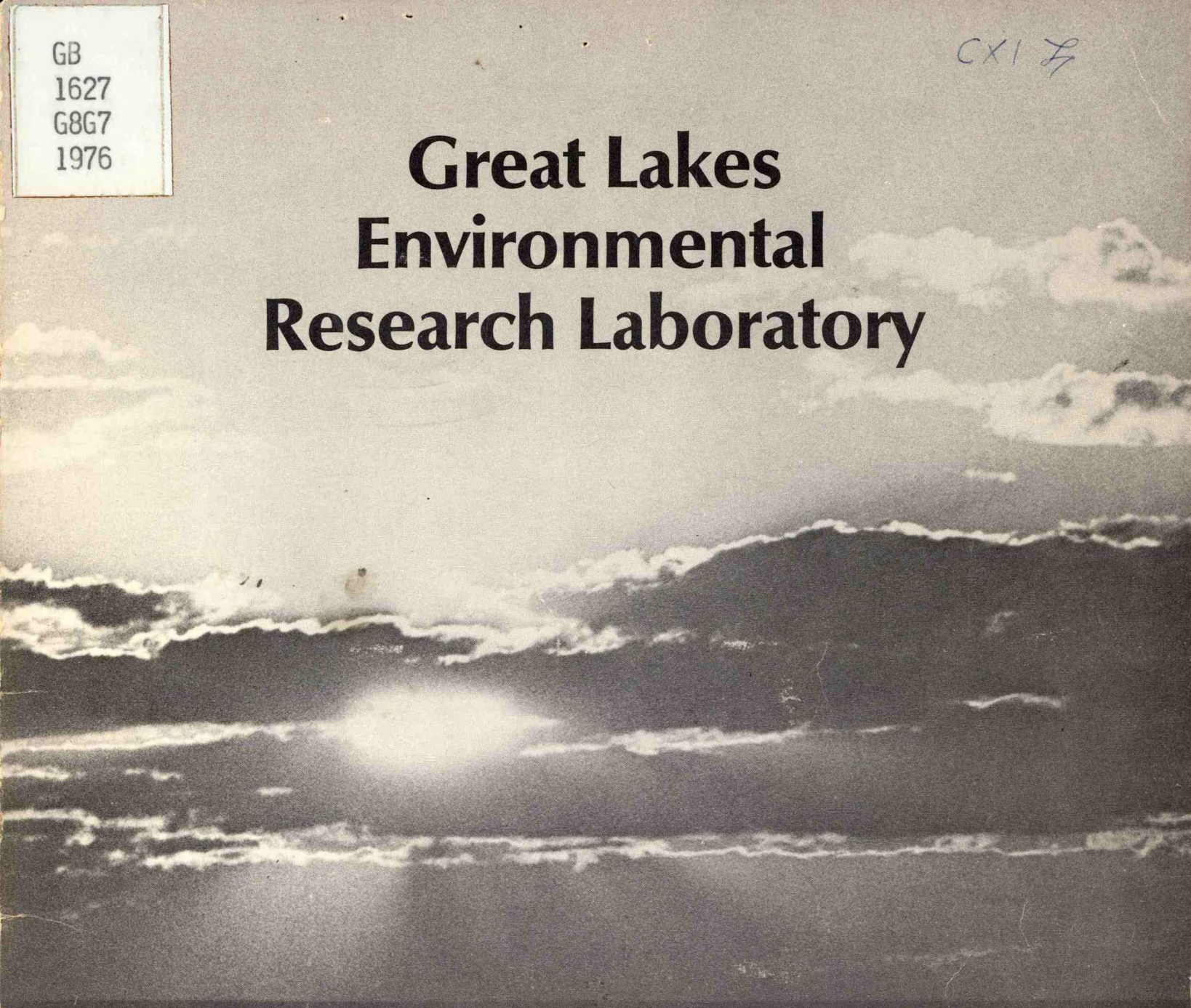
Great Lakes Environmental Research Laboratory



ANNUAL REPORT FY 1976

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

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY ANNUAL REPORT FY 1976

Eugene J. Aubert, Director

October 1976

U.S. DEPARTMENT OF COMMERCE
Great Lakes Environmental Research Laboratory
Environmental Research Laboratories
National Oceanic and Atmospheric Administration
2300 Washtenaw Avenue
Ann Arbor, Michigan 48104

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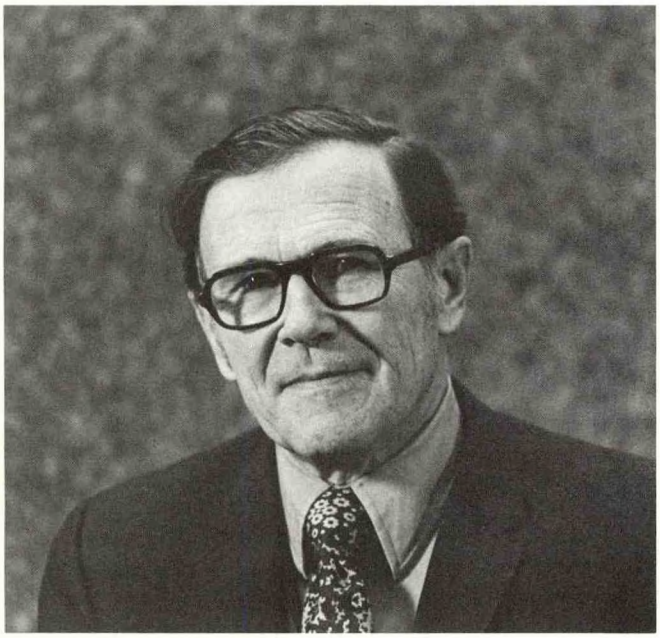
DIRECTOR'S PREFACE



GLERL Director—Eugene J. Aubert.

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

Understanding the complex lake-land-atmosphere system of the Great Lakes region and the many interactions that influence our lives in this region requires a team of scientists with many different backgrounds working together. The GLERL team includes scientists with capabilities in the fields of meteorology, geology, hydrology, physical limnology, aquatic chemistry, aquatic biology, applied mathematics, systems engineering, computer systems applications, instrument design and development, and experimental design and analysis.

The ultimate goal of the GLERL program is to understand the lake-land-atmosphere system to the extent that environmental simulation and prediction models can be built to provide adequate information on Great Lakes processes and phenomena to support the best possible use of the region's resources.

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

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

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

Other outlets for GLERL products include requests from private organizations and individual citizens. The scientific community is informed of the products through journal articles, NOAA Technical Reports and Memoranda, and presentations at society meetings. The location of GLERL in Ann Arbor with The University of Michigan provides for graduate student participation in GLERL projects. Visiting scientists have participated in GLERL research studies and this activity is continuing.

We expect that the future program will include even greater participation of GLERL scientists with the international, Federal, regional, state, and local organizations, private institutions, and individuals requiring GLERL products and expertise.

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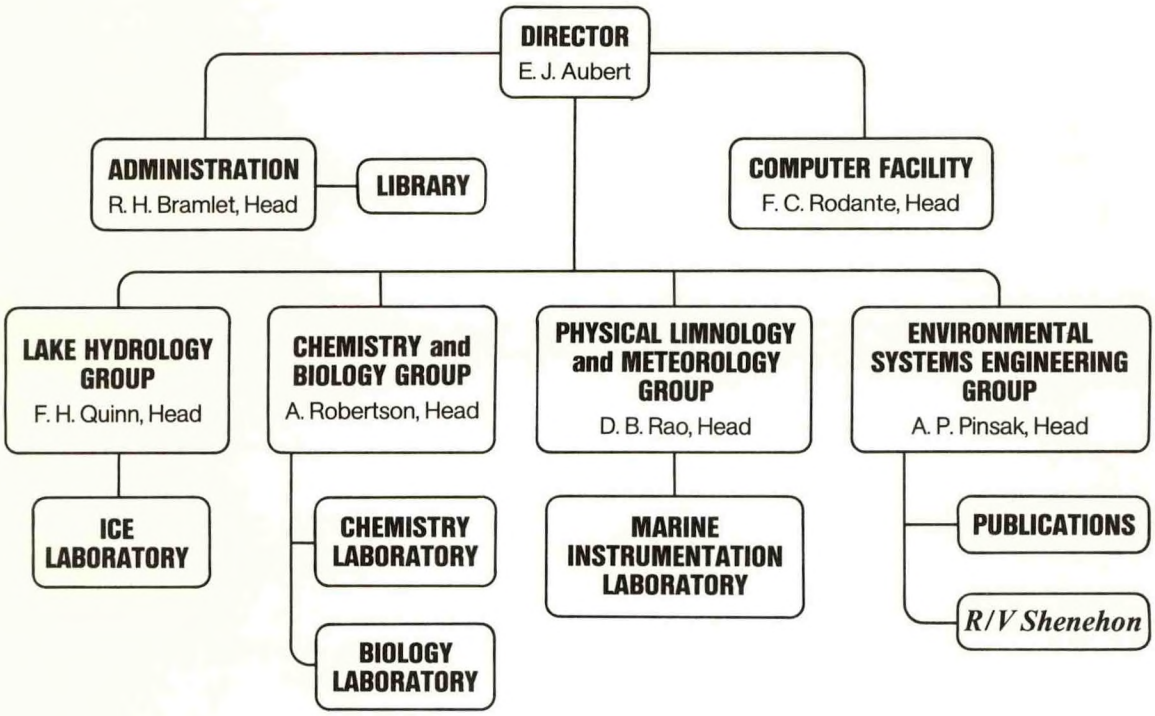
GLERL ORGANIZATION CHART



HIGHLIGHTS

Now, after its second year of operations in Ann Arbor, the laboratory has attained a firm organizational structure and the research program a better balance of experimental, theoretical, and numerical model studies in process and in problem-oriented research. The January 1976 *GLERL Technical Plan* reflects the gradual phase-over of work from the International Field Year for the Great Lakes (IFYGL) to other problem areas and to other lakes.

The GLERL research program is organized into four major groups: Lake Hydrology, Physical Limnology and Meteorology, Chemistry and Biology, and Environmental Systems Engineering. Laboratory support facilities are appended to various groups. Staff participate in process research and in problem-oriented multidisciplinary research. Large programs, such as IFYGL, require staff from all the groups.

Our support facilities have matured, with the chemistry, biology, marine instrumentation, and computer laboratories all reaching an increased level of capability in staff and equipment to become an integral part of the research effort. In concert, the marine instrumentation laboratory and the computer laboratory are developing hardware and software to automate the observing, recording, and data management-editing functions for several of our major data collection systems. A microprocessor based data acquisition system has been engineered and includes a data logger and a Hewlett Packard 9603A Scientific Measurement and Control System. The system is operational for surface wave measurements and will be operational in 1977 for current meters, meteorological buoys, towers, the *R/V Shenehon* meteorological system, and a water chemistry observation system. With the closing of the Lake Survey Center in Detroit, Michigan, the *R/V Shenehon* and the marine facility in Monroe, Michigan, were transferred to GLERL.

The GLERL in-house research program is supplemented by research grants and contracts with private institutions and other agencies. Likewise, GLERL receives some 5 percent of its fiscal support through interagency agreements with other government organizations. The primary GLERL product is the publication of our research results and their presentation and discussion at scientific and user meetings. During FY 1976, 66 papers written by GLERL staff members and 16 papers by GLERL contractors were published, and 22 papers were presented at meetings by GLERL staff.

A highlight of research accomplishments during FY 1976 follows:

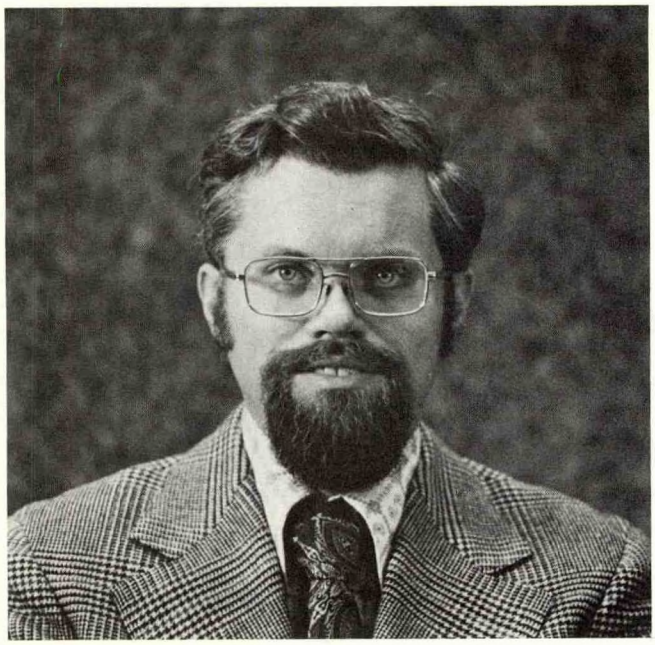
- A mathematical model to simulate the St. Clair River flow was developed. The Detroit River flow model was used to calculate the daily flow entering Lake Erie to support an Environmental Protection Agency (EPA) study of the pollution load.
- Daily evaporation rates were calculated for Lake Ontario by use of a mass transfer technique with the IFYGL data base and compared with other techniques, i.e., bulk transfer, terrestrial water balance, and atmospheric water balance.
- The monthly and annual flux of water through the Straits of Mackinac were computed for use in a GLERL water quality study.
- A technique for long-range forecasting of the percent of maximum ice cover on the Great Lakes was developed. This provides considerable improvement over climatology for most situations.
- Analyses of the monthly circulation and thermal characteristics of Lake Ontario during IFYGL were completed. The mean circulation sometimes shows a single cyclonic cell and sometimes two counterrotating cells. A comparison with a wind-driven numerical model shows some features of agreement, but some areas of disagreement have yet to be explained.
- The extensive winter current measurements made in Lake Huron during November 1974-May 1975 were analyzed. Results show that Lake Huron is characterized by a cyclonic flow pattern during the winter months.
- A comprehensive field experiment was undertaken from May to November 1976 to study the coastal current and temperature distribution in the southern basin of Lake Michigan.
- A four-level numerical hydrodynamic model of Lake Ontario was developed; it is now being tested on IFYGL data.
- Surface wave studies are being conducted to investigate the usefulness and applicability of empirical fetch-limited spectral formulas.
- Surface wave measurement systems were deployed in southern Lake Michigan in 1976 to study wave characteristics and the effects of wind fetch, duration, and depth.
- Studies were completed on the barotropic free oscillations of Lakes Michigan and Huron. Theoretical calculations of the periods and structures of several gravitational modes compare favorably with properties derived from spectral analyses of water level data.
- A one-dimensional, three-layer ecological model simulating seasonal changes was developed and tested on Lake Ontario for phytoplankton, zooplankton, detritus, nutrients, and benthos; it yields reasonable results. A three-dimensional ecological model of similar design, but incorporating lake hydrodynamics, was developed by a GLERL contractor.

- A two-layer ecological model was tested on each of the Great Lakes. Results for phytoplankton carbon and available phosphorus were good for the deeper lakes but poor for Lake Erie, owing, it is believed, to a seasonal variation in Lake Erie loads and to an inadequately modeled sediment-water exchange process.
- The chemistry of Lake Michigan in the vicinity of the Grand River was studied to increase our understanding of the movement of dissolved and suspended pollutants from a river into a large lake. The suspended load is deposited close to the river mouth. Further work is required on processes of resuspension, precipitation, and dissolution in order to predict the fraction of a chemical load that will reach the open lake.
- A unique IFYGL data series on oxygen profiles in Lake Ontario was analyzed. Oxygen levels can provide an excellent integrated view of the process of eutrophication in a lake. Oxygen levels fell below saturation during August and September 1972 for the total hypolimnion. Results that indicate the effects of storms were obtained.
- Studies were performed to investigate the milky appearance that occurs in summertime in Lakes Ontario and Michigan. Carbon budget studies have suggested that this phenomenon, which can be seen on satellite photographs, is due to calcium carbonate. Our studies confirm large numbers of calcite crystals present.
- A water quality model of Maumee Bay and western Lake Erie was developed and used successfully to assist in tradeoff analyses of alternative water resource plans in the Maumee River Basin.
- A phosphorus model to simulate the long-term variation of phosphorus concentration in the Great Lakes and to estimate phosphorus loads from point sources, land drainage, and the atmosphere was developed and tested. Results for phosphorus reductions consistent with the water quality agreement indicate a significant improvement in algal production for all lakes except western Lake Erie.

Significant IFYGL accomplishments include the following:

- The IFYGL data archive has been completed.
- Development of simulation and prediction models for several physical, chemical, and biological processes and phenomena in Lake Ontario shows promising results.
- The first of the 12 international summary scientific reports—Precipitation Project—has been completed.

LAKE HYDROLOGY



Lake Hydrology Group Head—Frank H. Quinn.

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

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

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

Hydrology

During FY 1976, a numerical hydraulic transient model of the St. Clair River flow was developed and tested. The model is now operational on the CDC 6600 computer. This model, in conjunction with the existing Detroit River flow model, was used to coordinate estimates of the Detroit and St. Clair Rivers monthly flows for the International Coordinating Committee on Great Lakes Basin Hydraulic and Hydrologic Data. The model was also used to support the IJC, Corps of Engineers, EPA, and GLERL water quality studies. Plans include the development of a transient model of the flow in the Niagara River.

Among the several studies completed or underway to improve and apply the operational hydrologic response model of the Great Lakes and the associated hydrologic data base (which contains data for the terms in the hydrologic cycle) is the computation of the net annual and monthly flow between Lakes Huron and Michigan for the period 1950 to 1966. This shows a variation of 500 percent between the maximum and minimum annual flows. The average flushing time for Lake Michigan was calculated from the mean annual flow through the Straits of Mackinac as 137 years; the average flushing time was estimated from additional information on the flow characteristics in the Straits of Mackinac during summer stratification as 69 years for Lake Michigan.

In addition, a data base on the beginning-of-month lake levels and changes in storage for each of the Great Lakes and Lake St. Clair was developed and published. Plans are to augment this data base yearly.

The basin runoff data for Lakes Michigan and St. Clair were extended from 1966 to the present. Annual augmentation of runoff data is comtemplated for all the Great Lakes.

Studies continue on evaporation estimates. Monthly evaporation estimates for Lake St. Clair for the period 1950 to 1975 have been determined by procedures developed and published for Lake Erie. Monthly Lake Superior evaporation estimates are planned for completion in FY 1977. Daily evaporation estimates for Lake Ontario have been computed by using the mass transfer method and the overwater physical data base. Comparisons have been made of the evaporation as computed by the mass transfer, bulk transfer, terrestrial water balance, and atmospheric water balance

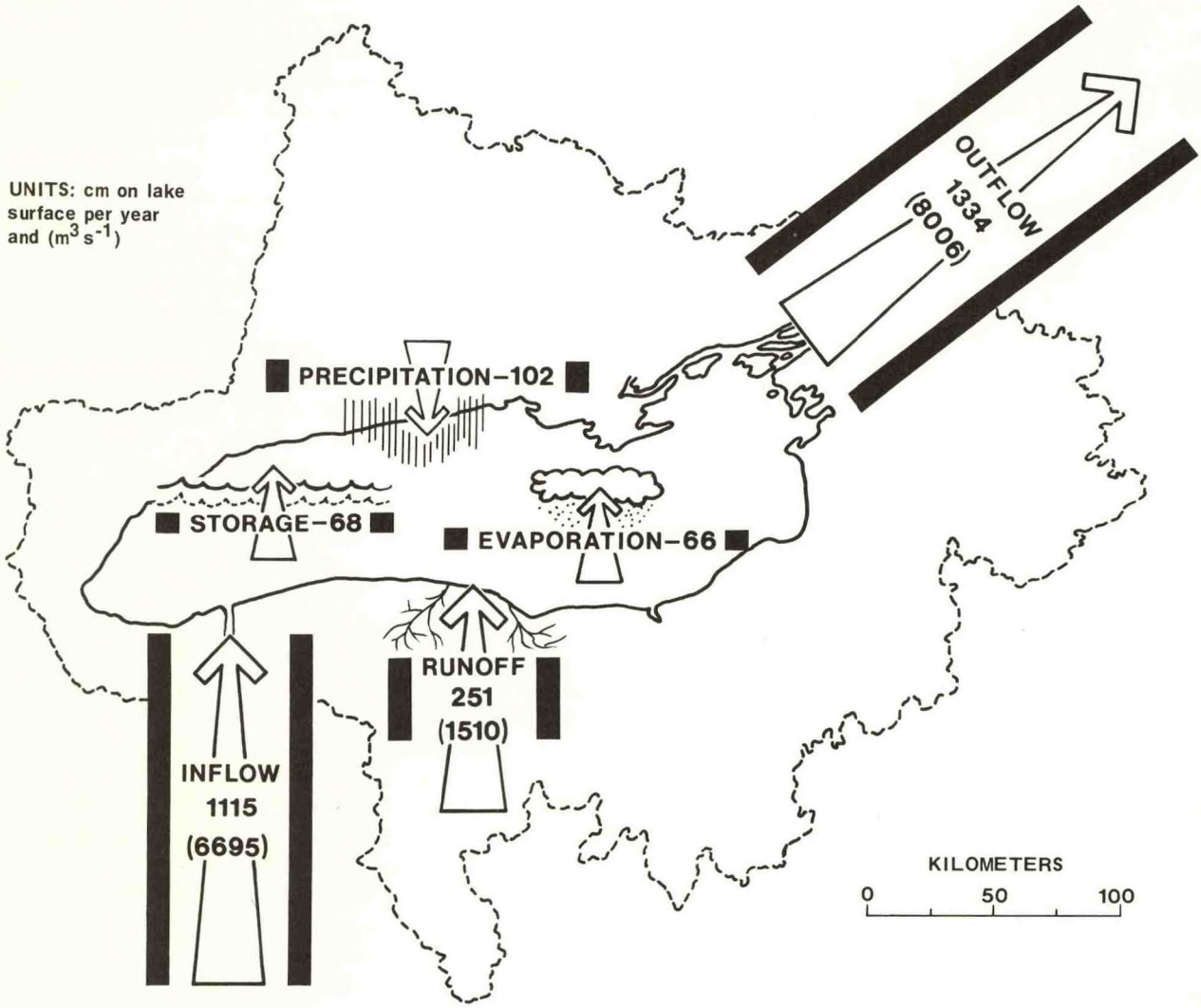
Lake Erie wind tide at Gibralter, Michigan, 9 April 1973. High lake levels such as this can cause extensive property damage and even loss of life.
(Photograph by *The Detroit News.*)

procedures. This evaporation synthesis work will also be completed in 1977.

A 5-year data set was analyzed to improve estimates of Lake Michigan monthly precipitation by using island data. It yielded negative results: the island precipitation data does not improve the over lake precipitation estimate. The analysis of the Lake Ontario precipitation data will be completed within the next few months.

A study is underway to develop a watershed model for the subbasins of the Great Lakes system. Two conceptual models containing an explicit moisture accounting procedure have been obtained and are being converted and tested. Initial model calibration and testing for the Genesee River Basin, in upper New York, is planned for FY 1977.

Also planned for 1977 is a study to quantify the historical effect of Lake Superior regulation on the water levels and flows of the downstream lakes.



The hydrologic cycle of Lake Ontario.

Ice

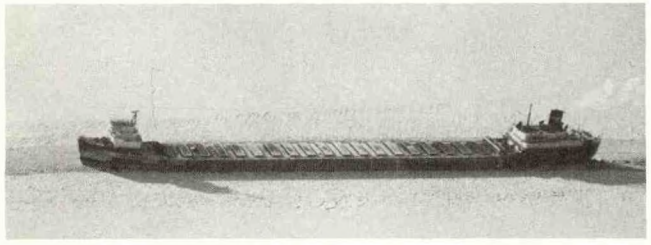
Much of the effort in ice prediction is directed toward winter navigation problems and the associated Demonstration Program to Extend the Navigation Season on the Great Lakes and the St. Lawrence Seaway. For example, a technique developed in 1975 for predicting water temperatures and time of ice formation on the St. Lawrence River at Massena, New York, is now operational at the National Weather Service. A technique to forecast times of ice break-up on the St. Lawrence River is planned. In addition, a long-range forecast technique of the percent maximum ice extent on the Great Lakes, based on pre-winter thawing and wintertime freezing degree-days, was developed. It was found to be a considerable improvement over climatology for most situations.

Data collected on Lake Superior the past four winters will be analyzed to examine winter thermal regimes and heat storage in that lake for use in the development of ice prediction techniques. Water temperature data were collected by using bathythermographs during a series of wintertime cruises across Lake Superior and by means of monitoring equipment in selected bays, harbors, and connecting channels.

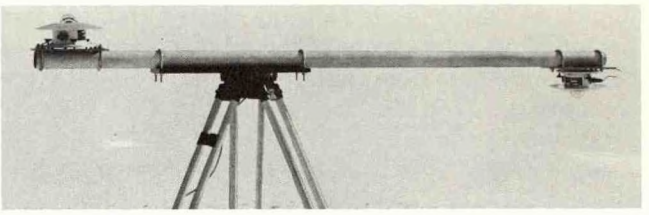
A project was initiated to determine the optical properties of ice types common to the Great Lakes and of use in improved ice forecasting. Measurements of the diurnal variation of albedo for certain ice types were made during the 1975-76 season. Significant day-to-day changes in albedo were noted for certain ice and atmospheric conditions.

Several experimental studies are underway to develop an improved ice climatology of the Great Lakes useful to engineers, shippers, and researchers.

One such study involves the analysis of satellite imagery, side-looking airborne radar (SLAR) imagery, and ice charts based on visual aerial ice reconnaissance and SLAR imagery. Data from the 1974-75 winter were analyzed and weekly charts showing ice-cover concentrations and distribution were produced to



Ore carrier moving through a channel in the ice on the St. Marys River. The Demonstration Program to Extend the Navigation Season on the Great Lakes and the St. Lawrence Seaway will help stimulate and stabilize the economy of the entire Great Lakes area.



Tripod-mounted pyranometers. This system measures the incident and reflected solar radiation over an ice surface.

LANDSAT-1 near-infrared image of Green Bay, 13 February 1975. Satellite pictures such as this aid in the analysis of the Great Lakes ice cover.

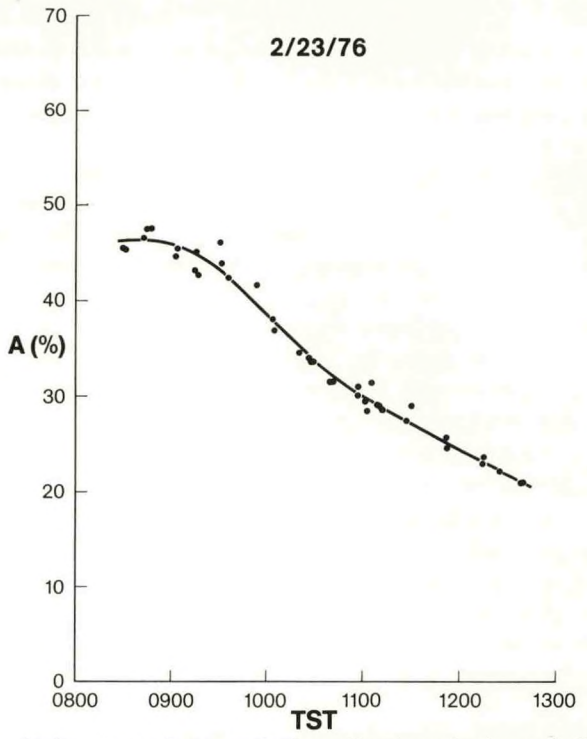
depict the ice conditions on the Great Lakes for that winter. Similar data were collected this past winter to develop the data base required for the improved ice climatology. This ice data collection and analysis program will continue in FY 1977.

During the 1975-76 season, the ice thickness measurements were continued. These provide data useful to siting, construction, and protection of shore structures. Analysis of the historical data was initiated and computer graphics of portions of the information are now available.

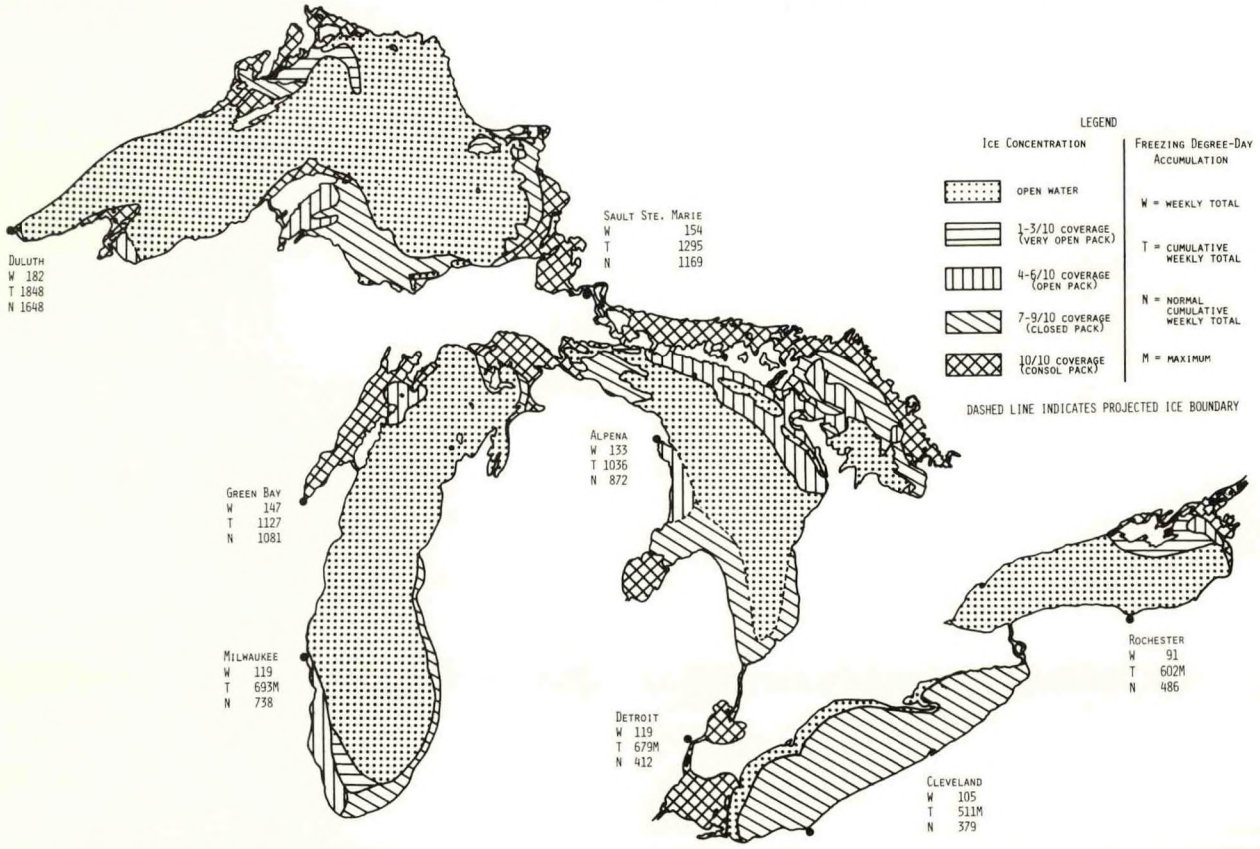
Results of a feasibility study completed to interpret remotely-sensed radiance data from the NOAA very high resolution radiometer (VHRR) visible imagery in terms of ice-cover concentration and extent indicate that the NOAA-VHRR imagery was useful for visual subjective estimates of ice-cover concentration and extent. Objective methods using an ice classification method were unsuccessful.

Consulting advice on ice characteristics problems was provided to the Corps of Engineers and the State University of New York.

The Detroit-based ice laboratory facility was closed in 1976, but plans exist to reopen the laboratory in Ann Arbor in 1977.

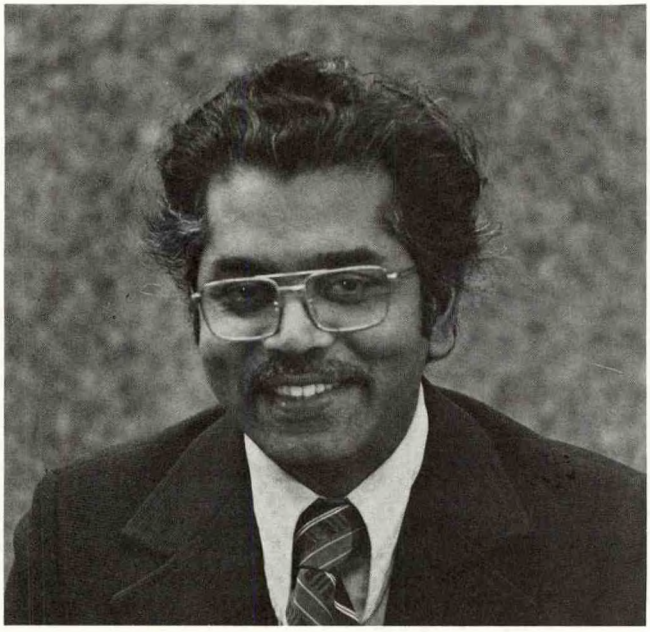


Graph showing a decrease in the reflection of solar radiation by lake ice during a period of melting.



Weekly ice chart for 8 February 1976. This is a composite of ice-cover information collected primarily from aerial ice reconnaissance and satellite and radar ice-cover imagery. It is an estimate of ice concentration and distribution on the Great Lakes for a particular date.

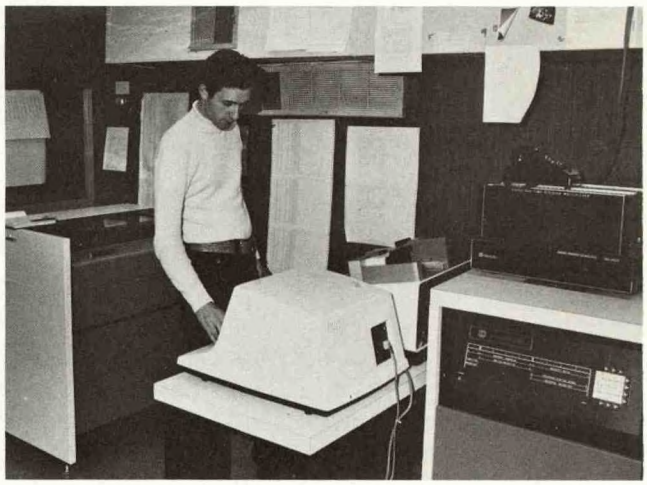
PHYSICAL LIMNOLOGY AND METEOROLOGY



Physical Limnology and Meteorology Group Head—Desiraju B. Rao.

The work in physical limnology and meteorology is in two broad projects: (1) water circulation, transport, and diffusion and (2) surface waves and oscillations. In each of these projects, the purpose is to improve understanding of the processes and to better predict the currents, temperatures, wind waves, etc. This improved understanding and prediction are important to user activities such as waste management, power generation, fishery management, water supply management, etc. The circulation, transport, and diffusion must be understood in order to predict the chemical and biological properties of the lake environment. Waves and oscillations present potential hazards important to shoreline property owners, navigation, commercial and sport fishing activities, recreational boating, beach erosion, coastal zone management activities, ship design, etc.

The phenomena needing study range in scale from annual and seasonal in time and hundreds of miles in space down to those with significant time variations in hours and seconds and space scales in feet. Of importance are a set of lake phenomena with common and scientific names: seasonal circulation, internal Kelvin and topographic waves, internal Poincaré waves, coastal jet, upwelling and downwelling, thermal bar, and seasonal stratification—all subjects for investigation in the water circulation project; and wind set-ups, seiches, storm surges and pressure jumps, surface waves, and short internal waves are phenomena for investigation in the surface wave and oscillation project. The studies are diverse in nature, comprising observational programs, data analyses, numerical simulations, and other theoretical studies.

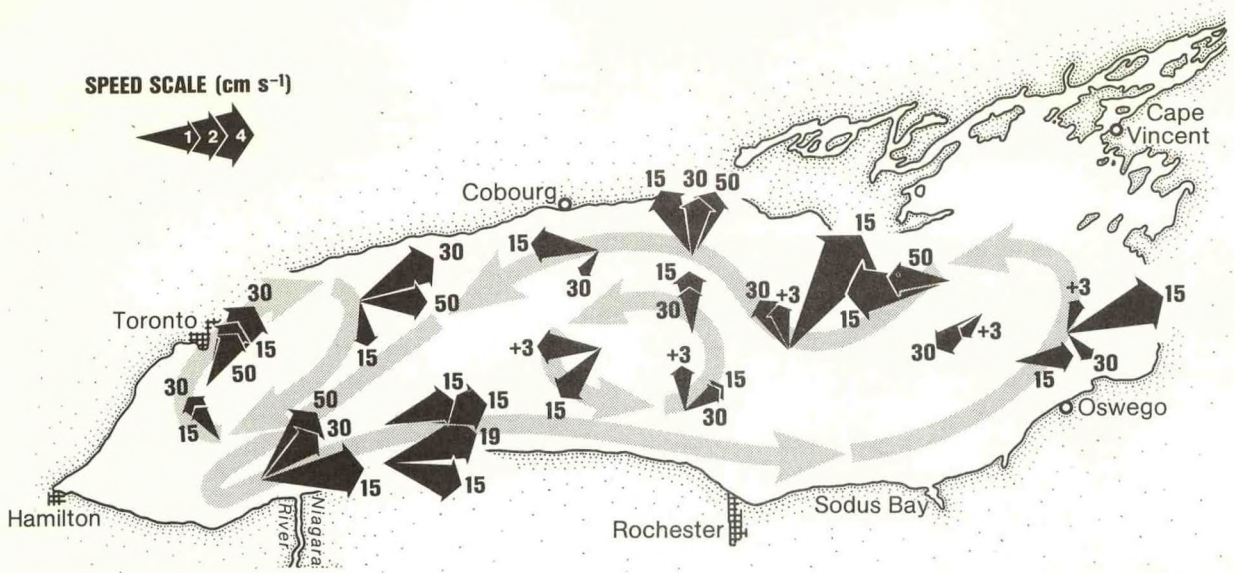


GLERL scientists use the Harris 1600 Remote Communications Processor to run simulation models or process data on the CDC 6600 computer in Boulder, Colorado.

Water Circulation, Transport, and Diffusion

Studies on the IFYGL program continued in FY 1976 in-house and under contracts. Some of the completed studies dealt with Lake Ontario water movements and temperature patterns near the coast in the spring, summer, and fall of 1972. The so-called "coastal jet" was examined in detail by the use of data from "coastal chains" at five coastal areas in Lake Ontario. This coastal flow pattern, including coastal waves and the upwelling and downwelling characteristics, is important in the transport and mixing of materials entering the lake from the basin. The seasonal variation in this coastal flow pattern and its relationship to the wind and temperature structure were studied as a part of this task. Other studies underway deal with detailed analyses of lake dynamics, principally the internal wave characteristics.

Data from adjacent Canadian and United States IFYGL automatic data buoys of different design were compared. These buoys recorded wind, air, and water temperatures and currents in western Lake Ontario. Statistical analyses of the data differences show that design accuracies are not generally achieved and suggest that field exposure generally degrades the accuracy by a factor of about two.



Lake Ontario summer currents (at given depths in meters; +3 is 3 m off the bottom). One use of current studies such as this is to aid in understanding the dispersal of pollutants.

The large-scale circulation for Lake Ontario was analyzed by using the buoy data and these results were compared with the output of a wind-driven numerical model. There was agreement in the western section, where a counterclockwise (cyclonic) circulation occurred, but results differed in the eastern portion. The monthly mean circulation patterns for all winter months are now completely analyzed. These indicate that the mean circulation sometimes consists of two counterrotating cells and other times of a single cyclonic cell.

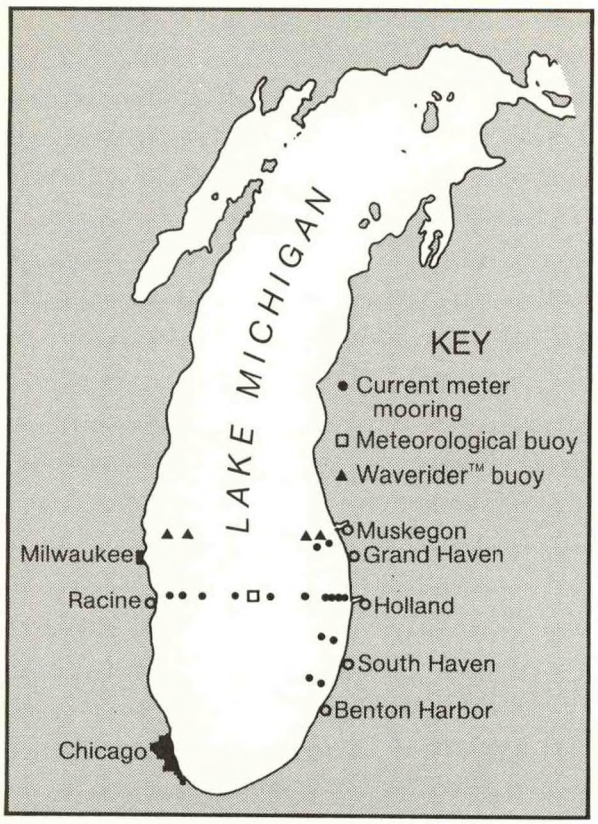
Analyses started on the extensive water current measurements made in Lake Huron during November 1974-May 1975. This study, partly supported by the EPA, was part of the IJC Upper Lakes Reference Study. Results show that Lake Huron is characterized by a cyclonic flow pattern during the winter months, with an especially steady and intense southward flow along the west coast of the lake. The cyclonic flow has many characteristics similar to observed summer circulation. Also completed during the past year was a summary of the present state of knowledge of the physical limnology of Lake Huron for inclusion in the final report of the IJC study.

In a previous study, long period waves of undetermined origin were found in the records of currents through the Straits of Mackinac during the summer and fall of 1974. The waves appear to be independent oscillations of both the Lake Michigan and Huron basins, and a long data record is required to identify these waves. Hence, two recording current meters were set in the straits in October 1975 and will be retrieved in May 1977. The vertical profiles of the flow through the straits during the stratified summer season show a strong flow of relatively pure water into Lake Michigan at depth, while the surface flow is from Lake Michigan to Lake Huron. This means that the flushing time for Lake Michigan is much shorter than indicated by the mean flow pattern.

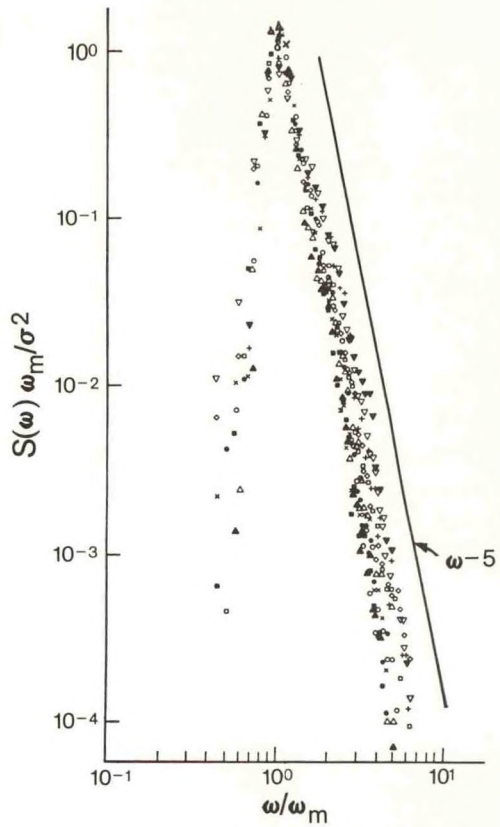
A comprehensive field experiment was undertaken in May 1976 to study the current and temperature distributions in the southern basin of Lake Michigan. Experiments in other lakes have shown that coastal currents are strongest in the first 10-15 km offshore. To study the characteristics of the coastal jet, its longshore variations, and the role of long internal waves propagating along the coastline in the nearshore dynamics, pairs of stations at 7.5 and 15 km offshore were set at intervals of 30 km along the east coast of southern Lake Michigan. A cross section extending from Racine, Wisconsin, to Holland, Michigan, has been instrumented to study the matching of coastal flow with the interior circulation and near-inertial internal waves on the thermocline. The University of Wisconsin-Milwaukee and the University of Wisconsin-Madison are participating in this study program. The field portion of the program was completed in November 1976.

A four-level, fine-mesh numerical hydrodynamic model of Lake Ontario was developed during the past year. IFYGL data were used to test the model's ability to predict the temperatures and currents for the months of May, July, and November of 1972. Further systematic verification and other diagnostic analyses on the whole basin model of Lake Ontario are planned.

Another three-dimensional model has been developed and tested under contract. The major problem to date is to resolve the small-scale nearshore flow properly. Both these models were developed to provide GLERL with the capability to



Locations of buoys for measuring atmospheric and lake water variables on Lake Michigan.



Normalized wave spectra prepared from data collected in Lake Michigan.

incorporate the physical characteristics of the Great Lakes into larger ecosystem models to simulate and/or predict the chemical and biological responses of natural and man-induced changes to the Great Lakes and to alternative resource management strategies. The plan for studies next year consists of continuing the analysis of IFYGL data dealing with lake circulation on a shorter time scale than a month, analysis of current meter data from Lake Michigan and the Straits of Mackinac, development of nearshore numerical circulation models, and further analysis of the large-scale lake model.

Surface Waves and Oscillations

In the area of surface wave studies, an investigation was made to assess the usefulness and applicability to the Great Lakes of the available empirical fetch-limited spectral formulas. These formulas have been applied for two episodes, one on Lake Michigan and the other on Lake Ontario.

It was clear, particularly from the Lake Ontario study, that considerable uncertainties exist in these formulas for application to the Great Lakes and more effort is needed to define the proper values of fetch, effects of atmospheric stability on the wind fields, duration of winds, etc.

A field program is presently underway to study surface wave characteristics in Lake Michigan. Two Waverider buoys were deployed—one at 15 km and the other at 20 km—offshore from Muskegon, Michigan, on the eastern shore of the lake and two more—one at 15 km and the other at 30 km—offshore from Milwaukee, Wisconsin, on the western shore. The data from this Waverider array will be used to examine fetch effects and wave generation and growth processes.

Studies have been completed on the barotropic free oscillations of Lakes Michigan and Huron, taking into account earth's rotation and the topography and geometry of the Lakes, including other connecting water bodies such as bays and channels. These oscillations are caused by atmospheric forcing and clearly show up in water level records. In both the lakes it is clear that there are oscillations dominant only in the connecting bays and others dominant in the main basin.

The plan for studies next year consists of analyses of wave data from Lake Michigan and collection of additional wave data.

TAPE NUMBER: 8172

DAY: 3 MONTH: 11 YEAR: 1972

STATISTICS OF TEN MINUTES

EST HOUR	TAB	RECORD	TYPE	STD DEV	H(AVE)	T(AVE)	H1/3	T(H1/3)
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2.0	13	1868-1879	CD	0.10	0.24	2.00	0.38	2.48
3.0	13	1880-1891	D	0.12	0.26	2.04	0.42	2.52
4.0	13	1892-1903	D	0.14	0.33	2.32	0.53	2.93
5.0	13	1904-1915	D	0.23	0.54	2.84	0.85	3.50
6.0	13	1916-1927	D	0.27	0.65	3.22	1.03	4.04
7.0	13	1928-1939	D	0.35	0.79	3.45	1.28	4.63
8.0	13*	1940-1951	D	0.44	1.07	4.22	1.70	5.17
9.0	14	1952-1963	D	0.51	1.18	4.40	1.97	5.57
10.0	14	1964-1975	D	0.56	1.29	4.64	2.11	5.90
11.0	14	1976-1987	D	0.56	0.95	4.81	2.30	5.76
12.0	14	1988-1999	D	0.52	1.18	4.48	1.98	5.78
13.0	14	2000-2011	D	0.56	1.33	4.99	2.09	6.21
14.0	14	2012-2023	CD	0.49	1.21	5.10	1.86	6.50
15.0	14	2024-2035	D	0.40	0.95	4.40	1.57	5.94
16.0	14*	2036-2047	D	0.36	0.82	4.39	1.36	6.02
17.0	15	2048-2059	D	0.29	0.62	3.38	1.06	5.01
18.0	15	2060-2071	D	0.28	0.65	3.81	1.05	5.05
19.0	15	2072-2083	D	0.26	0.62	3.50	0.98	4.58
20.0	15	2084-2095	D	0.26	0.59	3.20	0.96	4.20
21.0	15	2096-2107	D	0.26	0.61	3.26	0.97	4.06
22.0	15	2108-2119	D	0.22	0.51	3.07	0.83	3.83
23.0	15	2120-2131	D	0.22	0.55	3.26	0.83	3.90

X = SIGNIFICANT HEIGHT PLOTTED 0 TO 5 METERS

0H H H H . H H H H 1 H H H H . H H H H 2 H H H H . H H H H 3 H H H H . H H H H 4 H H H H . H H H H 5

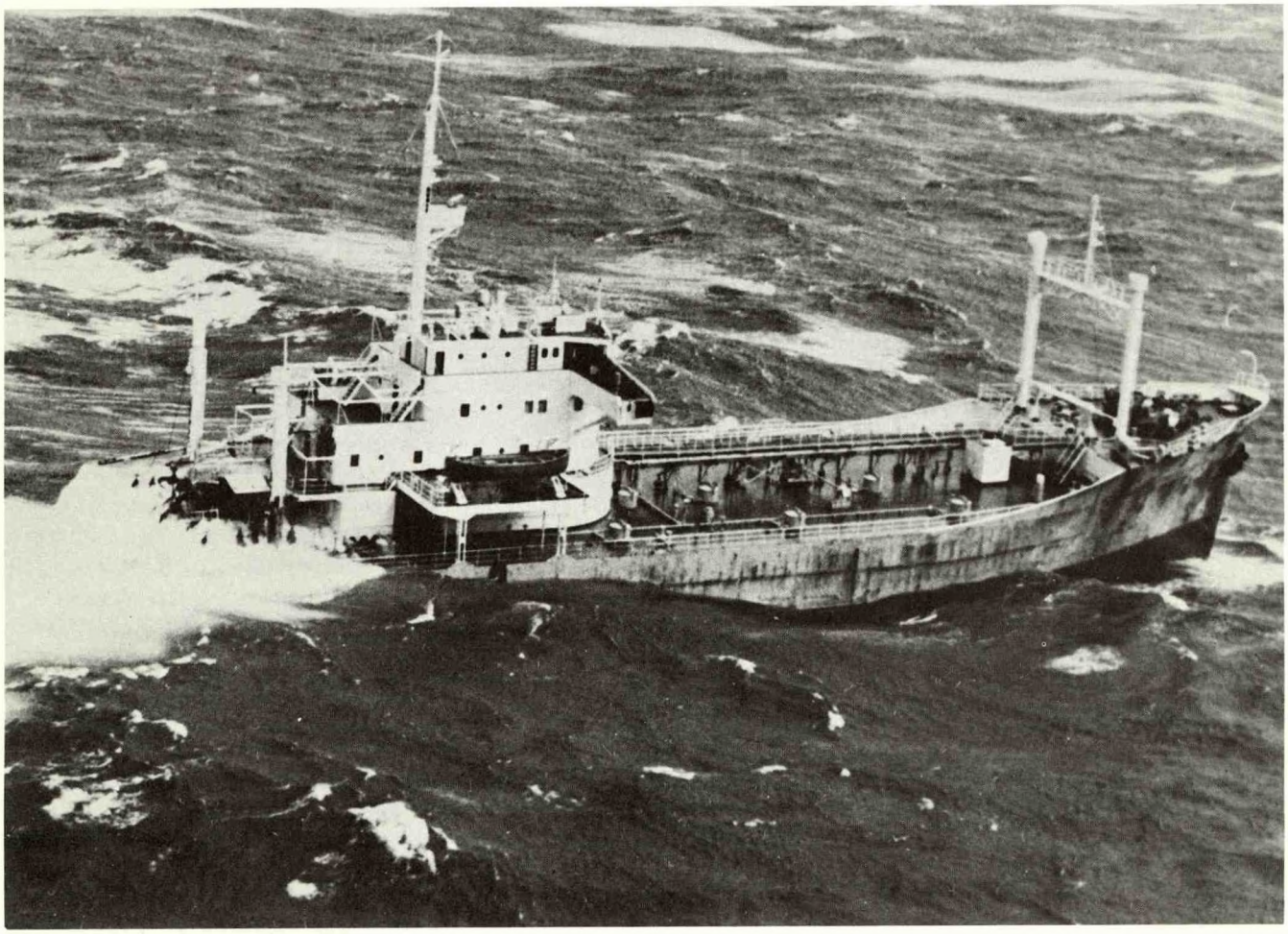
0 T T T T 1 T T T T 2 T T T T 3 T T T T 4 T T T T 5 T T T T 6 T T T T 7 T T T T 8 T T T T 9 T T T 10

+ = PERIOD OF H1/3 PLOTTED 0 TO 10 SECONDS

D = DATA RECORDS C = CALIBRATION RECORDS (10 METER=4 SECOND SINE-WAVE)

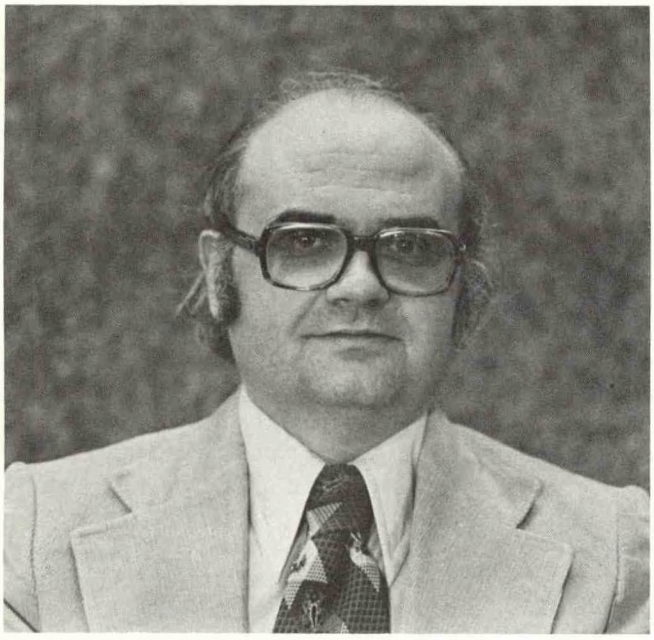
NOTE: EACH RECORD REPRESENTS 5 MINUTES OF DATA AT A NOMINAL DIGITIZING RATE OF 3 SAMPLES/SECOND. WAVE DETERMINATION BASED ON CONSECUTIVE ZERO UP-CROSSINGS.

Computer output of wave buoy data analysis for data collected in Lake Ontario.



Waves can represent a hazard to shipping in the Great Lakes and are a major factor in shoreline erosion. (Photograph by the U.S. Coast Guard.)

CHEMISTRY AND BIOLOGY



Chemistry and Biology Group Head—Andrew Robertson.

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

Ecosystems Modeling

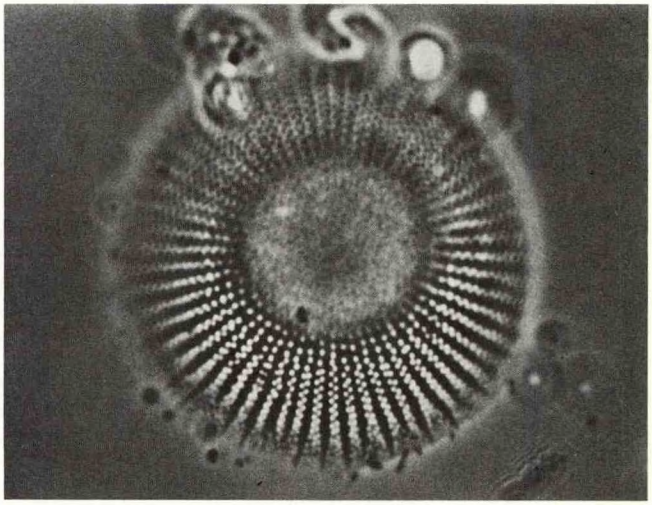
A series of models is being developed at several levels of complexity to realistically simulate the fluctuations in amounts of carbon and other ecologically meaningful components of the Great Lakes ecosystems. Once components are identified and interrelationships are defined, available data, including the IFYGL data base, will be used to test, tune, and verify the models. In the process, research areas requiring further effort will be identified.

A one-dimensional, three-layer ecological model simulating seasonal changes in four types of phytoplankton, six types of zooplankton, detritus, organic nitrogen, ammonia, nitrate, available phosphorus, the carbonate system, and benthic invertebrates was developed, calibrated to pre-IFYGL Lake Ontario data, and tested. Comparisons between predicted and observed rates of primary production, turnover, and the community production to respiration ratios and sedimentation showed good agreement. Predictions of the concentrations of chlorophyll *a*, zooplankton carbon, available phosphorus, Kjeldahl nitrogen, ammonia, nitrate, pH, and CO_2 gas exchange were all consistent with observed values for the period 1967-1971. Sensitivity of the model to diffusion, sedimentation, self-shading, fish predation, and temperature was also investigated. A three-dimensional ecological model similar to that above, but incorporating lake hydrodynamics, was developed by a GLERL contractor.

A two-layer version of the above model, modified to predict total phytoplankton carbon and available phosphorus, was tested in each of the Great Lakes. The accuracy of the simulation results varied in the different lakes. Results were generally good for the deeper lakes but poor for Lake Erie, where sediment-water interaction processes need improved definition and seasonal effects of external inputs must be included because of short residence time.

The two-layer model was modified by adding new terms accounting for silica dynamics and nitrogen-fixing blue-green algae. Comparison with simpler models of phosphorus loading showed agreement except in highly eutrophic situations.

Continued model refinement has included additional water column constituents, sediment kinetics, sediment-water column interactions, and dissolved oxygen, a major indicator of trophic state extremes. Plans for the future include continuing efforts to simulate the IFYGL data set on both one and three dimensions. The model will be used to investigate the Lake



Diatom (2500 X). When a high percentage of the algae in a water sample is in the form of diatoms, the water is fairly unpolluted.

Ontario ecosystem during IFYGL by interpreting the data at both the whole-system and process-interaction levels and by testing certain ecological hypotheses. The model will then be tested on Lake Michigan and Green Bay in both one and three dimensions and detailed comparisons with other modeling approaches (phosphorus loading models and other ecological models) will be made to determine their general consistencies and major differences.

Plankton Studies

An understanding of the Great Lakes ecology and successful ecological modeling requires detailed knowledge of the plankton dynamics in the Lakes, a significant component of the food chain. Until recently, the modeling of plankton biomass dynamics was limited to treating a single or a few groups of phytoplankton and similarly for zooplankton. For many problems of water quality management, information is required on particular groups of phytoplankton rather than just total phytoplankton biomass. In addition, the kinds of zooplankton present may represent the available food and affect fisheries. The ultimate goal of this work is to build a realistic dynamic model of seasonal succession for plankton.

Planktonic succession is being studied in Lake Michigan during summer, the period when nuisance forms of algae may proliferate. The objective is to measure growth rates of different phytoplankton species and relate their growth rates and population dynamics to different nutrient concentrations, grazing mortality by zooplankton, and other parameters. Experiments are underway to measure growth rates of different single species of phytoplankton and, later, combinations of species to include the mechanism of competition for limited food supply. Studies are underway to measure grazing mortality of different size classes of phytoplankton. Laboratory experiments are being conducted with several phytoplankton and zooplankton cultures to examine mechanisms under controlled conditions. Likewise, at an offshore station on southern Lake Michigan, field experiments using the ^{14}C method are underway and ^{33}P is being used as a tracer.

Technician using the Coulter Counter. This is used to determine the particle-size spectrum in lake water. By studying changes in these spectra, GLERL scientists are determining grazing rates on various classes of algae.

Measuring grazing mortality of different size classes of phytoplankton is a formidable problem since the state-of-the-art of available equipment and methodology is not satisfactory. Therefore, considerable effort is devoted to methodology and equipment design, development, and testing. Modified methods and equipment are now under evaluation.

We are presently measuring grazing rates for copepods of the genus *Diaptomus*. Preliminary results of our study, which measures grazing over a much larger size spectrum of particles than usually analyzed, suggest *Diaptomus* selects much larger phytoplankton than generally believed. In addition to studying the feeding of herbivorous zooplankton, studies have also been conducted on the feeding of a carnivorous cyclopoid copepod species, *Cyclops vernalis*. It has been found that the number of prey eaten by adult females increases with increasing prey density up to a maximum ingestion rate. This maximum rate decreases with increasing prey size; however, the number eaten for a given prey size and density is highly variable, indicating large variations in the feeding behavior of individual animals. Further studies are being conducted on the feeding of these animals to obtain a quantitative formulation of feeding that can be used in our ecological modeling efforts.

Plans for next year emphasize the analysis of Lake Michigan phytoplankton data collected this summer and fall. Laboratory grazing studies will be initated this winter as a lead into the development of a model of selective grazing by *Diaptomus*. Later an integrated study of summer succession that will include both phytoplankton growth and grazing mortality will be undertaken.

Water Chemistry

Great amounts of data specifying the levels of limnological properties at various places and times have been collected from the Great Lakes. But many of the data sets have had only a cursory analysis. This program uses these data to describe the distribution in space and time of certain variables, both for selected areas of special interest and more generally for the system as a whole. These studies are designed to answer specific questions concerning environmental conditions in problem areas but also to increase our understanding

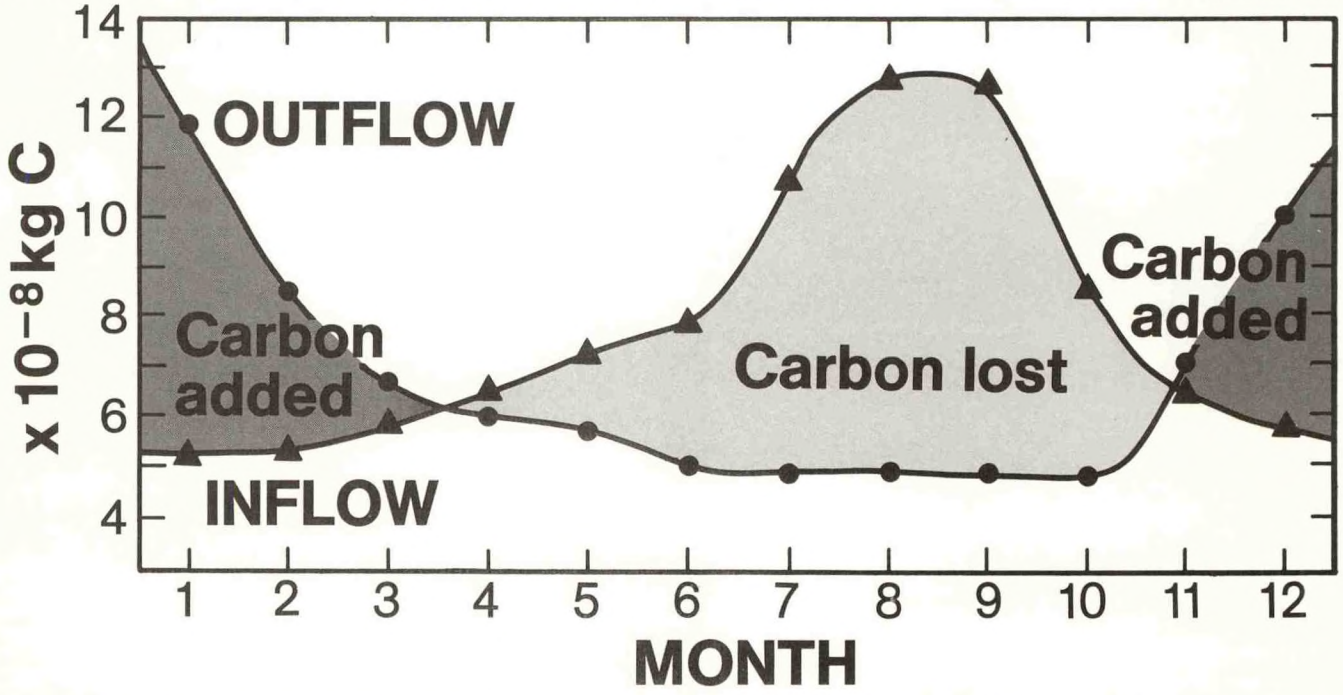
of the distribution and variability of properties within the entire system. Such understanding will be used to aid in the design of a monitoring system to detect long-term environmental trends by providing a basis for identifying where, when, and how often to monitor conditions in order to obtain a representative view of environmental trends in the Lakes.

Extensive amounts of O_2 data were collected in Lake Ontario during IFYGL. As oxygen levels are excellent indicators of nutrient enrichment conditions in a lake, these data have been subjected to an extensive analysis. Oxygen levels in Lake Ontario fell below saturation during August and September 1972 for the total hypolimnion. Depletion rates were more rapid on the western than on the eastern side of the lake, speculated to be owing to the differences in hypolimnion volume and loads of oxygen consuming material. On two occasions, when sizable storms perturbed the lake, large amounts of oxygen were added to the hypolimnion. Both exposure of the hypolimnion at the surface, i.e., upwelling, and turbulent mixing across the thermocline seem to have contributed to this input. The significance of this process in relation to retardation of hypolimnetic oxygen depletion is being investigated.

Another IFYGL study involved determination of the carbon budget for Lake Ontario during the field year period. The major carbon sources were found to be CO_2 gained from the atmosphere owing to photosynthetic activity and the addition of carbon by tributary streams, especially the Niagara River. The major losses of carbon were outflow at the St. Lawrence River and net CO_2 released to the atmosphere from the inorganic carbon pool. Seasonally, the lake added carbon during the warm months, when algal production was high, and lost it during the colder part of the year.

Now, a more detailed study of the inorganic part of the carbon cycle is being conducted. Satellite photographs have shown that cloudy or milky water is present at times during summer over large parts of Lakes Ontario and Michigan. Theoretical calculations have shown that these are times during which the concentration of calcium carbonate is substantially greater than saturation, thus suggesting that the cloudiness may be due to the formation of particles of calcium carbonate. Scanning electron micrographs have confirmed the presence of large numbers of what appear to be calcite crystals suspended in the water at these times. Further studies are being conducted to determine whether appreciable amounts of nutrients are associated with these crystals and so whether the sinking of these crystals could carry significant amounts of phosphorus and nitrogen to the sediments and out of the surface waters.

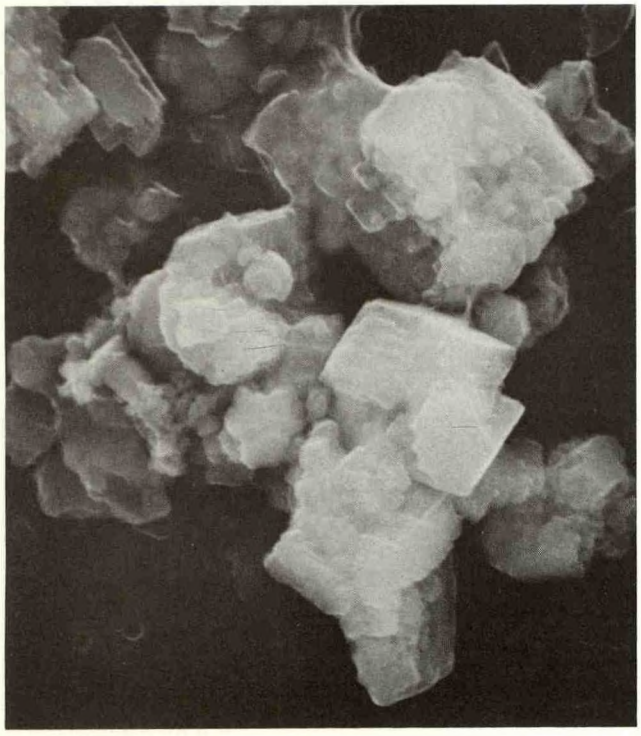
Other studies in the areas of chemistry have included detailed investigations of several river mouths, i.e., the Oswego, emptying into Lake Ontario, and the Grand, emptying into Lake Michigan. These studies are aimed at increasing our understanding of the movement of dissolved and suspended polluting and enriching substances from a river into a large lake. It is



Monthly means of total carbon inflow to and outflow from Lake Ontario, April 1972–March 1973. The darker areas represent a a net gain of carbon and the lighter areas a net loss.

evident that much of the material is deposited close to the river mouth and initially does not affect the lake ecosystem. However, much work is required to define the role of resuspension, precipitation, and dissolution in this process and to be able to predict the fraction of a chemical present in an inflowing river that will ultimately reach the open lake.

Further studies along these lines will be initiated in this project in FY 1977. More work will be directed toward obtaining an overall view and summary of the cycle of certain important chemicals in the Great Lakes. This work will aid in the design of the long-term monitoring system mentioned earlier. Data reports and summary distribution charts are being produced for the large amount of unpublished chemical data we have gathered in the past.



Calcite crystals collected 15 km off Grand Haven, Michigan (10,000 X).

ENVIRONMENTAL SYSTEMS ENGINEERING

Environmental Systems Engineering Group Head—Arthur P. Pinsak.

The work of the Environmental Systems Engineering Group includes projects on environmental engineering models and applications and the GLERL Advisory Service activity. The purpose of environmental engineering models and applications is to develop, test, and apply improved simulation and prediction models and other tools for user application. The Advisory Service involves the dissemination of GLERL products and other environmental information to identified users, the identification of new users and their needs, the response to requests for environmental information, and the participation of GLERL staff members in various interagency boards, committees, work groups, and symposia (e.g., Great Lakes Basin Commission, IJC). In combination, the Advisory Service provides environmental information and expertise to assist in the solution of Great Lakes issues and problems. Such involvements provide a direct two-way channel for our scientific expertise and tools, identify research needs pertinent to our program planning, and identify substantive areas for GLERL participation in interagency research.

Advisory Services

One of the major missions of the GLERL program is to provide environmental information to individuals and organizations involved in operational, planning, or management activities that impact upon or are impacted by the environment in the Great Lakes. An Advisory Service activity was established within the Environmental Systems Engineering Group to provide a focus within GLERL for communication with the users of GLERL data, information, and reports.

During FY 1976, over 200 requests for information, data, or reports were received from various user groups and answered. These user groups included universities, Federal and state agencies, private organizations, regional planning groups, and individual citizens. GLERL has identified over 400 recipients who desire and regularly receive one or more of six types of GLERL publications.

In support of NOAA's Office of Ecology and Environmental Conservation, 49 Draft Environmental Impact Statements pertinent to the Great Lakes or the Great Lakes Basin were reviewed and commented upon during 1976.

The determination of the need for Great Lakes environmental information and the interaction takes many forms. In addition to the requests received by mail, as discussed above, many GLERL scientists are involved in interagency and international meetings, symposia, and workshops where information exchange takes place. The scientists also serve as consultants; committee, board, and commission members; and officers in Great Lakes organizations and as working members of interagency special study or work groups.

Future plans call for increased contact with other Federal, regional, state, and local organizations to increase the awareness of the GLERL mission and program and to obtain further definition of the problems in the Great Lakes requiring input of environmental information. This will help in the evolution of the GLERL program to meet these needs.

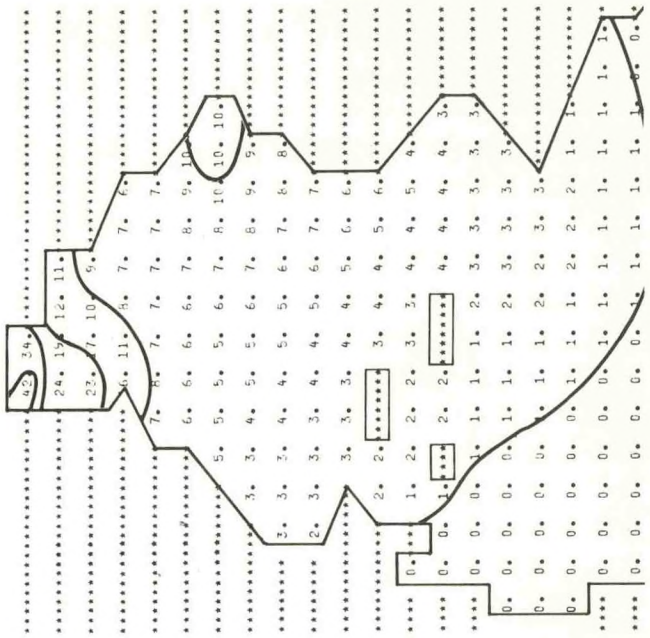
Environmental Engineering Models and Applications

During FY 1976, the Maumee River Basin Level B Study was completed. The objective of this multiagency, multistate study by the Great Lakes Basin Commission was to develop a basin-wide coordinated plan for water resource use and development. GLERL completed a baseline study of the limnology of Maumee Bay conducted in conjunction with studies by other agencies concerning all aspects of water and land-related water resource uses in the basin. As part of the analysis of planning alternatives, GLERL developed a mathematical water quality model of Maumee Bay and western Lake Erie using interdisciplinary inputs from the laboratory staff to simulate water transport, diffusion, and settling of water quality variables

of public and environmental concern and subject to a specified load from the Maumee River. The model was applied to estimate the impact of alternative future basin management strategies on the environment of Maumee Bay and Lake Erie to support decisions leading to the recommended management plan. By changing physical dimensions and applying realistic pollution loads, the model can be applied to similar types of management problems in other harbors and embayments in the Great Lakes.

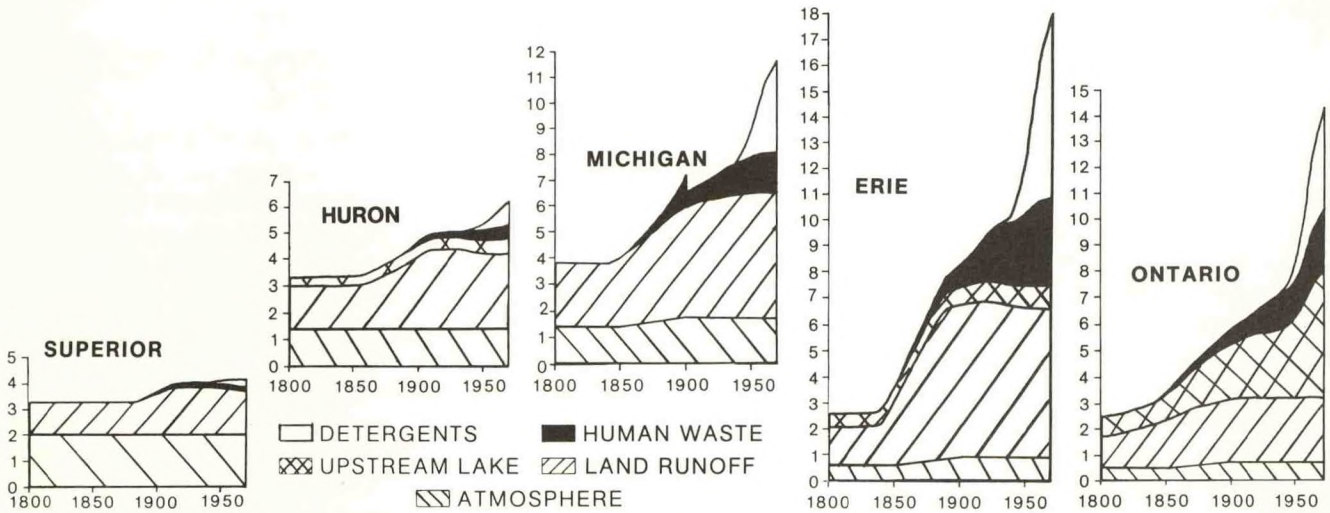
A mathematical model was developed and tested to simulate long-term phosphorus concentrations in the Great Lakes system for the 19th and 20th centuries. In the Great Lakes, phosphorus concentration relates to algal production. A load model applied to each lake accounts for domestic, land runoff, and atmospheric sources of phosphorus emanating from the drainage basin. The model has been used to simulate the effects of various phosphorus abatement programs as recommended by the IJC; other scenarios can also be analyzed. If the internationally agreed-to objectives for phosphorus in sewage effluents are achieved, the model indicates that all the lakes would show marked improvements in phosphorus concentrations. The western basin of Lake Erie, however, would require additional treatment of other phosphorus sources to attain acceptable levels of algal productivity. The model is designed to aid management decisions and is structured so that discrete segments of the Great Lakes Basin can be modified in the development of management scenarios.

A critical factor in the simulation of a phosphorus budget is the flux across the sediment-water interface. This long-term model parameterizes the annual phosphorus-algae cycle and considers the sediment a sink for phosphorus. For models which resolve the annual cycle, the sediment-water flux of phosphorus can be either up or down at the interface. Future plans for refinement of the long-term model include improved definition and handling of diffuse sources of phosphorus and examination of some of the modeling approximations and assumptions.



Simulated suspended sediment distribution in western Lake Erie assuming a 50 percent decrease from the Maumee River.

An atlas of Lake Ontario physical variables is under development with the use of IFYGL data. This study has broad participation from the GLERL groups and contractors. The atlas, planned for publication in 1977, will contain maps and tables of physical properties useful to the engineer, scientist, and resource planner.



Historical trends in total phosphorus loading to the Great Lakes as calculated by a mathematical model.

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES (IFYGL)

IFYGL is a multiagency, joint United States-Canadian program of environmental and water resources research addressing Lake Ontario and the Ontario Basin. The central objective is to improve knowledge, information, and simulation models of the environment to provide a scientific basis for improved management of Great Lakes water-related activities. The data collection program was initiated in 1972 and the analysis and reporting phase will be completed in late 1977.

NOAA is the U.S. lead agency and GLERL exercises management responsibility. IFYGL work cuts across all the disciplines at GLERL and constitutes a major part of the effort.

There have been a number of significant accomplishments to date on the IFYGL program. Some of these are:

- Completion of archives at the National Climatic Center, Asheville, North Carolina, and at the Canada Centre for Inland Waters, Burlington, Ontario, Canada, containing data collected by the United States and Canadian scientists. These data are available to interested users.
- Completion of most of the analysis tasks.
- Publication of over 280 articles and reports on the IFYGL results.
- Development and testing of numerical models to simulate and predict physical, chemical, and biological processes and phenomena in Lake Ontario related to water quality, water quantity, and living resources.
- Improved knowledge of the temporal and spatial distribution and variability of physical, chemical, and biological properties.
- Preparation of the first of 12 international Summary Scientific Report volumes to be published summarizing the IFYGL work.

The program remains on schedule for completion in FY 1977. An IFYGL Wrap-Up Workshop will be held in October 1977. A "Management Day" presentation will be given in Niagara Falls in early 1978 to inform the Federal, state, and local managers on the utility of the information gained from the IFYGL program.

In addition to the general GLERL distribution of information, there were over 50 requests for IFYGL data and reports over and above the regular IFYGL distribution to over 450 institutions and individuals.

INTERNATIONAL AND INTERAGENCY ACTIVITIES

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

International Joint Commission (IJC)

GLERL participates in many of the activities of the IJC. Various staff members are involved in committee and subcommittee work. These include work on the Research Advisory Board that provides the IJC with information on the state-of-the-art in Great Lakes research and recommends research programs. Also included is participation on the Research Needs Committee, the Scientific Basis for Water Quality Criteria Committee, the Upper Lakes Reference Group, the Pollution From Land Use Activities Reference Group, the Surveillance Subcommittee of the Water Quality Board, and the Federal Support Committee to the U.S. Cochairman of the Water Quality Board. The Research Needs Committee has prepared a report on the priority research needed to resolve significant Great Lakes water quality issues; the Scientific Basis for Water Quality Criteria Committee provides advice on the water quality objectives for pollutants in the Great Lakes; the Upper Lakes Reference Group has conducted studies on the status of pollution in Lakes Huron and Superior; the Pollution From Land Use Activities Reference Group is assessing the significance and sources of pollution from land drainage to the Great Lakes and will develop recommendations on remedial measures; and the Surveillance Subcommittee provides an annual assessment of the environmental quality of the Lakes, defines problem areas, and coordinates the surveillance activities of the many different agencies.

Great Lakes Basin Commission

GLERL staff are involved in the Great Lakes Basin Commission as Alternate Department of Commerce Commissioners, members of the Comprehensive Coordinated Joint Plan Committee, the Priorities Committee, the Plan and Program Formulation Committee, and the Coastal Zone Management Committee and as participants in the Maumee River Basin Level B Study. The Comprehensive Coordinated Joint Plan Committee has responsibility for updating and further detailing the water resources plan in the Great Lakes Basin. The next step is the development of plans for lake basins. GLERL staff members also serve on the Priorities Committee, which develops the priorities of the Federal or federally-supported water resource initiatives pertinent to the Comprehensive Coordinated Joint Plan; the Plan and Program Formulation Committee, which participated in the preparation of the 23-volume Framework Report; and the Coastal Zone Management Committee, which coordinates, exchanges, and develops information pertinent to the coastal zone management activities of the Great Lakes states. In addition, GLERL participated in the Maumee River Basin Level B Study by developing a water quality model and assisting in trade-off analyses of alternative water resource plans and will be working on the Fox-Wolf River Basin Level B Study to develop simulation models and to apply the research state-of-the-art to assist in trade-off studies of alternative management strategies for this river basin.

Winter Navigation Program

GLERL is working in support of the Corps of Engineers in a multiagency program to examine the feasibility of extending the navigation season through the Great Lakes system. The Ice Information Work Group is chaired by a GLERL staff member. Also, GLERL has membership on the Winter Navigation Working Committee and represents NOAA in the Environmental Evaluation Work Group. The laboratory provides data on the physical and structural character of lake ice; on ice formation, growth, and decay; and on the effects of winter navigation on shore properties. In addition, marine environmental service is provided to shippers during the extended season.

A report by the Winter Navigation Program was submitted to Congress in late 1976. Legislation passed Congress in 1976 to extend the program through June 1979. The emphasis of the extended demonstration program will be on the St. Lawrence River.

Great Lakes Basin Hydromet Network Work Group Study

The Great Lakes Basin Hydromet Network Work Group, with membership from NOAA, the U.S. Geological Survey, and the Corps of Engineers, was formed to determine specific alternatives with timeframes and cost estimates for implementation and for improving and expanding U.S. Great Lakes Basin hydrologic monitoring. GLERL is one of the NOAA members of this work group, the aim of which is to improve lake

level forecasts by expanding the basic observational network.

International Association for Great Lakes Research (IAGLR)

Members of GLERL actively participate in the management structure of IAGLR. They hold membership on the Publication Committee, the Membership Committee (Chairperson), and the Board of Directors of this association and a GLERL staff member currently serves as Vice President. This coming year, GLERL and The University of Michigan will cohost the 20th Conference on Great Lakes Research in Ann Arbor. It is expected that 600-800 scientists will attend and that 200-500 papers will be presented.

FACILITIES

GLERL leases two adjacent buildings in Ann Arbor, with a total space of about 13,000 ft². In addition, GLERL occupies a 10,000 ft² warehouse and dock facility in Monroe.

GLERL has a number of laboratory and support facilities that are an integral part of its research program. During FY 1976, the capability of these facilities grew in terms of both equipment and personnel; they provide significant contributions to the GLERL program.

Chemistry Laboratory

During the past year, the chemistry laboratory has been concentrating on measurements of chemical-biological variables. Several modules of Technicon's AutoAnalyzer II system have been obtained and are currently operational for NO_3, NH_3, organic nitrogen, soluble reactive phosphorus, and total phosphorus measurements. In addition, the SCOR/UNESCO method for chlorophyll and pigment analysis has been adopted and is being compared to fluorometric monitoring. These techniques are allowing us to engage in research involving nutrient uptake, sediment-nutrient interaction, and transport of nutrients into the lake system.

Our plans for the immediate future include the measurement of permanent gases (i.e., N_2, O_2, CO_2) by gas chromatography and the quantitative analyses of organic fractions.

Scientist performing atomic absorption spectrophotometry for toxic trace metals. Other equipment in the chemistry laboratory includes an AutoAnalyzer.

Biology Laboratory

The biology laboratory is equipped to carry out a variety of experimental studies involving benthos, zooplankton, and phytoplankton. Studies measuring nutrient uptake with radioactive isotopes are conducted with the aid of a liquid scintillation counter, and the effects of zooplankton feeding on particle size distributions are monitored with a Coulter Counter. Controlled environment chambers allow the culturing of various kinds of plankton. An inverted microscope is used to obtain species counts for algae and conventional microscopes are used to identify and count zooplankton and benthos.

The biology laboratory.

Ice Laboratory

Plans for 1977 include the reactivation of an ice laboratory in Ann Arbor. The laboratory will be equipped to conduct analyses of the physical properties of ice. These analyses will support several of the ice studies discussed earlier.

R/V Shenehon

Many of GLERL's field experiments are carried out on the *R/V Shenehon,* a converted T-boat, length—65.5 ft, beam—17.75 ft, and draft—6.5 ft. The vessel has a 2100 nautical mile range, with a cruising speed of 9.5 knots, and is fully complemented with navigational, communication, and depth sounding equipment. Forward and aft winches handle both hydrographic and multiconductor electric cable. The 120 ft² laboratory facilitates the conduct of onsite chemical and biological analyses. During 1976, a

The *R/V Shenehon.*

specially developed plankton trap for grazing experiments, in situ chemical probes, and incubation chambers for culture and radioactive isotope uptake experiments were added.

On 1 July 1976, responsibility for ship support services and operations was transferred from the National Ocean Survey to the Environmental Research Laboratories.

During 1976, the *R/V Shenehon* has been operating in southern Lake Michigan out of the port of Grand Haven in direct or logistical support of six GLERL projects. The ship was used to deploy and service telemetering accelerometer type surface wave buoys and to place meteorological sensors and recorders on a buoy in mid-lake to be used in conjunction with concurrent observations of water movement.

On a recurring basis during the open-water season, open-lake water samples were taken to perform in situ primary production measurements, to do on-board chemical and nutrient analyses of the lake water, and

to observe kinetics of ^{14}Carbon and ^{32}Potassium uptake by phytoplankton under a range of environmental conditions. Variations in grazing rates and selectivity of dominant zooplankton species were also observed during spring, summer, and autumn.

Concentrations of carbon and lake water nutrients were determined on a high frequency basis in both nearshore and open-lake environments to determine time rate of variability and availability of these essential constituents. A specially developed screen was used to obtain samples from the water surface for similar nutrient analyses.

Sediment cores were taken on a monthly basis at nine sites representing differing sediment types off the mouth of the Grand River. Various species of phosphorus, dissolved oxygen, and organic carbon in the sediment core and in water at the sediment-water interface were measured. These cores were also used to identify and quantify vertical and temporal distributions of micro- and macro-fauna, their interrelationship, and the total benthic biomass.

Meteorological observations and solar radiation were continuously recorded aboard ship in support of each of the sampling programs.

These various field investigations provide essential support to the laboratory programs concerned with determining natural distribution and variability of lake characteristics and defining physical, chemical, and biological processes and interrelationships and sediment-water and air-water exchanges that lead to improved understanding of the natural system and aid in simulation and forecasting at time and space scales of interest to users.

Marine Instrumentation Laboratory

The past year has been a period of rapid growth for the marine instrumentation laboratory, marked by major procurement, instrument development, reorganization, and field program activities. Acquisition and development activities provided many new observation capabilities, including a 240-liter incubation chamber, a Chapelsky-Vanderploeg-Soo plankton trap, a calcium carbonate saturometer with a pH probe, an improved phase lock circuit for the Data Well Waverider Receiver, a cassette reader interface for current meters, a microprocessor based data acquisition system, and several buoy system components. Significant steps were accomplished toward the objective of an automatic data acquisition system that includes a data logger and a Hewlett-Packard computer to automatically handle the data management-editing functions for a set of data collection systems: surface wave measurements, meteorological measurements, current meters, and water chemistry probes.

Computer Laboratory

During the year the GLERL computer laboratory and its staff have contributed greatly to GLERL projects in the following activities: data management, analysis, modeling, and evaluation. The programming activities are accomplished via remote batch processing through a Harris-1600 Remote Communications Processor connected to a CDC 6600 computer located at the Environmental Research Laboratories in Boulder, Colorado. A Tektronix 4014-1 Graphical Display Terminal is also connected to the CDC 6600 to assist the project scientists in the analysis of data and to provide them with the capability of graphical displays of their data.

A Hewlett-Packard 9603A Scientific Measurement and Control System was purchased to allow GLERL to process and edit existing raw data records from a variety of field data collection instruments and to develop a laboratory real-time interactive data acquisition system.

Tektronix 4014-1 Graphical Display Terminal.

STAFF AS OF 30 SEPTEMBER 1976

	Full Time Permanent	Commissioned Officers	Temporary or Part Time
Office of Director	5	0	3
Physical Limnology and Meteorology Group	16	1	5
Chemistry and Biology Group	11	0	3
Lake Hydrology Group	9	1	1
Environmental Systems Engineering Group	6	2	3
Computer Systems	5	0	0
Total	52	4	15

CONTRACTS AND GRANTS DURING FY 1976

Principal Investigator	Institution	Title
Allen	Illinois Institute of Technology	Trace Metal Species
Bennett	Massachusetts Institute of Technology	Circulation of Lake Ontario
Birchfield	Northwestern	Coastal Circulation of Lake Ontario
Chen	Tetra Tech, Inc.	Water Quality Ecological Model for Lake Ontario
Csanady	Woods Hole	Coastal Circulation
Dilley	General Electric	Nearshore Ice
Estoque	University of Miami	Mesoscale Disturbances
Grayson	National Weather Service, NOAA	4-Dimensional Analysis
Green	University of Wisconsin (Madison)	Current Measurements in the Coastal Zone of Eastern Lake Michigan
Houghton	University of Wisconsin (Madison)	Dispersion of Pollutants
Lee	University of Texas (Dallas)	Biological Characteristics of the Nearshore Waters of Lake Michigan
Mortimer	University of Wisconsin (Milwaukee)	Currents and Oscillations of the Offshore Waters of Lake Michigan
Mortimer	University of Wisconsin (Milwaukee)	Lake Ontario Temperature Transects
Mortimer	University of Wisconsin (Milwaukee)	Whole Basin Inertial Oscillations
Rumer	University of Delaware	Effects of Wind and Waves on Ice Transport
Scott	State University of New York (Albany)	Climatology Circulation Patterns
Stoermer	University of Michigan	Phytoplankton Associations in Lake Ontario
Sweeney	State University of New York (Buffalo)	Copepod Life History
Sydor	University of Minnesota	Studies of Ice Growth
Wilson	The Center for the Environment and Man	Completion of IFYGL

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

Writer-Editor
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Ann Arbor, Michigan 48104

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