allocated, may be built by GLRD under John Robbins).
- SCUBA gear (on hand).
- Portable Eh probe.

8.8 Task 6.8 Distribution of Benthic Invertebrates

Task Scientists. T. F. Nalepa and R. L. Chambers

Objectives. The objectives of this task are as follows:

(1) To determine the quantitative and qualitative distribution of the benthic meiofauna.

(2) To investigate the relationship between the distribution of the meio- and macrofauna and such factors as depth, sediment particle size, and sediment organic carbon.

(3) To determine the extent of seasonal variation in these populations.

(4) To determine the vertical distribution of these populations.

Background. The benthic invertebrate community can be divided into two components - the meiofauna, or organisms retained by approximately a 64μ sieve. No data is yet available on the distribution and abundance of the meiofauna in the Great Lakes. Before the role of the benthic community can be conceptualized for modeling purposes, the importance of this particular component must be discerned. On the other hand, the benthic macrofauna of the Great Lakes has been fairly well characterized. This component includes numerous indicator species and, therefore, has been studied extensively as a means to determine environmentally "disturbed" areas. Such factors as depth, sediment particle size distribution, and quantity and quality of organic material act in consort to dictate the distribution and composition of the macrofauna. However, few studies have included strong physical and chemical sediment data. Only through an intensive study on a seasonal basis can the importance and interrelationships of each of these factors be determined.

Interrelationships with Other Tasks. The data will eventually be incorporated into the benthic component of the ecosystem models of Project 4. Also, this task will be closely integrated with Task 6.7 and much of the data obtained from each will be complementary.

Approach. Nine stations will be located near the mouth of the Grand River, Lake Michigan. The stations will be located to optimize differences in sediment type (river influence) and water depth. Data collection will involve taking replicate cores by SCUBA at monthly intervals. Cores will be specifically taken for both invertebrate and chemical analysis. All cores will be frozen on board (dry ice) and sliced at 2 cm intervals. Core sections for invertebrate analysis will be thawed, washed through a sieve series, and preserved. Core sections for organic carbon and particle size distribution will be brought back to the laboratory for the appropriate analysis. All invertebrates will be identified, enumerated, and estimated for biomass.

Products.

(1) Scientific paper(s) describing the results of this study.

(2) A scientific talk.

Schedule.

Activity	Beginning Date	Completion Date
Obtaining and preparation of equipment.	November 1975	April 1976
Conduct field work.	May 1976	November 1976
Analysis of data.	November 1976	May 1977
Write paper(s).	May 1977	October 1977
Present talk.	April 1978	April 1978

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
T. F. Nalepa	33	33	33	33	33	33	33	10
R. L. Chambers*		25	15	15				
P. A. Szymusiak	33	33	33	33				
Consultant: Robertson, A.								

Ship time (SHENEHON):*
1.5 week block in May.
3 day block per month from June to November.

Special Equipment:
Nine surface buoys, cable, anchoring devices.
SCUBA dry suit.

*Time jointly with Task 6.7.

8.9 Task 6.9 Presentation and Analysis of LSC/GLERL Chemical Field Data, 1965-1975

Task Scientist. B. J. Eadie

Objectives. The primary objective of this task is to edit and catalog the chemical data collected by LSC and GLERL, 1965-1975. Secondary objectives are:

(1) To determine NDV of parameters collected by LSC 1965-present.

(2) To examine nearshore versus offshore variability.

(3) To develop crude models of components of interest (i.e., SO_4, SiO_2, toxic substances).

(4) To analyze the transparency (i.e., light attenuation properties) of all the lakes seasonally.

Background. The U. S. Lake Survey Center has run surveys on all of the Great Lakes during the period 1965-75 as follows:

1965	Erie
1966	Huron
1967	Erie + Harbors
1968	Superior
1969	Superior
1970	No. Michigan
1971	Ontario Harbors
1972	Oswego Harbor
1973	St. Clair
1974	Straits of Mackinac
1975	So. Michigan

For most years, the following data are available on a "synoptic" basis:

Water
- Water temperature (°C)
  - Reversing thermometers at sample depth
  - Electronic bathythermograph
  - Infrared thermometer for surface temperature
  - Air-water interface temperatures
- Transparency (relative to 100% in air)
- pH
- Eh (volts)
- Total and phenolphthalein alkalinity (mg/l $CaCO_3$)
- Chloride (mg/l)
- Specific conductance (micromhos at 25°C)
- Dissolved oxygen (mg/l and pct. sat.)
- Coliform bacteria (membrane filter proc.)

Waves
   Height (m)
   Period (m/sec)
   Direction (nearest 10°)

Bottom Sediment
   Description
   pH
   Eh
   Biochemical oxygen demand
   Percent solids
   Percent volatiles

Dissolved Ions (Beckman DU-2 Spectrophotometer)
   Nitrate
   Phosphate
   Sulfate
   Silica
   Magnesium
   Calcium
   Sodium
   Potassium

Suspended Sediment (mg/1)

Interrelationships with Other Tasks. This task will provide verification data for modeling in Project 4 and will also provide background relating to the status of Great Lakes chemistry.

Approach. Data from cards and log sheets will be put onto magnetic tape. Parameters will be edited through windows and histogrammed for analysis. Accuracy and precision will be examined through the results of analyses of standards. The edited data will be formatted into report form and prepared for permanent archiving.

Standard statisticsl techniques will be employed to examine the variability of measured parameters. Lakes will be divided into nearshore and offshore regions with and without point sources in an effort to determine "decay" coefficients (1st order).

Multivariant analyses techniques will be applied to selected data sets.

Products.

(1) Eleven ERL data reports (one for each field year).

(2) ERL technical report on data analysis.

(3) Paper on data analysis.

Schedule.

Activity	Beginning Date	Completion Date
Creation of magnetic tapes from cards.	September 1975	September 1975
Reformatting of tapes for data manipulation.	October 1975	November 1975
Development of editing routines.	October 1975	November 1975
Develop display techniques.	November 1975	March 1976
Evaluate data quality.	October 1975	March 1976
Processing of 1975 field data.	December 1975	February 1976
Edit data.	November 1975	December 1975
Evaluate data.	December 1975	January 1976
Develop data report format.	November 1975	January 1976
Evaluate sample report.	February 1976	March 1976
Production of 11 data reports.	March 1976	April 1976
Nearshore/offshore variability.	April 1976	June 1976
Transparency/$CaCO_3$.	July 1976	November 1976
Model of SO_4.	August 1976	October 1976
Model of toxic material (preliminary).	August 1976	November 1976
Chemical speciation.	September 1976	December 1976
Write ERL technical report on data analysis.	December 1976	March 1977
Write paper on data analysis.	March 1977	March 1977

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
B. J. Eadie	15	15	25	25
J. P. Manor	75	60	60	
J. D. Boyd		20	20	20
G. L. Bell	20	20	20	20
A. Robertson	10	10	10	10
R. L. Chambers		5	5	5
Computer Assistant	10	10	10	10
Computer Hours	3	3	3	3

9.0 Project 7 Hydrologic Properties

Project Scientist. F. H. Quinn

Objectives. The objectives of this project are as follows:

(1) To develop a hydrologic data base of sufficient quality for both scientific and water resource studies of the Great Lakes. Parameters to be included are precipitation, runoff, groundwater, evaporation, connecting channel flows, changes in lake storage, and beginning-of-month lake levels.

(2) To develop numerical models to predict and simulate the water flow through the Great Lakes system. Models to be developed include hydrologic response models of the entire system, hydraulic transient models for the connecting channels, water supply prediction models, and basin hydrologic models.

(3) To develop improved understanding of the hydrologic processes of the Great Lakes Basin as they related to Objective (2) above.

(4) To provide a Great Lakes Advisory Service on water supply parameters, water levels and flows.

Background. An understanding of lake hydrology is fundamental for water resource studies of the Great Lakes. 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. Knowledge of the water supplies and flows is necessary for water quantity, water quality, shore erosion, hydropower, navigation, recreation and flooding 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, tributary flooding and basin recreation. The research and modeling efforts are based upon the hydrologic cycle and the hydrodynamics of the connecting channel flows. The hydrologic cycle is expressed mathematically for any of the Great Lakes by:

$$P + R + Q_i = E + Q_o \pm D \pm \Delta S \pm G$$

where

P is the overlake precipitation

R is the runoff

Q_i is the connecting channel inflow

E is the evaporation

Q_o is the connecting channel outflow

D is the diversion

S is the change in storage

G is the groundwater flux

A hydrologic response model and a Detroit River transient model have been developed to date. These models are currently being used to provide an advisory service on water levels and flows. Typical users of the service are the general public, the Great Lakes states, international commissions, and federal agencies.

It is expected that as the base of scientific knowledge increases, Great Lakes system models will be developed. Increased hydrologic advisory services will provide a sound basis for systematic consideration of the more intensive multi-purpose utilization of the lakes that is certain to develop with growth of the region's population and economy.

Interrelationships with Other Projects. This project will provide input to Project 3, Lake Ontario Energy Budget (IFYGL); Project 8, Lake Ice; and Project 10, Environmental Engineering Models and Applications.

Approach. Data are being gathered and analyzed on lake hydrology factors such as inflow, outflow, precipitation, runoff, and evaporation in order to obtain a better understanding of their interrelationships and their effects on the Great Lakes. Process response models are being developed to simulate the complex interrelationships that exist between the hydraulic and hydrologic processes within the Great Lakes and their immediate environment. 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 Great Lakes Basin Commission, and the general public.

9.1 Task 7.1 Lake Precipitation

Task Scientist. S. J. Bolsenga

Objectives. The objectives of this task are as follows:

(1) To define Great Lakes precipitation patterns and amounts, and to determine overwater precipitation from shoreline records.

(2) To integrate overwater and overland precipitation estimating techniques for conventional and radar data to produce a total basin precipitation model.

(3) To provide accurate input into items such as hydrologic models for predicting lake levels.

Background. Projects have been conducted since 1952 to determine the effects of the Lakes on both overwater and overland precipitation. In 1952, a Great Lakes precipitation network was established in cooperation with the Weather Bureau in Lake Michigan. In 1963, the existing storage gages were replaced by recording gages until 1968 when the data collection program was completed. Recording gages were placed on islands in western Lake Erie in 1964 and removed in 1968. The data set was screened and found to be deficient for analysis of over the lake precipitation. One report, "Comparison of Precipitation on Islands of Lake Michigan with Precipitation on the Perimeter of the Lake" by F. Blust and B. G. DeCooke (1960), analyzed the early non-recording gage data. Another report, "Lake-Land Precipitation Relationships in Northern Lake Michigan" by S. J. Bolsenga, analyzes recording gage data and has been submitted to a journal for publication.

From 1969 to 1974, a shoreline and island recording gage network was established in cooperation with Canada on eastern Lake Ontario. A NOAA technical memorandum, "Eastern Lake Ontario Precipitation Network" by S. J. Bolsenga and D. C. Norton, is in technical editing and describes the data and field procedures from that network. Precipitation data was also collected from offshore towers during part of this period and from weather radar during IFYGL. Data from the offshore towers has been screened and that documentation is available from the IFYGL data bank. A NOAA technical memorandum, "Lake Ontario Basin: Overland Precipitation, 1972-73" by D. C. Norton, describes overland precipitation during IFYGL.

The current activity is concerned with analysis of both the conventional and the radar data and with development of a combined overwater and overland precipitation plan. A first step in development of a precipitation model has been taken with publication in the IFYGL Bulletin of "On the Selection of Representative Stations for Thiessen Polygon Networks to Estimate Lake Ontario Overwater Precipitation" by S. J. Bolsenga and J. C. Hagman.

Interrelationships with Other Tasks. This task is related to Task 7.2, Lake Evaporation (by water budget); Task 7.3, IFYGL Evaporation Synthesis (input on P term, atmospheric water budget); Task 7.4, Water Levels and Flows Simulation; Task 9.2, Advisory Service (scientific and general use); Task 10.5, Atlas of Lake Ontario Physical Properties; and Project 11, International Field Year for the Great Lakes (IFYGL).

Approach. Overland precipitation will be quantified by developing Thiessen polygon networks for each lake basin and subsequently using these networks to compute precipitation from regular National Weather Service observations. The networks will be computerized so that monthly basin precipitation is available as input to the total water balance equation. Indicator stations will be selected from this procedure so that overland precipitation might be estimated from a relatively small data sample. Early estimates can thus be derived, avoiding delays due to the normal procedures of processing station data. After development of the indicator equations, an operational procedure will be drafted for the Lake Survey Center to be used in calculating the values in their NOAA publication "Great Lakes Precipitation Bulletin."

A technique for estimating overwater precipitation on each lake will be developed using statistical methods applied to available data. Analytical procedures will depend on the amount of supporting meteorological data available. Data collected from Lake Ontario and from island networks on Lakes Michigan and Erie will be used. Results of contract work using digitized weather radar will be used to supplement and verify conventional overwater data. The final results of the conventional and radar analysis will provide the best possible insight into overwater precipitation using all available data.

After optimum procedures are developed for overwater and overland estimates, they will be integrated into a total basin (lake and land) operational model.

Products.

(1) A precipitation model will be developed for the Great Lakes which will provide as output the total precipitation on a desirable time scale (probably monthly) including overwater precipitation.

(2) "Automated Thiessen Polygon Networks for Estimating Overland Precipitation in the Great Lakes" by D. C. Norton - NOAA report.

(3) "Lake-Land Precipitation Relationships in Lake Ontario" by S. J. Bolsenga and D. C. Norton - Journal report.

(4) "A Precipitation Model for the Great Lakes" by S. J. Bolsenga - Journal report.

(5) "Eastern Lake Ontario Precipitation Network" by S. J. Bolsenga and D. C. Norton - NOAA Technical memorandum.

Schedule.

Activity	Beginning Date	Completion Date
Overland Precipitation		
"Eastern Lake Ontario Precipitation Network."		Complete
Complete automatic polygon computer program.		March 1976
Develop operational (computerized) polygon networks and indicator equations.	April 1976	March 1977
Publish "Automated Thiessen Polygon Networks for Estimating Overland Precipitation in the Great Lakes."		March 1977
Overwater Precipitation		
"Lake-Land Precipitation Relationships in Northern Lake Michigan."		Complete
Analyze IFYGL tower and island data.		Complete
Analyze Lake Ontario data eastern island network.	January 1975	October 1976
CEM Contract (IFYGL, Radar).		May 1976
Publish "Lake-Land Precipitation Relationships in Lake Ontario."		June 1977
Develop Precipitation Model for Great Lakes.	March 1976	September 1977
Develop standard operating procedure for use by Lake Survey Center in publication of "Precipitation Bulletin."	October 1977	December 1977

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
S. J. Bolsenga	10	10	10	10
D. C. Norton	100	100	100	100
A. W. Hodson	50	20	5	
Computer Hours	3	1	1	1

9.2 Task 7.2 Lake Evaporation

Task Scientist. J. A. Derecki

Objectives. The objectives of this task are to determine accurate values of water loss from the lakes through evaporation and to establish relationships with the interrelated factors.

Background. Three-quarters of the water supplied to the Great Lakes by precipitation is lost through evaporation. This water loss has an important effect on the availability of water in the lakes, on water quality, and on the heat budget of the lakes. Reliable estimates of evaporation and its relationship to other hydrologic and climatological factors are needed to improve determination and/or forecasting of water supplies and lake levels. Improved lake level forecasts would prove a significant contribution for planning and water resource studies of the Great Lakes system.

Interrelationships with Other Tasks. This task is related to Task 7.1, Lake Precipitation; Task 7.3, IFYGL Evaporation Synthesis; Task 7.4, Water Levels and Flows Simulation; Task 8.1, Lake Ice Distribution; and Task 9.2, Advisory Service.

Approach. Evaporation from the Lakes cannot be measured directly; it is therefore determined indirectly by the water budget, mass transfer, and energy budget methods, or a feasible combination of these. Because available data for all methods has some important reservations, multiple determinations permit interdependent verification of the evaporation estimates. The water budget method consists of solving the mass balance equation of water supplies and losses for the unknown evaporation component. The mass transfer method of computing evaporation is based on the removal of vapor from the water surface by turbulent diffusion, where evaporation is considered to be a function of the wind speed and vapor pressure difference. The energy budget method is based on the exchange of thermal energy between a body of water and the atmosphere, utilizing the residual latent heat transfer to compute evaporation. In all methods, monthly time intervals are used for determining evaporation.

Products. The products of this task are the following reports in the active or planned stages:

(1) "Evaporation from Lake Erie" - ERL report.

(2) "Multiple Estimates of Lake Erie Evaporation" - 1975 IAGLR Conference presentation and Journal of Great Lakes Research paper.

(3) "Lake Erie Terrestrial Radiation" - Water Resources Research paper.

(4) "Heat Storage and Advection in Lake Erie" - ASCE, Journal Hyd. Div. paper.

(5) "Evaporation from Lake Superior" - ERL report.

(6) "Lake St. Clair Evaporation Estimates" - 1976 IAGLR Conference presentation and Journal of Great Lakes Research paper.

Schedule.

Activity	Beginning Date	Completion Date
Lake Erie evaporation study.		Complete
Lake Erie multiple evaporation estimates.		Complete
Lake Erie terrestrial radiation.		Complete
Lake Erie heat storage.		Complete
Lake Superior evaporation study.	March 1974	June 1976
Lake St. Clair evaporation estimates.	January 1975	September 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. A. Derecki	80	80	60	
R. N. Kelley	40	40		
Computer Hours	1	1		

9.3 Task 7.3 IFYGL Evaporation Synthesis

Task Scientist. F. H. Quinn

Objectives: The objectives of this task are:

(1) To synthesize best estimates of Lake Ontario evaporation during IFYGL.

(2) To obtain a constant for the mass transfer equation for Lake Ontario.

Background. Since the early stages of program planning for IFYGL, the determination of evaporation has been a primary consideration. Evaporation determinations were planned by the terrestrial water budget, energy budget, boundary layer, and lake meteorology panels. The evaporation synthesis group evolved at a late stage in the IFYGL development when it became apparent that much useful information could be derived from a thorough comparison and analysis of all evaporation determinations by one interdisciplinary group. Although efforts of the group are small at the current time, the project will develop into one of major proportion as the individual evaporation estimates of the panels are completed. The first publication from this task is "Lake Ontario Beginning-of-Month Levels and Changes in Storage" by F. H. Quinn, 1975, IFYGL Bulletin No. 15.

Interrelationships with Other Tasks. This task is related to Task 7.2, Lake Evaporation; Task 7.4, Water Levels and Flows Simulation; Task 9.2, Advisory Service (scientific use); and Project 11, International Field Year for the Great Lakes (IFYGL).

Approach. Phase I will consist of a review of evaporation estimates derived from evaluations of the lake energy balance, the terrestrial water budget, the atmospheric water budget, and operational type (mass transfer) calculations, from which will be derived best estimates of average evaporation for periods on the order of two weeks to a month. The estimates will then be used to derive the Lake Ontario mass transfer constant and to derive estimates of lake evaporation from shoreline evaporation pan measurements.

Phase II of the project will consist of an in-depth study of the parameterization problem aimed primarily at the development of improved parameterization schemes for use in numerical models which incorporate lake-atmosphere interaction processes.

Products. The primary product of the task will be an IFYGL scientific report on evaporation synthesis.

Schedule.

Activity	Beginning Date	Completion Date
Panel estimates of evaporation.		March 1976
Prelimary planning and coordination of development of evaporation estimates.		December 1975
Analysis of estimates:		
First cut.	March 1976	June 1976
Refinement of estimates.	June 1976	October 1976
Final analysis.	October 1976	January 1977
Report.	January 1977	September 1977

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
F. H. Quinn	30	40	40	40
J. A. Derecki	10	10	30	30
R. N. Kelley			60	60
WAE		40	40	
Computer Hours	.5	1	1	1

9.4 Task 7.4 Water Levels and Flows Simulation

Task Scientist. F. H. Quinn

Objectives. The main objectives of this task are:

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

(2) To use hydraulic transient models for specific problems involving the water quantity in 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 various factors which impact upon the water levels and flows, such as lake effects of long term barometric pressure variations and effects of water temperature changes on lake volume.

Background. This task addresses the modeling, simulation and special studies aspects of the hydrologic research program. Two models have been developed for use to date. A hydrologic response model for the entire Great Lakes System incorporating the regulation plans for Lakes Superior and Ontario is being used for simulation studies on precipitation augmentation, ice retardation, system diversions, and connecting channel changes. Hydraulic transient models have been developed for the Detroit River incorporating the complete equations for continuity and motion. These models can compute flow rates on any time basis. They are being used to compute monthly flow rates, flow rates during wind tides and seiches, and flow rates for water quantity studies. Publications from this task include the following:

(1) *Quantitative Dynamic Mathematical Models for Great Lakes Research* by F. H. Quinn, 1971.

(2) "Transient Analysis of the Detroit River by the Implicit Method" by F. H. Quinn and R. B. Wylie, 1972, *Water Resources Division.*

(3) "Effects of Ice Retardation on Great Lakes Water Levels" by F. H. Quinn, 1973, *Proceedings of the Sixteenth Conference on Great Lakes Research.*

(4) "Detroit River Flow Characteristics," presented at the 18th IAGLR Conference in May 1975.

Interrelationships with Other Tasks. This task relates to Tasks 7.1, 7.2, 7.3, 7.6, 8.2, 9.2, and 12.1.

Approach. The approach to meet the objectives of this task is as follows:

(1) To convert the Great Lakes hydrologic response model and its data base to the metric system and to update the model error analysis.

(2) To determine the effects of the water temperature changes on lake volume using Lake Ontario data obtained from IFYGL.

(3) To determine probable causes for the lowering of Lake Michigan between 1880 and 1900.

(4) To use the models for simulation and water resource studies.

Products. The following products will be forthcoming from this project:

(1) Technical journal article entitled "Hydrologic Response Model of the Great Lakes System" to be submitted to the *Journal of Hydrology*.

(2) Technical paper entitled "Detroit River Flow Characteristics" to be submitted to the *Journal of Great Lakes Research*.

(3) Technical paper entitled "Effects of Long Term Areal Barometric Pressure Variations on Great Lakes Levels" to be submitted to *Surveying and Mapping Journal of ASCE*.

(4) Technical paper entitled "Annual and Seasonal Flow Variations through the Straits of Mackinac" to be submitted to *Water Resources Research*.

(5) Journal article on "Effects of water temperature changes on lake volume."

(6) Journal article on Lake Michigan water level lowering in the 1880's.

(7) Water levels and flows advisory service.

Schedule.

Activity	Beginning Date	Completion Date
Development of Great Lakes hydrologic response model.		Complete
Study on effects of ice retardation on Great Lakes water levels.		Complete
Study on Detroit River flow characteristics.		Complete
Study on effects of long term areal barometric pressure variations on Great Lakes water levels.		Complete
Study on annual and seasonal flow variations through the Straits of Mackinac.		Complete
Conversion of response model to SIU.	April 1976	June 1976
Technical journal article on response model.	July 1976	September 1976
Determine effects of water temperature changes on Lake Ontario volume.		December 1976
Technical journal article on Detroit River flow characteristics.		June 1976
Technical journal article on flow through the Straits of Mackinac.		June 1976
Technical paper on atmospheric pressure variations on Lake levels.		November 1975
Determination of Lake Michigan water level lowering.		June 1977
Advisory service.		Continuing

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
F. H. Quinn		10	20	20
J. C. Hagman	40	60	70	70
Computer Hours	1	1	1	1

9.5 Task 7.5 Great Lakes Shoreline Flooding

This task has been deleted due to lack of available resources.

9.6 Task 7.6 Great Lakes Beginning-of-Month Levels

Task Scientist. J. A. Derecki

Objectives. The objective of this task is to develop the beginning-of-month lake levels and monthly changes in storage for each of the Great Lakes and Lake St. Clair from 1900 to date. The quality of the data will be suitable for scientific, engineering, and planning studies in the Great Lakes Basin.

Background. This task was initiated in the late 1960's to accurately quantify the storage term in the water budget and to provide a historical lake level data base for modeling, prediction, and simulation studies. The first output from the task, a data base for Lakes Michigan, Huron, St. Clair, and Erie for 1950-1966, was published in 1971 in "Quantitative Dynamic Mathematical Models for Great Lakes Research" by F. H. Quinn. The first of the lake series publications, "Lake Superior Beginning-of-Month Water Levels and Monthly Rates of Storage Changes" by Quinn and Todd, was published in February 1974.

Interrelationships with Other Tasks. Output from this task will be used in Task 7.2, Lake Evaporation; Task 7.4, Water Levels and Flows Simulation; and Task 9.2, Advisory Service.

Approach. Water level data measured by United States and Canadian water level gages will be analyzed using the Thiessen polygon procedure. A time series of Thiessen polygon networks will be developed for each lake using available water level gages. The effect of the network size on the beginning-of-month levels will be determined. A data base of beginning-of-month levels from 1900 to date will be established and monthly changes in storage will be computed from this base.

Products. A series of ERL Technical Reports will be generated, one for each lake, containing the results of the study.

(1) "Lake Superior Beginning-of-Month Levels and Changes in Storage."

(2) "Lake Michigan Beginning-of-Month Levels and Changes in Storage."

(3) "Lake Huron Beginning-of-Month Levels and Changes in Storage."

(4) "Lake Erie Beginning-of-Month Levels and Changes in Storage."

(5) "Lake Ontario Beginning-of-Month Levels and Changes in Storage."

(6) "Lake St. Clair Beginning-of-Month Levels and Changes in Storage."

(7) Recommendations will be made on the adequacy of existing water level gage networks.

Schedule. The task will be completed in CY 1976 with periodic updating of the data base afterwards.

Activity	Beginning Date	Completion Date
Lake Superior study.		Complete
Lake Michigan study.		Complete
Lake Huron study.		Complete
Lake Erie study.	February 1975	January 1976
Lake Ontario study.	September 1975	March 1976
Lake St. Clair study.	January 1976	June 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. A. Derecki	10	10		
R. N. Kelley	60	60		
Computer Hours	1	1		

9.7 Task 7.7 Runoff and Groundwater

This task has been deleted.

9.8 Task 7.8 Hydrologic Forecasting

Task Scientist. F. H. Quinn

This task is complete. A final report is on file.

9.9 Task 7.9 Connecting Channels Transient Models

Task Scientist. F. H. Quinn

Objective. The main objective of this task is to develop, test, and document one-dimensional hydraulic transient models of the Detroit, St. Clair, and Niagara Rivers for use in flow simulation in the connecting channels.

Background. Two hydraulic transient models have been developed for the Detroit River incorporating the complete equations of continuity and motion. One model incorporates the Windmill Point-Fort Wayne-Wyandotte reaches of the upper river while the other includes the total river from Lake St. Clair to Lake Erie with branches around Grosse Ile. These models can compute flow rates on any time basis.

In late 1975, work was initiated on the development of transient models for the upper St. Clair River. Requests have been received from the Corps of Engineers, the International Joint Commission, and the Canadian Department of the Environment for simulated St. Clair River flows for water quality studies.

Publications from this task include Quantitative Dynamic Models for Great Lakes Research, and Transient Analysis of the Detroit River by the Implicit Method.

Interrelationships with Other Tasks. This task will furnish models and input to Task 6.1, Physical-Chemical Study of the Detroit River, Lake St. Clair, and the St. Clair River; Task 7.2, Lake Evaporation; Task 7.4, Water Levels and Flows Simulation; Task 8.2, Ice Forecasting; and Task 9.2, Advisory Service.

Approach. The approach to meet the task objectives is as follows:

(1) To fully document the Detroit River transient models and verify the Trenton Channel calibration using discharge measurements, requested by GLERL, conducted by the COE in 1975.

(2) To investigate the applicability of the models to generate monthly Detroit River flow time series for the river regime prior to 1962.

(3) To develop, test, and document St. Clair River transient models using discharge measurements taken by the COE from 1959 to 1973.

(4) To investigate the applicability of the models to generate monthly St. Clair River flow time series for the river regime prior to 1962.

(5) To investigate new instrumentation and procedures for accurately measuring the flows in the connecting channels.

(6) Instrument measuring sections to provide long term time series for model verification.

(7) To develop, test, and document transient models of both the upper and lower Niagara River using measurements obtained from the COE, the Canadian Water Survey, and GLERL field measurements.

Products. The following products will be forthcoming from this task:

(1) Fully documented hydraulic transient models of the Detroit, St. Clair, and Niagara Rivers for use in water resource studies of the Great Lakes.

(2) A comprehensive GLERL technical report on the development, calibration, testing, and uses for each of the models.

Schedule.

Activity	Beginning Date	Completion Date
Develop upper Detroit River transient model.		Complete
Develop total Detroit River transient model.		Complete
Verify Trenton Channel calibration.	January 1976	January 1976
Documentation and technical report of Detroit River transient models.	January 1976	March 1976
Develop and test St. Clair River transient models.		June 1976
Documentation and technical report of St. Clair River transient models.	1977	
Investigate new methods of discharge measuring.	1977	
Niagara River model development.	1977	
Connecting channel flow advisory service.		Continuing

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
F. H. Quinn	25	10		
J. C. Hagman	40	20	10	10
J. E. Gales	20	20	20	20
Computer Hours	1	1	1	1

9.10 Task 7.10 Lake Michigan Evaporation

Task Scientist. J. A. Derecki

Objectives. The objectives of this task are to determine accurate values of water loss from Lake Michigan through evaporation and to establish relationships with the interrelated factors.

Background. This task forms a natural research sequence to Task 7.2, Lake Evaporation. In contrast to the other Great Lakes, there has been no recent determination of evaporation from Lake Michigan during the last two decades. Unlike other Great Lakes, Lake Michigan lies entirely within the boundaries of the United States and does not receive direct input from the cooperative international research projects. Lakes Michigan and Huron also form a single hydrologic unit, which eliminates individual application of the traditional mass balance concept to these two lakes. To facilitate determination of evaporation from Lake Michigan by other methods, a research station was established by the Lake Survey Center at South Manitou Island. As a result, five years of field data (1963-1968) have been collected. Utilization of these data requires extensive editing which was postponed until now because of higher priority of other ongoing projects.

Interrelationships with Other Tasks. This task is related to Task 7.2, Lake Evaporation; Task 7.3, IFYGL Evaporation Synthesis; Task 7.4, Water Levels and Flows Simulation; Task 8.1, Lake Ice Distribution; and Task 9.2, Advisory Service.

Approach. Long term evaporation losses from Lake Michigan will be determined for monthly time intervals by the mass transfer and energy budget methods. Based on limitations imposed by the availability of required data, these determinations will be made for the individual monthly rates or average monthly values. The mass transfer method will be used to compute monthly evaporation rates during individual years. Determination of the average monthly evaporation estimates by the energy budget method will serve as a verification check for the mass transfer results.

Products. Initial products planned for this task as as follows:

(1) "South Manitou Island Data" - ERL data report (memorandum).

(2) "Evaporation from Lake Michigan" - ERL report and journal paper.

Schedule.

Activity	Beginning Date	Completion Date
South Manitou data.	July 1976	March 1977
Lake Michigan evaporation.	August 1976	December 1977

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
J. A. Derecki			10	70
R. N. Kelley			40	40
D. J. Holt			40	40
Computer hours			1	1

10.0 Project 8 Lake Ice

Project Scientist. F. H. Quinn

Objectives. The objectives of this project are as follows:

(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 freezeup, breakup, areal extent, and thickness of the Great Lakes ice cover.

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

(4) To provide a lake ice advisory service.

Background. An understanding of the Great Lakes ice cover is necessary for winter navigation, shoreline engineering, hydro-power generation, water supply forecasts, and pollution studies. The lake ice studies began in 1963 with initial work on lake ice distribution. This task has been continued to date with a series of technical reports documenting each year's ice cover. In addition, a climatologic report, *The Great Lakes Ice Atlas*, was compiled and published. The ice characteristics studies began with a field program on Whitefish Bay in the winter of 1965-66. Since then, ice samples have been collected and used for petrographic analysis. The Winter Navigation Demonstration Program, authorized by Congress in 1970, has given impetus to Great Lakes ice studies. GLERL participation in this program is through membership on the working committee and through the Chairmanship of the Ice Information Work Group. Research in many areas, including ice forecasting, is being supported by the program.

Interrelationships with Other Projects. This project will provide input to other GLERL projects, such as Project 3, Lake Ontario Energy Budget (IFYGL); Project 7, Hydrologic Properties; Project 9, Environmental Information Services.

Approach. Data related to ice formation, accumulation, composition, and decay; time and areal distribution; and structural and crystallographic features are being acquired over the Great Lakes. These data are analyzed and correlated with physical, hydrologic, and meteorological conditions. Mathematical models and ice forecasting techniques are being developed from the analysis.

10.1 Task 8.1 Lake Ice Distribution

Task Scientist. R. A. Assel

Objectives. The primary objectives of this task are as follows:

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

(2) To provide an advisory service on Great Lakes ice cover distribution.

Background. A knowledge of the natural distribution and variability of the ice cover on the Great Lakes has applications for marine engineering, power production, and navigation on the Great Lakes. It is also necessary to develop, test, and improve forecasts of ice conditions on the lakes, and it is required for researchers needing ice information as input to other related studies, such as shore erosion.

The present task began in the early 1960's with visual aerial ice reconnaissance flights over the Great Lakes. Ice charts and annual reports on the ice cover each winter were produced from the reconnaissance data. The initial flights were made by LSC observers with Civil Air Patrol, National Guard, and Coast Guard flight support. Currently, the majority of flights are made by the Coast Guard, and there is coordination of flights and a free exchange of ice charts between U. S. and Canadian agencies.

Aerial photography in the infrared, color, and black and white wave lengths, as well as radar and satellite imagery are additional sources of ice cover information collected under this task. The bulk of the photography was made in the 1960's by the U. S. Air Force in areas considered critical to navigation. Satellite imagery, collected the past three winters, consists of positive paper prints and transparencies of ERTS, LANDSAT, and NOAA2, NOAA3, and NOAA4 VHRR imagery. The side looking airborne radar (SLAR) ice cover data consists of two winters worth of ice cover imagery compiled during the 1973-74 extended navigation seasons.

Currently much ice cover information is still obtained from visual aerial ice reconnaissance flights; however, present experimentation with SLAR and satellite imagery to document ice cover has reduced the need for visual ice reconnaissance flights. With this in mind, part of this task is viewed as the development of methods of interpreting such data.

Interrelationships with Other Tasks. This task has direct or indirect application to the following projects and tasks: Project 7, Hydrologic Properties; Task 8.2, Ice Forecasting; Task 8.3, Lake Ice Characteristics; and Task 8.4, Winter Navigation Program.

Approach. Data on the extent, characteristics, and distribution of Great Lakes ice cover is currently collected during the ice season by the following methods:

(1) Visual aerial ice reconnaissance.

(2) Satellite imagery.

(3) Side looking radar.

(4) Water surface temperatures (as determined by ART and satellite imagery).

The data from the above sources are analyzed and collected, and weekly ice cover charts depicting ice cover concentration and distribution are generated for each of the Great Lakes. At the end of the ice season, an ice cover report is generated. The *Great Lakes Ice Atlas*, a report illustrating ice cover on each Great Lake for winters classified as mild, normal, and severe (based on freezing degree-day accumulation), will be updated as warranted.

A key to updating the Ice Atlas will be the identification of the statistical characteristics of the ice cover. In order to develop statistics on ice cover concentration and distribution, it will be necessary to reduce the data to a common mode which would make feasible statistical manipulation and analysis. The use of computers for this purpose will be investigated.

The approach used to develop methods of interpreting satellite and other forms of remotely sensed ice cover data involves both GLERL staff and outside expertise. Current efforts are concerned with the development of an objective method for identifying various classes of ice concentration from satellite imagery. This investigation is being conducted as a directed study at the University of Michigan by a graduate student working part time for GLERL.

Products. The following reports have been published under this task:

(1) Annual reports of Great Lakes ice cover from 1962 to the present.

(2) *Great Lakes Ice Atlas* (1969).

(3) *Great Lakes Ice Atlas*, revised edition (1971).

(4) "Lake Superior Ice Characteristics" (1968).

(5) "Fine Resolution Radar Investigation of Great Lakes Ice Cover (under contract) (1971).

(6) Great Lakes Ice Cover, Winter 1973-74.

In addition, information to other government agencies and to the public at large has been provided upon request, if available, from the very beginning of this task.

The following products will be generated from present activities in this task:

(1) A report titled "Great Lakes Ice Cover, Winter 1974-75."

(2) A report titled "Great Lakes Ice Cover, Winter 1975-76."

(3) A report on density analysis of NOAA VHRR imagery to interpret ice concentration.

(4) Information on Great Lakes ice cover distribution for requests that can be filled with present staff and data.

(5) Revision of *Great Lakes Ice Atlas*.

Schedule.

Activity	Beginning Date	Completion Date
Publication 1973-74 ice cover report.		Complete
Write up and complete 1974-75 ice cover report.	July 1975	January 1976
Compilation of ice cover information for the 1975-76 winter season:		
(1) Satellite data	November 1975	April 1976
(2) Visual reconnaissance	December 1975	April 1976
(3) Side looking radar	May 1976	September 1976
(4) Thermal imagery	November 1975	April 1976
NOAA VHRR image density analysis for ice concentration interpretation report.	August 1975	January 1976
Analysis of 1975-76 ice cover data and write up of 1975-76 ice cover report.	May 1976	September 1976
Completing information requests for ice cover data.		Continuing
Revision of *Great Lakes Ice Atlas*.		Early 1980's
Investigation of conversion of ice cover data to computer compatible format.	June 1976	December 1976

Resources.

Staff (% of time):	CY 76 (Quarters) 1	2	3	4
R. A. Assel	15	15	15	15
B. B. Hagman	80	80	80	80
G. Leshkevich	70	70	70	70
J. E. Gales	15	15	15	15
Computer Hours	1	1	1	1

10.2 Task 8.2 Ice Forecasting

Task Scientist. S. J. Bolsenga and R. A. Assel

Objectives. The objectives of this task are to develop, test, and and improve techniques for short and long range forecasts of the following:

(1) Ice formation.

(2) Ice growth (thickness and areal extent).

(3) Ice decay.

Significant benefits will accrue to shoreline management and engineering, water level forecasting, and winter navigation.

Background. The need for ice forecasts increased with the advent of the Winter Navigation Season Extension Program to investigate the practicability of extending the navigation season on the Great Lakes and the St. Lawrence Seaway. Accurate ice formation forecasts were first required for navigation on the international section of the St. Lawrence River. GLERL (formerly LSC) was requested by an exchange of letters between the Administrator, St. Lawrence Seaway Development Corporation and the Administrator of NOAA, to develop freezeup and breakup forecasts for the St. Lawrence River. A freezeup forecast was developed and tested for three winters. As a result of these efforts, the National Weather Service initiated freezeup forecasts for the St. Lawrence River, based on procedures developed at GLERL, in October 1975.

Current efforts are directed toward the development of a breakup forecast for the St. Lawrence River. In addition, water temperature data will be analyzed in conjunction with meteorological records for a study on heat loss during the fall and winter months.

Technical development of forecasts are coupled with a continuing assessment of user needs including the NWS which, in many cases, issues the operational forecasts. Coordination is accomplished by individual meetings and larger workshops which would include representatives of all user and operational elements.

Approach.

(1) St. Lawrence Freezeup Forecast.

The St. Lawrence freezeup forecast procedure will be reevaluated using Airborne Radiation Thermometer (ART) data to calculate the river heat flux term used in the current SOP. Airborne Radiation Thermometer data will be obtained from the Canadian Department of Transport. River surface water temperatures will be obtained from the ART data and used to calculate the heat loss rate along the river. These heat flux terms will be used in the present SOP to hindcast freezeup dates and the standard errors computed and compared to those obtained using the present method to calculate heat flux to determine which of the heat flux values give more accurate forecasts.

(2) St. Lawrence Breakup Forecast.

In ice formation forecasts, the initial conditions are always known and well defined (open water). With ice breakup, the problem is significantly more complex. One factor contributing to the greater complexity is the requirement that before a forecast is started, the physical characteristics of the ice sheet must be defined with respect to ice coverage, types of ice present and thickness. Ground surveys by personnel of the St. Lawrence Seaway Development Corporation (SLSDC) will be undertaken to provide this information after a stable ice sheet has developed. Contract aerial photography (SLSDC) covering the river will be provided. With proper definition of the ice sheet, the amount of heat required to melt the ice, both from the atmosphere and river water, will be calculated. The standard equation for calculation of the heat budget will be used to calculate the amount of heat available from above the ice sheet for melting. The SLSDC will be operating five meteorological stations located from Massena to Lake Ontario. Estimating equations will be used when reliable data is not available. Contribution of the river water to the melting process will be calculated from thermograph measurements on the eastern side of Lake Ontario. Attention will also be given to special effects such as rainfall on the snow-ice sheet and buckling of the weakened ice sheet from below due to high spring runoff.

After calculations of the amount of heat necessary to weaken the ice sheet are completed, they will be compared to normals for each meteorological parameter to obtain a normal breakup date. The final step will be a readjustment of the breakup date according to available information on the divergence of the meteorological parameters from normal conditions.

While the basic approach is to use energy and heat budget techniques in developing the breakup forecast procedure, additional meteorological and hydrological data will be used to identify wintertime characteristics which may lead to earlier or later than normal breakup. This includes determining the relationship between ice thickness, air temperature, upstream water temperature, and the breakup dates. The relationship between yearly variations in total daily solar radiation at Ottawa with time of breakup will also be analyzed in conjunction with the other data. A breakup forecasting technique of this type has never been attempted before and it is expected that the additional analysis of relationships between meteorological and hydrological data and past breakup dates will help assure that the objective of three months in advance forecasts may be met.

(3) St. Marys and St. Clair Rivers Heat Budget Analysis.

Water temperature records for two thermograph locations on the St. Marys River and two locations on the St. Clair River will be used to define heat loss from these rivers during the period of fall and early winter. Evaluation of the utility of the heat budget to predict ice formation on the St. Marys River will be made using much the same approach as was used to develop the St. Lawrence River freezeup technique.

(4) Lake Superior Winter Thermal Regime.

Expendable bathythermograph probes will be used to obtain a record of water temperature profiles along the ship track between Sault Ste. Marie and Duluth on Lake Superior during the 1975-76 winter. As in the past three winters, data will be reduced to tabular values. Calculations of the heat content will be made and changes in heat content for different cruises will be calculated and compared. The usefulness of these values of heat content along the ship track as indicators of total heat storage in the lake during the early winter period will be examined by comparative analysis with heat budget approximations of heat storage and change in heat storage during the appropriate time periods. A data report on Lake Superior bathythermograph data covering the first two winters of the program (1972-73 and 1973-74) was published in June 1975. A second data report covering the 1974-75 and 1975-76 winters will be published as time permits but will not be included in scheduled activities.

(5) Duluth Harbor Ice Formation Forecast.

As a first approach, long term air temperatures using a method developed by Bilello were used to develop similar forecasts for Great Lakes bays and harbors. A report describing the results of this approach is in press at this time. Loss of the task scientist has delayed use of second approach involving the heat budget.

Products. Reports produced as a result of this task the past year (1975) include the following:

(1) Operational Ice Forecast for the Little Rapids Cut at the Sugar Island Ferry Crossing (in press).

(2) St. Lawrence River Freezeup Forecast Procedure (in press).

(3) Estimate of Water Temperatures and Time of Ice Formation on the St. Lawrence River (in press).

(4) Analysis of Techniques for Long-Range Forecasting of Air Temperatures and Ice Formation (in press).

(5) Lake Superior Bathythermograph Data (NOAA TM ERL GLERL-3).

(6) Freezeup Forecasting on the Great Lakes Using Weighted Mean Temperatures (in press).

(7) Sea Surface Temperature Anomalies (in press).

(8) Long-Range Forecasting of Maximum Ice Cover (in press).

The following products will result from current efforts in this task:

(1) Evaluation of ART data to improve St. Lawrence River freezeup SOP (report).

(2) An operational ice breakup forecast model will be developed. The results will be published as journal reports, ERL reports and a technical memorandum defining the standard operating procedure of the techniques involved.

(3) A report on fall and early winter heat budget of the St. Marys and St. Clair Rivers with applications for forecasting ice formation will be published.

(4) A report on the winter thermal regime of Lake Superior will be published as a journal article.

(5) A report on Duluth Harbor freezeup forecast technique using energy balance.

Schedule.

Activity	Beginning Date	Completion Date
Operational ice forecast for the Little Rapids Cut - Sugar Island Ferry.		Complete
Lake Superior bathythermograph data.		Complete
St. Lawrence River freezeup forecast procedure.		Complete
St. Lawrence freezeup forecast:		
Obtain ART data.		
Analyze data for river heat flux.		
Evaluation of heat flux for use in freezeup forecast.	April 1976	June 1976
St. Lawrence breakup forecast:		
Literature survey and data compilation.		March 1976
Technical development and evaluation.	April 1976	September 1977
Forecast verification (two winters).	September 1977	May 1979
Development of standard operating procedure.	May 1979	September 1979

St. Marys and St. Clair River heat budget analysis:		
Removal of instrumentation.		April 1976
Data reduction.		September 1976
Heat budget analysis.		
Evaluation of utility for forecasting ice formation on St. Marys River.		
Final report.		
Lake Superior winter thermal regime:		
Data collection.		April 1976
Data reduction.	May 1976	November 1976
Data analysis.		
Final report.		

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
S. J. Bolsenga	5	15	15	20
R. A. Assel	75	75	75	75
G. Leshkevich	15	15	15	15
J. E. Gales	35	35	35	35
Technician (WAE)		30	30	
Replacement (J. Rogers)			100	100
Computer Hours		2	1	1

10.3 Task 8.3 Lake Ice Characteristics

Task Scientist. S. J. Bolsenga

Objectives. Task objectives include the following:

(1) Defining the natural distribution and variability of the physical characteristics of the Great Lakes ice cover.

(2) Providing information useful in modeling the cycle of ice formation to decay and associated phenomena such as ice jams, forces on shore structures, ice movement, and effects on ecology.

(3) Application of results to establish design and performance criteria for equipment users such as vellel operators who must function under winter conditions.

Background. Past activities in this task have centered on a number of areas to satisfy specific user needs as indicated by the following publications:

(1) "Total Albedo of Great Lakes Ice" - Bolsenga, 1968.

(2) "River Ice Jams" - Bolsenga, 1968.

(3) "A Literature Review of Dusting Techniques in Deicing" - Cavin, 1969.

(4) "Winter Climatology and Ice Characteristics: St. Marys River - Whitefish Bay Waterway" - Brazel, 1971.

(5) "Petrographic and Chemical Properties of Great Lakes Ice" - Adams and Smith, 1973.

Information on ice thickness and type has been collected for a number of years at sites on the Great Lakes and nearby inland lakes.

Ice samples have been collected from bays, harbors and connecting channels and subjected to analysis of the crystallographic and chemical features using a systematic procedure applied in a cold room laboratory. Due to the loss of key personnel, activities on crystallographic analysis of ice samples and further collection of samples have been suspended. However, an internal, comprehensive wrap-up report on the investigations to date will be available.

Interrelationships with Other Tasks. This task has direct or indirect application to Task 1.1 and Projects 3, 4, 6, 7, 8, and 10.

Approach. A new program to quantify the optical properties of ice will be initiated. As a first step, a study to develop a catalog of albedo values for lake ice according to ice types, atmospheric conditions, and radiation wave lengths will be implemented.

Studies on ice albedo have received considerably less attention than those on snow albedo. It is known that snow cover albedo varies with time according to surface roughness change, impurity content, melting or refreezing, and atmospheric state. Similar processes occur in ice, but they have not been quantified.

A modest study was conducted in early 1967 to obtain the total albedo (0.3 - 3.0μ) of various types of ice common to the Great Lakes. It was found that albedo values ranged from 10% for clear ice to 46% for snow ice. The program indicated, however, that diurnal variations occurred in the albedo, that different ice types would probably exhibit different diurnal characteristics, and that the type and amount of cloud cover was a factor.

In this new program, a catalog of information will be compiled over a period of several years indicating the albedo of various types of ice common to the Great Lakes (i.e., clear, slush, ball, pancake, etc.) according to a wide range of solar altitudes (10 - 45^{o}), cloud types, and cloud amounts.

Initially, a measurement system will be fabricated consisting of incident and reflected, tripod-mounted pyranometers with a precision portable potentiometer to measure pyranometer output. During the first year, tests will be conducted in locat lakes to refine the instrument system and to determine to what degree the more conveniently located inland lakes reflect ice conditions in the Great Lakes. Measurements will be conducted in subsequent years to complete the catalog of information.

Operations of the network for collecting ice thickness and type data will be continued. Management of the paid observers, tabulation of the data and converting the data to computer format are involved.

The large amount of information already collected will undergo an analysis for gaps and deficiencies. Changes in the observation schedules and observation locations will be made, as necessary. It is hoped that the information compiled thus far will be sufficient to provide a comprehensive description of the stratigraphy of Great Lakes ice.

Chemical laboratory analysis of ice samples obtained in previous years will continue although no new samples will be collected during the 1975-76 season. Melt water from ice samples and water samples from a standard depth below the ice will be analyzed for chemical concentrations of PO_4, NO_3, SO_4, SiO_2, Cl, Na, Ca, K, and Mg.

Elementary analysis of the spatial and temporal variability of chemical concentrations will be made.

A continuing review of this task will broaden the scope of the program so that a comprehensive study of the characteristics of fresh water ice is implemented. The availability of personnel and installation of an on-site cold room will influence timing of this expansion. Plans are already well underway to expand the optical properties of ice study to include research on the spectral transmittance of ice to insolation.

Products. Reports will include:

(1) "Stratigraphy of Great Lakes Ice" - NOAA report.

(2) "Great Lakes Ice Cover - Thickness and Types" - journal article.

(3) "Albedo of Great Lakes Ice" - journal article.

Schedule.

Activity	Beginning Date	Completion Date
Report on ice thickness prediction based on freezing degree-day ice thickness correlation.		Complete
Internal preliminary report on crystallographic analysis of ice samples and associated laboratory techniques.		Complete
Optical Properties:		
Ice albedo -		
Purchase instrumentation	October 1975	December 1975
Assemble and fabricate field instrumentation array.	January 1976	February 1976
Initial shakedown measurements.	February 1976	March 1976
Full-scale field program and analysis of data.	January 1977	April 1980
Publication of "Albedo of Great Lakes Ice."		September 1980
Thickness and Type:		
Organizing observing schedules, instructing observers, contracting for observer services.	October 1975	December 1975
Compiling, cataloging and computer processing 1976 data from observers.	January 1976	July 1976
Analysis of historical data base.	December 1975	November 1976
Publication of "Stratigraphy of Great Lakes Ice."		January 1977
Publication of "Great Lakes Ice Cover - Thickness and Types."		March 1977

Ice Chemistry:

Laboratory analysis of ice samples.	As time is available - first half of 1976.

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
S. J. Bolsenga	40	60	60	60
G. Leshkevich	15	15	15	15
J. E. Gales	30	30	30	30
B. B. Hagman	20	20	20	20
Technician (WAE)	10	30	30	
Computer Hours	2	2	1	1

NOTE: Scheduling of resources partially depends on installation of an on-site ice laboratory (new building).

10.4 Task 8.4 Winter Navigation Program

Task Scientist. F. H. Quinn

Objectives. The objective of this task is to support the Ice Information Work Group whose objectives are to:

(1) provide data that will permit a better understanding of the physical and structural character of lake ice;

(2) observe and document ice formation, growth, decay, and movement, both with and without winter navigation;

(3) determine the effects of winter navigation on shore properties along confined channels; and

(4) to provide necessary marine environmental service to shippers during an extended navigation season.

Background. Navigation on the Great Lakes - St. Lawrence Seaway system is suspended every winter from about mid-December until early April because of the effects of ice. As a result, commerce and industry served by this great waterway system must resort to expensive stockpiling of materials to carry them through the winter months or must move cargoes during this period via more expensive modes of transportation. For many years, and particularly since the opening of teh Seaway, commercial shipping interests have sought an extension to the navigation season in order to make maximum use of this vast inland waterway. Until the Demonstration Program, however, no major concerted effort had been made to test the practicability of an extended season. In Section 107 of the River and Harbor Act of 1970 (Public Law 91-611), Congress authorized a Winter Navigation Program which included a 3-year, $6,500,000 action program (later extended to a 5-year program with additional funding) aimed at actually demonstrating the practicability of extending the navigation season on the Great Lakes - St. Lawrence Seaway system. The Act directed the Secretary of the Army, acting through the Chief of Engineers, to carry out this program in cooperation with the Departments of Transportation, Interior, and Commerce, and the Environmental Protection Agency.

Interrelationships with Other Tasks. This task is related to Task 8.1, Lake Ice Distribution; Task 8.2, Ice Forecasting; and Task 8.3, Lake Ice Characteristics.

Approach. Data on water temperatures has been collected at selected locations around the Lakes and in the St. Marys and St. Clair Rivers. The Lake Superior temperature decline was monitored using ships of opportunity and an expendable bathythermograph system. The ice thickness measuring network was augmented for this task. The collected data has served as input for ice forecast studies partially supported by this program.

Products. The following products were produced by this task:

(1) A data report on Lake Superior winter water temperature.

(2) Tabulations of water temperatures for two locations on the St. Clair and St. Marys Rivers.

(3) Annual reports on:

(a) Environmental effects of ice breaking on the St. Clair River.

(b) Ice Information Work Group activities.

(4) Various ice forecast products listed in Task 8.2 as follows:

(a) A report on a method to predict freezeup on the St. Lawrence River at Massena, New York.

(b) A report on the Little Rapids Cut ice problems forecast.

The following products will be produced in the remaining year of the extended season program:

(1) Ice Information Work Group activities report, 1975-76.

(2) Environmental effects of ice breaking on the St. Clair River, 1975-76.

(3) Final report of Ice Information Work Group for the Demonstration Program.

Schedule.

Activity	Beginning Date	Completion Date
Ice Information Work Group activities report, 1975-76 winter.	April 1976	July 1976
St. Clair River ice breaking environmental evaluation report, 1975-76 winter.	April 1976	July 1976
Final report on Ice Information Work Group on Demonstration Program.	July 1976	December 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
F. H. Quinn	5	5	5	5
R. A. Assel	10	10	10	10
S. J. Bolsenga	5	5	5	5

10.5 Task 8.5 Archiving Ice Information

Task Scientist. R. A. Assel

This task is inactive.

10.6 Task 8.6 Water Temperature Observations

Task Scientist. J. L. Grumblatt and F. H. Quinn

Objectives. Water temperature is measured on an annual basis at sites around the periphery of the Great Lakes (Figure 4). The objective of this task is to continuously and accurately monitor water temperature variations and trends in the Great Lakes. This data is fundamental in energy budget studies, forecasts of ice formation and decay, thermal enrichment, and water motion and suspended sediment studies. A long term temperature regime will provide a framework within which short term intermittent data and studies can be aligned in their proper perspective.

Background. Ten stations have been in operation since 1965. The number was increased to 18 since 1972. Three of the recent stations have telephone telemetry capabilities; they are a part of the data system used by the St. Lawrence Seaway Development Corporation in the operation of the Seaway system. Four of the stations installed since 1972 are operated in connection with winter navigation studies and with basic research in the formation and decay of fresh water ice.

Two types of water temperature recorders are in operation at the present time. The newest installations are of the digital type and have an Enviro-Labs, Inc. temperature servo-system and temperature probe connected to a Stevens model 7000 digital recorder. Output is on paper tape designed to accommodate four decades of binary coded decimal (BCD) punching across the tape, 16 bits in parallel. The older installations are Bristol Series P-92663 Dynamaster AC powered continuous analog tape recorders connected by a three-wire temperature compensated cable to Bristol 7NA resistance thermometer bulbs (RTB). Atmospheric Environment Service (AES), Canada, is complementing the system with Airborne Radiation Thermometer (ART) overflights of the international lakes.

Interrelationships with Other Tasks. This task relates to Task 8.2, Ice Forecasting; Project 3, Lake Ontario Energy Budget; Project 6, Natural Distribution and Variability of Lake Properties; Project 7, Hydrologic Properties; and Project 9, Environmental Information Services.

Approach. The system is maintained and operated through a renewable agreement by Lake Survey Center, National Ocean Survey. Contract on-site observers perform sensor checks and mail tapes to Detroit on a monthly basis. Raw data are translated to magnetic tape, edited for technical adequacy and put in disk pack. Software is developed to provide basic temperature data to users. Special purpose software may be developed as usage of the system expands.

Products.

(1) Hourly and mean daily temperatures are published each month.

(2) A basic report will be published containing historical and current system output including a tabulation of daily, monthly, and annual mean water temperature at each station in the network.

(3) Annual tables of the frequency distribution of daily mean temperatures will also be included. Average diurnal water temperature curves will be generated, probably on a monthly time period.

(4) Monthly data summaries are prepared for distribution to users by Lake Survey Center. A list of those using this information includes consulting engineering firms engaged in power plant siting and design, Great Lakes shippers engaged in shipping temperature critical cargoes, other governmental agencies with an interest in the Great Lakes, and the Government of Canada, including the Department of the Environment, Floating Ice Group, with whom we interact in ongoing studies of the upper St. Lawrence River.

Schedule.

Activity	Beginning Date	Completion Date
Convert old software to Litton system.		Complete
Convert Litton system to CDC 6600.		Complete
Edit system output.		Complete
Write report.	December 1975	March 1976
Submit listings to LSC for distribution.	September 1975	Continuing

Resources.

	CY 1976 (Quarters)				CY 1977 (Quarters)			
Staff (% of time):	1	2	3	4	1	2	3	4
J. Grumblatt	20							
F. Quinn	5	5	5	5	5	5	5	5
S. Bermick	5	5						
Technician			5	5	5	5	5	5
Computer Hours	.2	.2	.2	.2	.2	.2	.2	.2

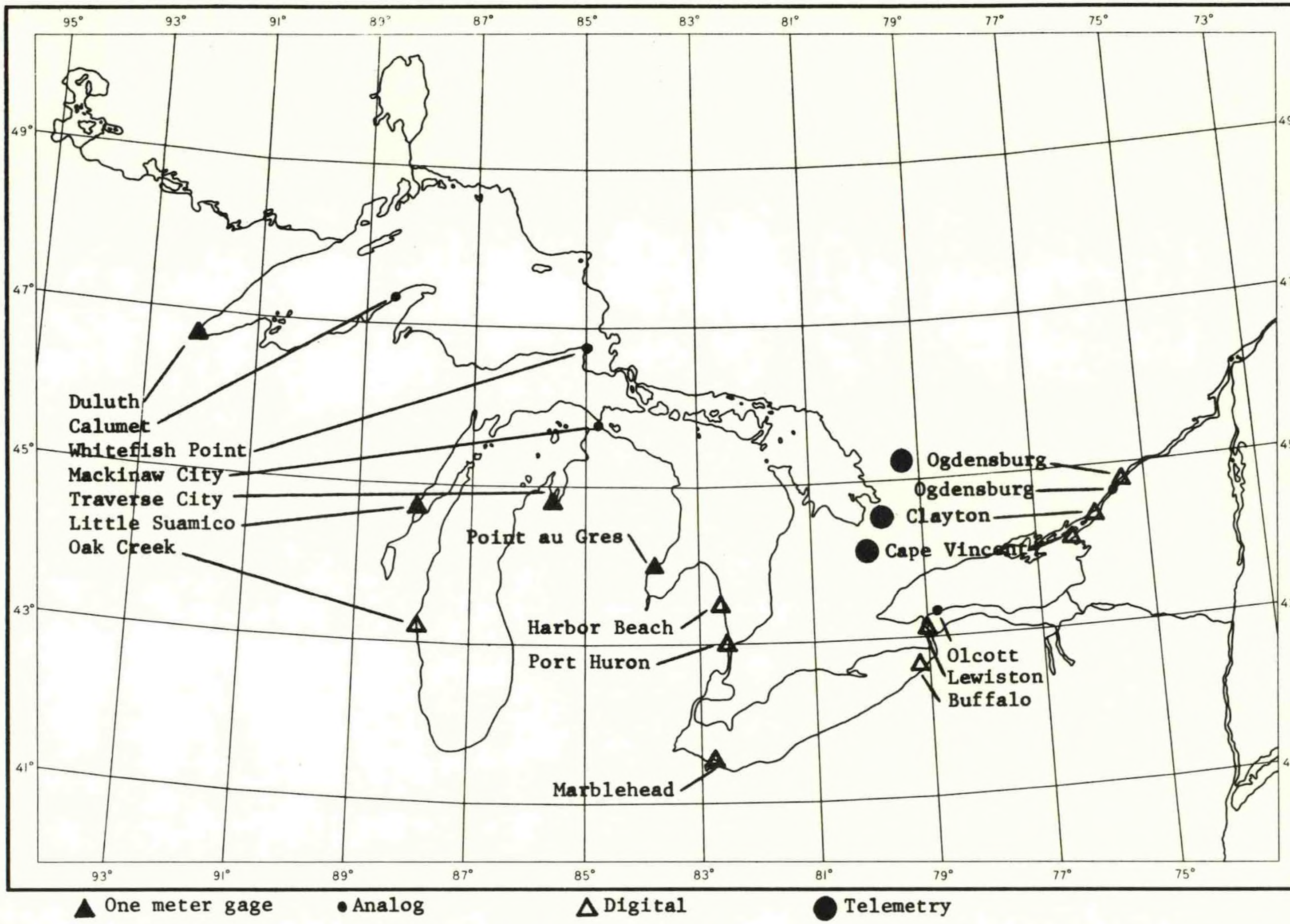

Figure 4. Water temperature network.

11.0 Project 9 Environmental Information Services

Project Scientist. C. F. Jenkins and A. P. Pinsak

Objectives. This project will define an information system of value to Great Lakes resource managers and planners in their decision-making activities, will develop an information system to meet the needs of the Great Lakes community, and will coordinate information needs and exchange. This information system will consist of data, analyses, simulation/prediction techniques and models formatted or designed for application to resource management problems.

Background. The two tasks under this project are needed to make the GLERL program most valuable to the Great Lakes inhabitants and indirectly to the entire United States. The first task - that of determining the environmental information requirements associated with Great Lakes activities - is vital to GLERL because it will shape the future program of applied research and will focus the efforts within the existing program. The second task - the establishment and direction of an advisory service - provides the mechanism for utilization of the GLERL products.

A basic prerequisite to accomplishment of GLERL mission objectives is an understanding within GLERL of the problems involving environmental stress and how the environmental factors are considered when decisions are made on the use of Great Lakes resources. The GLERL staff must provide research products that are understood and applied correctly to the solution of planning or operational problems. Products that are misunderstood or misused will only result in a waste of the GLERL research effort and a distrust on the part of the Great Lakes managers of the value of the GLERL program.

Interrelationships with Other Projects. This project relates to all the projects and tasks within GLERL in that it provides both the basis for establishment of projects as well as a means for the application of the output of the projects.

Approach. This project provides the means of establishing and maintaining communication between GLERL and federal, state, and local government agencies, institutions, private organizations, and the general public. Identification will be made of the individuals who require environmental information for problem-solving, and interactions will be held with these individuals to determine their needs for an environmental information system. User contacts will be through membership on regional and international boards and commissions, workshops and public appearances as well as through interactions with federal, state, and local agencies. These activities will provide advisory service products to the user as well as provide user requirement information.

Information requirements will be structured in such a way as to provide guidance to GLERL in developing short and long-range program objectives to satisfy the maximum number of most urgent needs. These requirements will provide a basis for the formation and operation of an advisory service. The advisory service staff will maintain communication with users of the GLERL information and will work as the catalyst to bring GLERL products to the user and expedite their application. This established link with the Great Lakes community will greatly enhance the practical utilization of GLERL products.

Products. This project will provide a periodically updated set of user requirements, will provide environmental information in a form useful to the Great Lakes community (data, processed information, models), and will provide services for the application and interpretation of environmental information.

11.1 Task 9.1 Environmental Information Requirements

Task Scientist. C. F. Jenkins and A. P. Pinsak

Objectives. To define the Great Lakes problems requiring environmental information for their solutions and to define an information system of value to Great Lakes resource managers and planners in their decision-making role.

Background. Information is defined by Dworsky and Swezey in their "Reader on Management Improvement Studies for the Great Lakes" as "data or observations so arranged as to be of value in decision-making." They quote the Organization for Economic Cooperation and Development (OECD) report, *Information for a Changing Society*, on the problem of information use as follows: "(1) various types of information are needed for decision-makers at all levels through society; (2) information must be appropriately packaged and interpreted for each specific community of users; and (3) quality of information - that is, its reliability and credibility - is more important than access to great masses of raw data." Dworsky and Swezey also state that "The information system is an integral and essential part of all management activities and must not be looked upon as a separate organizational unit which only provides input."

The GLERL mission includes the development of environmental information on the Great Lakes region to improve understanding and to provide improved environmental service tools, data, information, and consulting services to support user needs in government and private organizations. This task is necessary to know and understand the user needs.

Interrelationships with Other Tasks. This task will provide input to all GLERL projects in the form of user needs.

Approach. The GLERL approach to this task will include the following activities:

(1) Develop mailing lists for various GLERL products.

(2) Identify those individuals in federal, state, and local government, industry, and public groups who require environmental information for decision-making. Sources of information will include, but not be restricted to, the NOAA Marine Advisory Service, the Great Lakes Basin Commission, the Great Lakes marine advisory service, the Sea Grant directors, Sea Grant Advisory Service, the Federal Energy Office, the Atomic Energy Commission, the Federal Power Commission, the Army Corps of Engineers, the United States Coast Guard, state resource agencies, and GLERL staff members. Individual GLERL scientists will contribute to this activity through participation in interagency committee work and contacts on their project and task activities.

(3) Develop and distribute information on GLERL to the Great Lakes community. This will initially be a mailing announcing the GLERL formation, mission, and capabilities sent to all known federal, state, and local groups undertaking Great Lakes planning or operations involving environmental considerations. Follow-up information on GLERL may be included in existing Great Lakes publications, such as the *Communicator* published by the Great Lakes Basin Commission, the University of Michigan Sea Grant Advisory Service monthly newsletter, and the University of Wisconsin and State University of New York Sea Grant publications.

(4) Participation by appropriate GLERL staff in interagency and international activities. These presently include the International Joint Commission Research Advisory Board, Water Quality Board, and Upper Lakes Reference to study pollution in Lakes Superior and Huron; Department of Commerce representation on the Great Lakes Basin Commission and its work groups; Consultant to WMO Lakes Victoria, Kyoga and Mobuto Sese Seko Projects; interaction with and participation in Sea Grant Programs; membership on an international hydraulic and hydrologic data coordinating committee; participation in the Corps of Engineer's Lake Erie Wastewater Management Study; work activities on ICMSE ad hoc committees and conferences; participation on IAGLR committees and board of directors; and participation in the Corps of Engineer's directed Winter Navigation Program. Input to Task 9.1 is identification of specific environmental needs within the Great Lakes Basin.

(5) Interact with resource managers identified in Item (2), as time and manpower permit, to better identify their problems and to define the problems in terms of type of environmental information needed (specific parameters, formats, space and time scales, model input and output, etc.).

(6) Organize the information requirements in such a way as to provide guidance in structuring or modifying the GLERL technical program. This includes information requirements from Items (2) and (4).

(7) Provide the background information necessary for the formation and operation of a Great Lakes Advisory Service.

Products. The products of this task will consist of output of Items (1), (3), (6), and (7) above.

Schedule.

Activity	Beginning Date	Completion Date
Develop GLERL mailing lists.	October 1975	December 1975
Identify individuals with need for Great Lakes environmental information in their decision-making capacity.	April 1975	Continuing

Design, prepare, and send a mailing on GLERL mission and capabilities.	September 1975	February 1976
Participate in international and interagency programs and activities.		Continuing
Interact with resource managers.		Continuing
Organize information requirements obtained and relate to the GLERL technical program and to the formation and operation of a marine advisory service.	April 1975	Continuing
Continue updating information requirements, as needed.		Continuing

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
C. F. Jenkins	15	15	15	15
A. P. Pinsak	20	20	20	20
E. J. Aubert	10	10	10	10
A. Robertson	5	5	5	5
F. H. Quinn	10	10	10	10
J. H. Saylor	5	5	5	5
Senior GLERL Staff in an ad hoc capacity				
Support	20	20	20	20

11.2 Task 9.2 Advisory Service

Task Scientist. C. F. Jenkins

Objectives. The principal objectives of this task are to provide information in a form useful to the Great Lakes community (particularly for planning and decision-making activities) and to provide services for the application and interpretation of the environmental information and/or techniques/models provided.

Background. The value of GLERL products will depend, in part, on their utility in the solution of Great Lakes problems that involve environmental impact and effects. Applied research results are often relegated to a report stored on shelves without being applied to the problems they were intended to help solve. In other cases, the results are misunderstood or misapplied by the user who then doubts the credibility of the scientists who undertook the research. In many cases, a relatively small effort by the scientist working with the planner, manager, or field operations user in the application of the product can reap significant benefits. The aviation meteorologist works closely with the airline crews in preflight planning and with the dispatchers in flight following. While no such purely operational service is foreseen for GLERL, it is apparent that some interpretation and explanation by the scientist is of significant value to the user of environmental information.

Every GLERL scientist cannot, nor will he desire to, be in contact with the potential user of his product. However, this task will provide the channel through which he can be put in contact with specific users and his product can be tailored to the problem. The aim of this task is to facilitate the utilization of GLERL products in a timely and efficient manner.

Interrelationships with Other Tasks. This task potentially relates to all projects of GLERL in that the end products of the project efforts have applications to environmental impact and effect problems in the Great Lakes.

Approach. The users of GLERL environmental information (products) will be identified in Task 9.1 and a dialogue established between the GLERL staff and these users. The Advisory Service activity will include the review of the information requirements output from Task 9.1 and determination of how existing GLERL programs can fulfill these requirements either directly or with modifications. The participation of GLERL staff in interagency and international activities such as the International Joint Commission boards and committees, the Great Lakes Basin Commission work groups and committees, the Corps of Engineer's programs, etc., as shown in Item (4) of the Approach Section of Task 9.1 will also constitute Advisory Service products.

Gaps in the GLERL program will be identified and recommendations made to the Director of GLERL for specific tasks needed to meet user requirements. These recommendations will include the technical plan for the proposed tasks.

When products are available to meet user needs, the Advisory Service staff will be made available to assist the user in the interpretation and application of the information to the planning or decision-making activity. Where necessary, additional GLERL staff will be involved in the interactions with the users to help in the information application. This final link is extremely important to assure that the GLERL product is usable and is applied correctly; otherwise, the confidence of the user in GLERL will suffer through misunderstanding or misuse of GLERL information, techniques, or models.

Products. The products of this task will be data, analysis results, simulation/prediction techniques, or models (or simply expert judgment based on scientific experience). These products will be applicable to the planning and decision-making activities of users ranging from the general public and industries through local, state, and federal agencies to planning commissions and public organizations.

Schedule.

Activity	Beginning Date	Completion Date
Maintain a file of all GLERL products provided to users upon request.	April 1975	Continuing
Study user requirements as determined in Task 9.1 and review GLERL program to determine useful products.	April 1975	Continuing
Interact with Great Lakes users of environmental information to clarify requirements where necessary.	October 1974	Continuing
Develop plans for the utilization or modification of GLERL products and the implementation of new tasks to meet user requirements.	April 1975	Continuing
Coordinate the development of information in terms of data, analysis results, or models applicable to the solution of specific problems.	October 1974	Continuing as part of individual task efforts
Work with the user in the interpretation and application of GLERL products to specific problems.		Continuing
Establish plans and staff allocation for continuing advisory services.	January 1976	July 1976
Provide continuing advisory service activity.		Continuing

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
C. F. Jenkins	15	15	15	15
A. P. Pinsak	10	10	10	10
E. J. Aubert	10	10	10	10
A. Robertson	10	10	10	10
F. H. Quinn	10	10	10	10
J. H. Saylor	5	5	5	5
Various senior staff members				
Support	20	20	20	20

12.0 Project 10 Environmental Engineering Models and Applications

Project Scientist. E. J. Aubert

Objectives. The objectives of this project are as follows:

(1) To develop and test improved simulation and prediction models and other tools for user applications.

(2) To develop a basis for rational decisions for the development and utilization of Great Lakes resources.

Background. Accurate scientific information is a prerequisite for effective environmental management. In its absence, the decision-maker must rely on economic, social, and political considerations or on intuition. Thus, decisions affecting the environment have often been made without the benefit of current scientific knowledge. This project hopes to improve the transfer of environmental information particularly through the medium of the problem-oriented mathematical model.

The expression of natural processes in a mathematical framework has advanced considerably over the past decade. Methodology developed in a technological context has been applied to a variety of natural systems and processes. The approaches have ranged from those based on scientific principles to those of an empirical nature and have addressed such problems as eutrophication, lake water levels, and fisheries management. While many of the developments have been made in marine systems, the possibilities for application to the Great Lakes have been well documented.

Unfortunately, models have at times been represented as panaceas, capable of answering every environmental question. This can only be avoided by close interaction with the user and careful explanation of the capabilities and limitations of the model. If done properly, the capability of the model of organizing large and varied information for the decision-maker will be optimally exploited.

Interrelationships with Other Projects. This project is potentially related to all of GLERL's scientific research projects to the extent that their results could be incorporated into the solution of an environmental decision. Several projects are developing models which are of a scientific nature but which could be modified to answer management questions. These include Project 1, Lake Circulation, Transport, and Diffusion; Project 2, Surface Waves and Oscillations; Project 4, Aquatic Ecology Models and Related Studies; and Project 7, Hydrologic Properties.

Project 9, Environmental Information Advisory Services, will support this project by establishing communication between the GLERL scientist or engineer and the decision-maker.

Approach. At present, the approach will consist of initiatives in the following three areas:

(1) Information reports. Although the project primarily deals with models and the application of analysis and prediction techniques to data sets to develop information of use to decision-makers, data will be summarized in a form which will be comprehensible to both the layman and the scientist.

(2) Application of existing models. The laboratory will maintain a library of computerized models and other techniques which will be applied directly or with minor modification to general classes of environmental problems.

(3) Development of models. When a problem-oriented model is needed but not available, development will proceed under this project, if appropriate.

As a final note, it should be stated that in all applications, the GLERL engineer or scientist will interact closely with the user to insure that the model is used and interpreted properly.

2.1 Task 10.1 Maumee Bay Level B Study

Task Scientist. A. P. Pinsak

Objectives. In accordance with the approved plan of study for the Maumee River Basin Level B Study which is being implemented by the Great Lakes Basin Commission in accordance with guidelines established in Public Law 89-90, this aspect of the comprehensive study will describe the limnology of Maumee Bay, distribution of parameters, structural modifications, and the interrelationship of the bay with the runoff from the drainage basin on the one side and with Lake Erie on the other. Short and long term impact of critical inputs from the basin will be assessed and the potential effect of management alternatives to be developed for the Maumee Basin will be evaluated. This study will contribute to development of a basin-wide coordinated plan by affected local, regional, state, and federal agencies for optimum management and development of water and related land resources in the Maumee Basin.

Background. The States of Ohio, Indiana, and Michigan requested that the Great Lakes Basin Commission consider a study of the Maumee River Basin because so many problems have been identified but not solved by the numerous studies made without comprehensive direction. The study is designed to respond to expressed desires concerning erosion and sediment control, land use and management, conservation of recreational opportunities, and the relationship of water quality in the basin to that in Maumee Bay and Lake Erie.

Interrelationships with Other Tasks. The modeling phase can be applied to Tasks 6.1, 6.5, and 6.6. It will provide input to Task 12.1 and, with proper inputs, can be used extensively in Task 9.2. Results satisfy some objectives of Project 1.

Approach. Descriptions of Maumee Bay and estimates of historical trends will be based on available published investigations, unpublished data sources, ongoing studies, and active monitor programs. Existing uses of the bay will be itemized. Problems indigenous to Maumee Bay will be assessed, reduced to their significant elements, and collated. Existing data will be used to describe the limnology of Maumee Bay, including transport and flushing, circulation, level fluctuations, erosion and sedimentation, bottom characteristics, water chemistry, benthos, plankton, and nekton.

Effects of recommended management strategies will be tested through application of a simulation model consisting of vertically integrated time averaged hydrodynamic equations encompassing the entire lake and a mass balance equation for 2-dimensional diffusion and transport. The bay area considered extends from the mouth of the Maumee River eastward to the line joining Cedar Point and North Cape. Lake boundary conditions will be based on background levels of interest variables in the western basin of Lake Erie.

Impacts and feasibility of management alternatives will be evaluated systematically in relation to established standards, broadscale objectives, and the immediate desires of users and developers. Assessment of impacts on Maumee Bay will rely on input from the other elements participating in the study and will be based on criteria considered to be most critical by those study elements and advisors.

Products. Shore and bay modification, use, and development will be described and related to the bay.

Significant short term and seasonal fluctuations of inputs to Maumee Bay from the drainage basin will be described. Cause-effect relationships of various Maumee Basin goals on the bay and the feasibility of attainment of Maumee Bay goals will be assessed. Established standards will be used as basic guides and the Level B Study goals and objectives will be used as directed.

A working paper will be submitted to the study committee for publication in an interim report; a baseline reference for Maumee Bay will be published; a final report to be published will be used in development of a comprehensive coordinated joint plan for optimum development and management of the Maumee Basin.

A transport and diffusion model to be developed will have direct application to other harbors and embayments in the Great Lakes.

Schedule.

Activity	Beginning Date	Completion Date
Inventory available data.		Complete
Define problems.		Complete
Describe natural setting of Maumee Bay.		Complete
Prepare first working paper.		Complete
Define relationship of bay processes to basin through model simulation.		Complete
Prepare baseline reference report.		Complete
Prepare management goals evaluation.	March 1975	December 1975
Prepare final working paper.		January 1976
Develop comprehensive coordinated joint plan.	November 1975	May 1976
Prepare report for publication.		August 1976

Resources.

Staff (% of time):	CY 1976 (Quarters) 1	2	3	4
A. P. Pinsak	25	20	10	
R. L. Pickett	5			
S. Bermick	5			
Computer Hours	2			

12.2 Task 10.2 Phosphorus Model

Task Scientist. S. C. Chapra

Objectives. The objective of this task is to investigate the feasibility of simulating long term trends of total phosphorus in the Great Lakes using social and economic factors as forcing functions.

Background. O'Connor and Mueller's (1970) approach to modeling long term levels of a conservative substance in the Great Lakes is depicted in Figure 5.

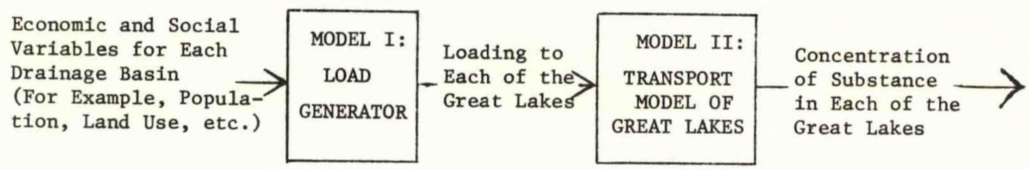

Figure 5. O'Connor and Mueller's approach to modeling long term levels of a conservative substance in the Great Lakes.

The approach consists of two simple models which simulate mean yearly values. The first uses empirical relationships to transform variables such as population and lake use into mass loadings. The loadings are then introduced into a model which methematically depicts the lakes as continuously stirred tank reactors which are linked by their interconnecting flows.

The application of O'Connor and Mueller's approach is, among other things, contingent on the ability to formulate simple but accurate models. Enough development has proceeded on both load generators and transport-kinetic models of total phosphorus to warrant an investigation of their applicability to the Great Lakes.

Interrelationships with Other Tasks. This task is related to Task 4.1 (Level 1 Ecological Model), Task 4.3 (Three-Dimensional Ecological Model), and Task 4.4 (Ecological Modeling).

GLERL is presently developing models of the ecology and water quality of the Great Lakes with time scales of less than a year. The phosphorus model would complement these models in two ways:

(1) The shorter scale models are generally expensive to run for more than a decade. The phosphorus model, which would be designed for the long term, could be used to generate the average loadings and concentration of the lakes at some future date. These could be used as initial conditions for the finer detail models which could then be used to simulate the variability of the system within the year.

(2) Also, the waste generator could be used alone to estimate loadings for the finer scale models.

The methodology and tools developed in this project will hopefully be general enough to be applicable to other substances (e.g., silica, cesium, pesticides). The ability to address this class of long term pollutant problems would be extremely valuable.

Approach. A first iteration will be made using existing methodology. The results of this iteration will be compared with observations and an assessment of the feasibility of the techniques and suggestions for possible modifications will be made.

As expressed in the section on background, the O'Connor-Mueller approach used two models to simulate chloride concentrations. Chloride is considered a water quality variable since high levels in fresh water are perceived as harmful in themselves. This is not true of the levels of total phosphorus which could be expected in the Great Lakes. Total phosphorus is important as it stimulates biological activity. For this reason, a third model will be added to transform total phosphorus concentration into an appropriate gauge of water quality. This addition is included in Figure 6, which depicts the approach to be adopted in this task. This is followed by short descriptions of each of the models.

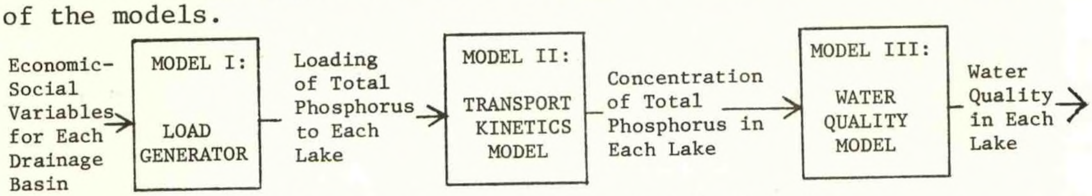

Figure 6. Approach to modeling total phosphorus.

Model I: Using empirical relationships between social-economic variables (population, land use, etc.) and generation of exportable phosphorus, loadings of total phosphorus for the individual basins of the Great Lakes will be simulated as a function of time.

Model II: These loadings will be introduced to a simple model based on the conservation of mass. Relatively large units of each lake will be represented by compartments (e.g., hydplimnion, sediment, etc.). Coupling of the compartments within each lake and between lakes will be done with a series of first-order differential equations. Kinetics will be developed to reflect the non-conservative properties of the element. All computations will be computerized.

Model III: Empirical and theoretical relationships between total phosphorus levels and water quality will be taken from the literature and will be used to simulate water quality due to phosphorus in each of the Great Lakes.

Products.

(1) "Long Term Model of Total Phosphorus in the Great Lakes." Paper to be submitted to journal.

(2) Paper to be presented at IAGLR meetings at Guelph (May 1976).

(3) Chapra, S. C. Comment on "An Empirical Method of Estimating the Retention of Phosphorus in Lakes" by W. B. Kirchner and P. J. Dillon. Water Resources Research, December 1975.

(4) Chapra, S. C. and S. J. Tarapchak. A Chlorophyll a Model and its Relationship to Phosphorus Loading Plots for Lakes. In GLERL review.

Schedule.

Activity	Beginning Date	Completion Date
Preliminary analysis.		Complete
Historical simulation and predictive runs - paper in review.		Complete
Incorporation of sediments into model, long term simulation of other nutrients (silica, nitrogen), development of seasonal model of phosphorus, incorporation of nearshore effects.	August 1975	March 1976
Final report.	March 1976	June 1976
Presentation of paper at IAGLR meeting.		May 1976

Resources.

Staff (% of time):		CY 1976 (Quarters) 1	2	3	4
S. Chapra		70	70		
Consultants:	Tarapchak, S. J.				
	Scavia, D.				
	Robertson, A.				
	Rodante, F. C.				
	Chambers, R. L.				
	Eadie, B. J.				
Computer Hours		.25	.25		

12.3 <u>Task 10.3</u> Lake Scale Water Quality Model

This task was deleted in November 1975 and the research is now being conducted under Tasks 4.3 and 4.4.

12.4 Task 10.4 Monitoring Water Characteristics

This task has been transferred to Project 8, Lake Ice, and now appears as Task 8.6, Water Temperature Observations.

12.5 Task 10.5 Atlas of Lake Ontario Physical Properties

Task Scientist. C. F. Jenkins

Objectives. The objectives of this task are to develop pertinent analysis information, to prepare a summary publication, an atlas of selected data and analysis results to depict the physical environment observed during the IFYGL, and to develop and present this information in forms useful for engineering and design purposes as well as for future research purposes.

Background. Data have been collected and are being analyzed by a great many scientists as a part of the IFYGL program. These data and analysis results will be published in many forms and in many separate reports and articles. By pulling together information from many sources and developing some special formats, it will be possible to summarize the data and analysis results so that they will be of value for both engineering applications and research in the future. While it is recognized that a 1-year data collection does not provide a climatology, it is believed that a comprehensive data collection and analysis effort, such as the IFYGL, provides a unique source of information for future Great Lakes activities as a background of knowledge.

Interrelationships with Other Tasks. This task will use products from Projects 1, 2, 3, 6, 7, 8, and 10. These projects all have tasks involving analysis of IFYGL data that will result in statistical or graphical depiction of the analysis results.

Approach. The format and contents of the atlas will be developed through an iterative process by the IFYGL participants. Data from the IFYGL program and other sources will be collated into a mockup that will be reviewed for completeness, format, and content details. Participants will then be requested to develop specific charts, tables, graphs, etc., designed for the most useful data presentation. The atlas will be collated at GLERL and processed by ESIC through technical editing and final preparation of graphics. Printing and distribution will result in the placement of hard-bound copies in libraries and organizations where the most extensive use is anticipated or where special requests are generated. Conceptually, the atlas will summarize or excerpt pertinent temporal and spatial variations and variability of all the physical variables of importance for various engineering applications and for scientific uses in graphical and tabular form. Detailed scientific reports in the various IFYGL projects and tasks will contain more in-depth analysis results.

Products. The product will be a one or two-volume atlas containing a summary of the field year results. Contents will include information on parameters measured in and over Lake Ontario and its basin. Parameters for which information will be presented will include the following:

Water levels	Precipitation
Currents	Winds
Water temperature	Total dissolved solids
Air temperature	Ice
Specific humidity	Waves
Inflow outflow	Light penetration
Tributary flow	Radiation/sunshine

Presentations will be in the form of maps of mean values (weekly, monthly, etc.), histograms, time series, statistics (means, variances, extreme values, spectra), and episodes when special features are noted in the lake and basin.

The users of this atlas are expected to be government and private organizations concerned with the following:

Environmental impact studies	Local political decisions
Construction and design	Navigation
Recreation	Public information
Environmental Conservation	Research

Schedule. The following are the major milestones:

Activity	Beginning Date	Completion Date
Workshop on IFYGL atlas.	October 1974	Complete
Preparation of atlas mock-up's.	October 1974	Complete
Collation of atlas inputs.	December 1974	Complete
Review of collated atlas by contributors and others.	March 1975	Complete
Coordination with SUNY on Sea Grant Lake Ontario climatic atlas preparation.	June 1975	Complete
Review of draft atlas by GLERL Director.	August 1975	Complete
Coordination with ESIC on mechanics of publication.		Complete
Preparation of base maps and formatting of presentations in Rockville.	November 1975	December 1975
Determination of final atlas content and formats and preparation of guidance for contributing authors.	November 1975	January 1976
Workshop on atlas.	January 1976	January 1976
Preparation of final atlas and approval by GLERL Director.	January 1976	July 1976
Editing, printing, and distribution.	July 1976	December 1976

Resources.

Staff (% of time):		CY 1976 (Quarters) 1	2	3	4
C. F. Jenkins		20	20	20	20
Technician and Typist			30	10	
Contributors:	Aubert, E. J.				
	Almazan, J. A.				
	Bolsenga, S. J.				
	Liu, P. C.				
	Pickett, R. L.				
	Pinsak, A. P.				
	Quinn, F. H.				
	Saylor, J. H.				
	Sloss, P. W.				

13.0 Project 11 International Field Year for the Great Lakes (IFYGL)

Project Scientist. E. J. Aubert and C. F. Jenkins

Objectives. The objectives of this project are to successfully complete the data management, archiving, analysis, and modeling activities of IFYGL as internationally agreed to in the IFYGL Technical Plan; to maximize the analysis and modeling results as much as is feasible within the available time and resource constraints; to document the elements of the program so that the IFYGL data and analysis results are of the highest possible utility in furthering the understanding of the Great Lakes and in aiding the Great Lakes resource managers in their planning and decision-making capacity.

Background. IFYGL was conceived as a part of the International Hydrological Decade (IHD) - 1965 to 1975 - and is a joint Canadian-U.S. program of environmental and water resources research in the Great Lakes, specifically Lake Ontario and its basin. The National Academy of Sciences in the U. S. and the National Research Council in Canada are responsible for general policy as related to the studies of worldwide water resources. In 1970, NOAA was made the lead agency for administering the U. S. part of the program and for coordinating this with the Canadians. The IFYGL Project Office was formed under the Associate Administrator for Environmental Monitoring and Prediction. As of April 1974, the IFYGL Project Office was incorporated into the new Great Lakes Environmental Research Laboratory under ERL. The results of IFYGL are expected to provide a scientific basis for improved Great Lakes management activities related to water quality and quantity and environmentally sensitive operations.

There are six major components of IFYGL and a synthesis program as follows:

(1) Terrestrial Water Balance

(2) Lake Energy Budget

(3) Water Movement

(4) Evaporation Synthesis

(5) Atmospheric Water Balance

(6) Chemistry and Biology

(7) Atmospheric Boundary Layer

An intensive one-year field observation program was mounted on Lake Ontario and its basin from April 1, 1972 through March 31, 1973 to provide a comprehensive data set including physical, chemical, and biological parameters. Over 600 scientists from Canadian and U. S. government agencies, universities, and private industry participated in the program. The data archive and analysis results will provide a stimulus to Great Lakes applied research for many years to come.

Interrelationships with Other Projects. This project will provide data and analysis results for use in Task 10.5, Atlas of Lake Ontario Physical Properties. Project 3, Lake Ontario Energy Budget (IFYGL) is an integral part of the IFYGL program as are the following tasks: 1.1, 1.2, 1.3, 1.7, 6.2, 6.4, 6.5, and 7.3. Several other projects and tasks are partly involved with IFYGL; e.g., Task 2.1.

Approach. The IFYGL program will continue to be monitored, coordinated, and managed both through direct funding and management by the GLERL as well as through the IFYGL Joint Management Team, Joint Steering Committee, and interagency agreements. Additional research tasks in analysis and modeling will be added to fill gaps in the research, to maximize the utility of the products, and to fully utilize the data collection. The Environmental Data Service of NOAA will continue to carry out the data management and archiving activities under the general direction of GLERL. The analysis work in each of the seven major scientific discipline areas (panels) will be monitored through the Joint Management Team. Task work is also being carried out under contract and interagency funding.

Products.

(1) Data archive (documented) at NCC in Asheville, North Carolina.

(2) Sets of published reports documenting individual projects and tasks.

(3) IFYGL Technical Plan (four volumes).

(4) IFYGL Quarterly Bulletins.

(5) IFYGL Technical Manuals.

(6) IFYGL Summary Scientific Report series covering:

Terrestrial Water Budget program.
Biology and Chemistry program.
Boundary Layer program.
Energy Balance program.
Lake Meteorology program.
Water Movements program.
Evaporation Synthesis program.
IFYGL Program Summary.

Schedule.

Activity	Beginning Date	Completion Date
Development of the IFYGL Technical Plan.		Complete

Preparation for field operations.		Complete
Engineering, tests, and data system comparisons.		Complete
Field year operations.		Complete
Data management - archiving.	August 1971	December 1975
Analysis and final scientific summary reports by panels.	August 1971	September 1977
IFYGL wrap-up workshop.	October 1975	October 1977
Final IFYGL summary report (JMT Co-Chairmen).	August 1977	December 1977

Resources. The budget required for funding of data management; archive activity; analysis & modeling; contracts with universities, industrial organizations, & other government units as well as in-house analysis; coordination & management activities will total close to $1.7M for FY 1976 and funding will continue through FY 1977.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
E. J. Aubert	10	10	10	10
C. F. Jenkins	50	50	50	50
A. Robertson	5	5	5	5

14.0 Project 12 Program Development

Project Scientist. E. J. Aubert

Objectives. The objectives of this project are as follows:

(1) To facilitate the development of multidisciplinary research programs within the mission and objectives of GLERL and of significance to the Great Lakes region where the breadth and interdependence of research program indicates that a project office approach will increase the likelihood of success.

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

(3) To undertake pilot, feasibility, or other preliminary research studies as pertinent 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. IFYGL is a multidisciplinary research program for which GLERL has the NOAA U.S. lead agency responsibility. It was the experience of IFYGL that multidisciplinary research programs have merit and can produce the critical research mass required to attack broad objectives in limnology, hydrology, meteorology, and limnogeology. 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 processes as a logical follow-on to the IFYGL. This new multidisciplinary research program has broad research objectives both from a scientific and user orientation. Further problem definition is required in terms of user needs for environmental information.

Interrelationships with Other Projects. This project is potentially related to all other research projects of GLERL. 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 developed.

Approach. This project involves the problem and program definition phase of research for large or multidisciplinary objectives. Here the approach includes the definition of environmental issues and research needs pertinent to resource development, resource management and environmental hazards. Activities include the definition of 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.

14.1 Task 12.1 Nearshore Environmental Problems

Task Scientist. E. J. Aubert

Objectives. The broad objective of this task is to develop improved environmental information (statistical description, understanding, and prediction) concerning the physical, chemical, and biological variables, processes, and phenomena of importance in the coastal and nearshore regions of the Great Lakes to resolve the environmental problems of Great Lakes resource development and management.

The specific objectives of this task are to undertake program development:

(1) To identify specific environmental issues and information needs of importance to Great Lakes resource development and management.

(2) To develop project plans and program documentation.

(3) To coordinate project plans within NOAA and with potential users and participatory agencies.

(4) To undertake pilot studies, as appropriate.

Background. The national focus on planning, development, and management of the coastal zone and the various conflicting multi-use activities has emphasized a fundamental need for improved understanding of the nearshore physical, chemical, and biological properties and processes of the Great Lakes and the interdependencies between the nearshore and the open lake. Gaps in knowledge exist as pointed out by the National Advisory Committee on Oceans and the Atmosphere (NACOA), but nevertheless Great Lakes States are developing plans for the orderly development and utilization of their shorelands with incomplete knowledge. State shoreline planning is being assisted by the NOAA Sea Grant programs and the Coastal Zone Management programs. A recent workshop on Priority Great Lakes Environmental Research Initiatives also focused on the need for better understanding of the nearshore physical, chemical, and biological processes in the Great Lakes and the interdependent multi-use conflicts of the coastal zone as the current major Great Lakes environmental program.

Under Title II - Comprehensive Research on Ocean Dumping of the Marine Protection Research and Sanctuaries Act of 1972 (PL 92-532), the Department of Commerce is directed to initiate a comprehensive and continuing program of research on the long-range effects of pollution on the aquatic ecosystem. This applied research in Ocean Dumping has a set of research needs for a variety of ecological issues on the Great Lakes involving eutrophication (e.g., oxygen depletion, beach fouling) and hazardous substances (e.g., heavy metals, PCB's, radionuclides, pesticides) which include effects on Great Lakes biota, budgets, source identification, transport and diffusion, distribution and variability, fates and transformations, aquatic ecosystem simulation and prediction, and exchange mechanisms between the lake and land, atmosphere and sediments. Mission agencies; e.g., EPA, U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and ERDA also undertake research within this scope of research needs.

Reference is made to Program Memo 1978-1982 "Great Lakes Nearshore Processes" of November 1975 for the background planning.

Interrelationships with Other Tasks. It is anticipated that interdependencies will be developed with many of the other projects, including Projects 1, 2, 4, 5, 6, 7, 9, and 10.

Approach. Initiatives will be undertaken to define the environmental issues and research needs pertinent to the effects of dumping of materials into the Great Lakes (PL 92-532, Title II, Section 201) and pertinent to the possible long-range effects of pollution, overfishing and man-induced changes of ocean ecosystems (PL 92-532, Title II, Section 202). In this regard, interactions will be undertaken within NOAA and with other agencies. Surveys of Great Lakes dump sites will be considered to assist in program definition. Use will be made of the planning workshop where appropriate.

Products. The output of the program definition phase will be program memoranda and technical plans for studies in Great Lakes Nearshore Processes.

Schedule.

Activity	Beginning Date	Completion Date
Program Memorandum 1978-82.		Complete
Program Memorandum 1979-83.	January 1976	November 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
E. J. Aubert	5	5	5	5
A. Robertson	5	5	5	5
D. B. Rao	5	5	5	5
A. Pinsak	5	5	5	5
Others	10	10	10	10

14.2 Task 12.2 Great Lakes Waves and Flooding

Task Scientist. E. J. Aubert

Objectives. The broad objectives of Great Lakes wave and flooding are to develop and publish improved wave and flooding climatology and to develop and implement improved forecasts of wind waves, storm surge, seiche and run-up.

The specific objectives of this task are to undertake program development to formulate technical and financial plans, to undertake pilot studies as appropriate, and to prepare program documentation.

Background. While the record high lake levels of the past few years have decreased, the potential for natural disasters resulting from shore flooding and shipping losses remains. These result from storm surges, wind waves, and seiches usually associated with strong winds produced by storms. In many instances, residents have to be evacuated from low lying shore areas. As is pointed out by the Federal Coordinator for Meteorological Services and Support Research in "A Federal Plan for Natural Disaster Warning and Preparedness, First Supplement FY 1976-1980," "Objective guidance forecasts of wind waves and storm surge are now available for the Great Lakes. An objective technique exists for forecasting seiches on Lake Michigan, but such procedures are not yet available for predicting this relatively rare event in other areas. Research aimed at producing such procedures is needed."

Considerable damage occurs along the shoreline of the Great Lakes due to the natural effects of wave action and flooding. Shore erosion is one of the major problems of the Great Lakes shoreland. While exposure and shore type; e.g., sand, forested, erodible bluffs, are of prime importance, the major cause of shore erosion is a combination of high water and wind generated wave action associated with storms.

The importance of the erosion and flooding issue is documented by the Great Lakes Basin Commission Framework Study Appendix 12 "Shore Use and Erosion." Likewise, the Joint Federal Regional Council - Great Lakes Basin Commission Task Force for Great Lakes Shoreland Damage Reduction has pointed out that shore erosion and flooding are major water resource problems on the Great Lakes.

Reference is made to Program Memo 1978-1982 "Great Lakes Wave and Flooding Processes" of November 1975 for background planning.

Interrelationships with Other Tasks. It is anticipated that interdependencies will be developed between Projects 2, 7, and 9.

Approach. This task is one of program definition. Interactions are underway with the National Weather Service (NWS) and the Corps of Engineers (COE) to define the issues and research needs of importance to climatology and forecasting. Alternate approaches are being considered to define the natural variability and the forecast problem (e.g., evaluate existing forecasting methods), to develop and test improved forecasts of the surface wind and wind stress, to develop and test improved models to simulate, predict and hindcast, and to develop products useful to the users.

The NWS and COE will either participate in this research or close coordination will be maintained. The approach will build upon the operational and research state-of-the-art in IFYGL, GLERL, NWS and COE.

Products. Revised Program Memoranda will be developed as necessary to assist in the program definition phase. Detailed Technical Plans will be developed as appropriate.

Schedule.

Activity	Beginning Date	Completion Date
Revise Program Memo 1978-82.	Underway	January 1976
Program Memo 1979-83.	July 1976	November 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
E. J. Aubert	5	5	5	5
F. H. Quinn	5	5	5	5
D. B. Rao	5	5	5	5

14.3 Task 12.3 Fox-Wolf River Basin Study

Task Scientist. E. J. Aubert and A. P. Pinsak

Objectives. The broad objective of this study planned by the Great Lakes Basin Commission (GLBC) is to undertake a water resources Level B planning study of the Fox-Wolf River Basin and Green Bay. GLERL is programmed to support the GLBC along with other federal agencies and the State of Wisconsin.

The specific objectives of this task are of a program development nature:

(1) To define the desired GLERL role for participation in the Fox-Wolf River Basin Study.

(2) To examine the issues and the research needs of the water resource planning studies contemplated, and the applicability of existing environmental engineering models.

(3) To undertake preliminary development or modification and test of additional environmental engineering models, as appropriate.

Background. The GLBC contemplates undertaking a 2-year study of the Fox-Wolf River Basin during FY 1977 and 1978 which will involve various federal agencies and the State of Wisconsin. A Proposal to Study was prepared which presents the initial technical plan for this study.

The need for a Level B study for the Fox-Wolf River Basin and Green Bay is in recognition of the urban-industrial problems and the various interdisciplinary evaluations that will be required to solve the problems of the area. The water and related land resource needs and problems of the area are diverse. The major problems are those relating to municipal and industrial wastewater discharges, methods of agricultural land use, rural and urban flooding, stream-bank erosion and sedimentation, deterioration of recreational areas, disappearance of important sports fish population, and plant nutrient enrichment of streams and lakes. Eutrophication is a critical problem in the Basin, with particular concern and action needed for Green Bay, Lake Winnebago, and for restoration of eutrophic small lakes. The most severe water pollution problem in the State of Wisconsin and one of the most severely polluted areas in the nation, occurs on the lower Fox River and in Green Bay. This problem is the result of inadequately treated wastewater discharges, primarily from paper mills and municipalities. The pollution condition is further increased by the discharge of nutrient-rich algae-laden waters from Lake Winnebago to the lower Fox River. The upstream portion of the Basin also suffers degraded water quality conditions in many of the small lakes and streams. These pollution conditions primarily result from municipal point source discharges, from seepage, from septic tanks, and run-off from agricultural lands. Silt-laden streams are common in the rural areas, and these streams also receive quantities of chemicals used in farming. The Governor of the State of Wisconsin and the Wisconsin Department of Natural Resources have assigned the highest priority for study and analysis to the Fox-Wolf River Basin and indicate a need for an intermediate Level B planning stage to be conducted at the earliest possible date.

Interrelationships with Other Tasks. It is anticipated that interdependencies will be developed with Projects 1, 4, 7, 9, and 10.

Approach. A team of GLERL scientists will review the documentation of the Fox-Wolf River Basin Study and interact with the GLBC staff to define the water resource planning study contemplated. This GLERL team will then conceptualize the modeling approaches most suitable for this study considering the state-of-the-art in engineering models. Gaps in knowledge and research needs for improved environmental engineering models will be identified. A desired role for GLERL in the Fox-Wolf Study will be identified.

Environmental engineering model development and test will be initiated as GLERL staff and resources are available.

Products. A Program Memo will be developed which defines the desired GLERL role in the Fox-Wolf River Basin Study.

Schedule.

Activity	Beginning Date	Completion Date
Review Proposal to Study.	April 1976	May 1976
GLBC Staff Interaction.	June 1976	June 1976
GLERL Program Definition.	June 1976	August 1976
Develop Program Memo.	August 1976	September 1976

Resources.

	CY 1976 (Quarters)			
Staff (% of time):	1	2	3	4
E. J. Aubert		5	5	
A. P. Pinsak		10	10	
A. Robertson		5	5	
D. B. Rao		5	5	
S. C. Chapra		10	10	
Other staff, as required		20	20	

U. S. GOVERNMENT PRINTING OFFICE 1975 - 677-347/1252 Reg. 8