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THE INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES*

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ABSTRACT

The historical background of the International Field Year for the Great Lakes, a coordinated study of many aspects of Lake Ontario, one of the Laurentian Great Lakes of North America is described. The overall scientific programme is described briefly in terms of the six basic disciplinary divisions: atmospheric boundary layer, biology and chemistry, energy balance, lake meteorology, terrestrial water balance, and water movements.

RÉSUMÉ

L'historique de l'International Field Year for the Great Lakes, l'Amérique du Nord, le Lac Ontario, est décrit. Une vue scientifique générale est brièvement élaborée en fonction des six disciplines de base suivantes : l'atmosphère dans la couche limite; la chimie et la biologie; le bilan énergétique; la météorologie des lacs; le bilan terrestre des eaux; et les mouvements des eaux.

INTRODUCTION

The International Field Year for the Great Lakes (IFYGL) is a coordinated, multi-disciplinary, international study of Lake Ontario and its land basin. This paper presents briefly how the overall scientific programme and its component parts evolved, their objectives and the data-gathering activities associated with them. Because at the time of writing, data were still being collected, few preliminary results can be included. However, the descriptions of the programmes underway will call the attention of the world limnological community to them and to the fact that within the next three years, a large number of scientific reports will become available.

Lake Ontario, with an area of 19,400 km^2, occupies almost 28 per cent of the total basin. It receives about 80 per cent of its water supply through the Niagara River and Welland Canal, and its outlet to the Gulf of St. Lawrence and the Atlantic Ocean is the St. Lawrence River. Its maximum length is 310 km, maximum width 85 km, and maximum depth is about 242 m with an average depth of 86 m. These dimensions, along with the varied uses to which the lake is put, its effects on the weather and climate of the surrounding area, and the degree of man-inspired depreciation are some of the factors that have made the IFYGL such a challenging and important undertaking.

* Prepared on behalf of the Steering Committee of the International Field Year for the Great Lakes, which was established jointly by the United States and Canadian National Committees for the International Hydrological Decade.

Historical Background

For a number of years, many scientists and engineers from a number of disciplines had been conducting research on a wide variety of topics concerned with scattered portions of the Great Lakes of the St. Lawrence River system. The annual conferences on Great Lakes Research had been growing larger, and by the mid- and late sixties were drawing over five-hundred participants. It was proposed by a leading Canadian lakes scientist that if all such efforts during one year were coordinated on one lake, much more could be learned for much less cost and effort. This met with the approval of many, and subsequently the United States and Canadian Committees for the International Hydrological Decade (IHD) adopted the idea as eminently appropriate to their goals and in 1966 established an international Steering Committee consisting of four scientists from each country.

The Steering Committee formed four international working groups along disciplinary lines to develop a total scientific programme dealing with the physical hydrological regime of Lake Ontario and its basin. The four working groups were concerned with the Terrestrial Water Balance, Lake Energy Budget, Water Movements and Lake Meteorology. Each working group contained a number of scientists and engineers from each country who could best identify the major gaps in knowledge about the hydrology, limnology, hydraulics, meteorology and geology of the lake and its basin. After each working group had individually prepared recommendations, they met together to develop a coordinated, feasible scientific programme and to identify the data-gathering facilities that would be required. Naturally, because facilities were limited, compromises on ships cruises, tracks and stations, and buoy locations were required. The compromises were accomplished and the joint recommendations returned to the Steering Committee which subsequently approved the total programme in almost every detail. This phase of the planning had required more than one year to complete.

Until this point, the planned programme dealt completely with the physical sciences because these were basic to all other aspects of water problems of the lake. However, because of changing national priorities and increasing interest on the part of biologists and chemists in the potential of tying their studies to a base of soundly collected physical data, the Steering Committee enlarged the scope of the programme in a most timely and relevant way by adding a biological and chemical component. Two additional members were appointed to the Steering Committee to reflect the new area of endeavour, and the process of developing a coordinated Biology and Chemistry programme was begun.

At about the same time, it was recognized that the scientific working groups had served their primary function, and served it well, but a new emphasis was required. The planning of the scientific programme was now complete, and the new immediate needs were to develop operational plans for data-gathering, data management and scientific analysis, and then to implement these plans. To this end, a Joint Management Team, six scientific advisory panels, and several support groups were established. In the United States, the National Oceanic and Atmospheric Administration (NOAA), the lead agency in that country for the execution of IFYGL, established a Project Office. The Project Office appointed the US side of the various panels and proceeded with the detailed planning and management, including the issuing of contracts for the required tasks. In Canada, implementation was decentralized with the individual portions of the federal and provincial governments performing those functions for the areas which were appropriate to their regular mission. The Canadian side of the Joint Management Team coordinated the overall Canadian effort. The scientific panels which were established were: Biology and Chemistry—for such matters as fish populations, food chains, materials balance and allied processes; Boundary Layer—for the portion of the programme dealing with the exchanges of momentum, sensible heat and latent heat at the air–water interface, and the processes by which these energies were handed over to the general circulation; Energy Balance—for that portion of the total programme dealing with all of the terms in the heat balance of the lake; Lake Meteorology—for the studies dealing with meteorological processes on the meso-

and synoptic scales, and to provide meteorological data in support of the other projects; Terrestrial Water Balance—to define as accurately as possible the individual terms in the water budget of the whole basin; Water Movement—for studies of currents, waves (both internal and surface) and the diffusion process.

Several support groups were established at the same time. Technical Operations was charged with scheduling and operating the ships and support vessels, placing and servicing the deep-water buoys and similar tasks. Data Management established the two national archives, made provision for the flow of data into the archives, made all participants aware of the needs of others for their data, and otherwise expedited the interchange of information between principal investigators. The Navigation group contracted for and monitored a special Decca precision positioning system for the use of all ships and aircraft suitably equipped. The Public Information group was responsible for liaison with the news media and general public, arranging for press conferences and the like when appropriate. The Publications Committee arranged for the writing and printing of manuals, and established a publications policy fo the guidance of investigators. Future IFYGL 'Bulletins' and technical and scientific reports are the responsibility of the Joint Management Team. These will be supplemented by papers submitted to the various scientific journals and periodicals.

In order to provide guidelines to investigators and serve as a permanent record of many of the important details, a four-volume Technical Plan was prepared and issued. Volume 1 provided details of the scientific programmes; Volume II gave specifications for the instrumentation and data-acquisition systems; Volume III described the Technical Operations, including schedules and Volume IV discussed Data Management. To facilitate internal communication, a quarterly 'IFYGL Bulletin' has been issued.

The above has been only a cursory description. Details may be found in a report by Richards and Drescher (1972). A comprehensive summary of the preliminary phases is being prepared for distribution in late 1973.

Implementation

A Field Data Centre and Field Operations Centre were established in the United States at Rochester, N.Y., and in Canada at the Canada Centre for Inland Waters in Burlington, Ontario. The data-gathering phase of IFYGL began on 1 April 1972, and continued for one year. Certain activities related to the Energy Budget and Biology and Chemistry programmes have been extended to the end of July 1973, because of a scarcity of relevant data for the spring or meteorologically stable period.

To accommodate special programmes, several 'intensive' periods were selected because during them the climatological expectation of the occurrence of various phenomena was high. The basic IFYGL data-gathering networks and systems operated continuously throughout the year, but when an 'intensive' period arrived, complementary observations were made. For example, the flux-measuring projects of the Boundary Layer Panel were concentrated almost exclusively within these periods. Their main purpose was to provide better definition of some of the smaller scales (higher frequencies) of the water currents, internal waves, energy fluxes, etc.

On some programmes, analysis accompanied data gathering, but on others, the latter activity fully occupied those concerned. This meant that the analysis phase of many projects had to wait until the data were collected, quality-controlled and archived. Recognizing this, the planning included up to three years after the end of the data-gathering for analysis and report writing. This phase of IFYGL has barely started, so it is not unexpected that even preliminary results are not yet available in many areas. The results of preliminary and feasibility studies, and some early summaries of instrument performance have been presented in several issues of the 'IFYGL Bulletin'.

Facilities and Data-Acquisition Systems

As might be expected, existing operational observing networks were not adequate for many of the scientific tasks that were identified in the planning phase. Because the new facilities were shared amongst the various disciplines, they are described briefly below without specific reference to individual projects which will be presented in more detail later. The summary below is not intended to be exclusive.

(1) *Capital vessels* — monitor surveys of the heat content of the lake at one- or two-week intervals; collection of water samples; observations of dissolved oxygen and chlorophyll; measurement of meteorological variables including radiation; servicing of the buoy network; and various other tasks such as bathymetry. Five major vessels were involved.

(2) *Smaller vessels and launches* — servicing of buoys; measurement of coastal currents; fish sampling; dye diffusion studies; detailed studies of the coastal zone, including sediments.

(3) *Deep-water buoys* — a network of 21 buoys observing water currents and temperatures, and meteorological variables.

(4) *Lake towers* — several such facilities for micro-meteorological studies and profiles in the air and water of temperature, velocity, etc.

(5) *Land meteorological facilities* — 11 automatic shoreline stations; an evaporation pan network; additional rainfall stations.

(6) *Rawinsonde network* — for the period mid-September to mid-December (1972), a six station network around the lake.

(7) *Aircraft* — for weekly measurement of surface-water temperature by infrared thermometer; measurement during specific intensive periods of the turbulent energy fluxes in the lowest portion of the atmosphere; surveys of groundwater, snowpack and other hydrological variables using remote sensing techniques.

(8) *Radar* — three radars with facilities for digitization covering almost all of the basin.

(9) *Streamgauging* — additional measurements of inflow and outflow using new equipment and techniques to reduce the uncertainties in the observations and calibrate more precisely the standard ways of doing this.

The Scientific Programmes in Brief

Terrestrial Water Balance

This programme was a well organized and comprehensive attempt to better define the individual terms of the water budget of the lake itself, and of the lake plus its basin. Individual tasks were directed to the measurement of: inflow through the major tributaries and outflow through the St. Lawrence River; runoff; precipitation over the lake and the basin; soil moisture; groundwater flow and storage; snow hydrology; standing water in the basin; and change in lake storage. Two major by-products were the estimation of evaporation as a residual in the water budget of the lake, and the testing and improvement of existing simulation models. The programme also provided an opportunity to add to the knowledge of the geology of the basin, especially the water-related characteristics of the land portion.

Energy Balance

The Energy Balance Programme concentrated on the calculation of the various individual terms in the energy budget of the lake, the balancing of the budget, and the estimation of evaporation as a residual. Also included were detailed studies of the 'thermal bar' a facet of the thermal structure of the lake each spring which has a major impact on circulation and dispersion of pollutants during its existence. Individual tasks included the specification of: the

radiation budget; the heat storage term; the fluxes of sensible and latent heat from the lake surface; heat exchange between the lake and the sediments; heat inputs from the tributaries; and advection of heat on a regional basis. As an ancillary project, the formation and decay of near--shore ice was also studied.

Boundary Layer

This programme could be generally described as oriented towards description of the structure of the surface boundary layer over the water, the specification of the fluxes of momentum, heat and moisture across the air–water interface, and the exchange of energy from the micro-scales in the boundary layer to the synoptic scales and the general circulation. Those involved in this latter aspect looked at their projects as feasibility studies for the Global Atmospheric Research Project (GARP) from the point of view of parameterizing the energy fluxes into the atmosphere in terms of generally available meteorological measurements. The ability to do this appears to be a critical aspect of the World Meteorological Organization's World Weather Watch.

Among the tasks included in this subject area were the measurement of the energy fluxes by micrometeorological instruments and by aircraft; the calculation of these fluxes from buoy data and the comparison of these results with the observations made above; the estimation of the downward transport of air pollutants into the water and the formation of the internal boundary layer at the lake shore. Again, this list is not exhaustive but serves to illustrate the broadness of the approach being taken in this subject area.

Lake Meteorology

There were several foci to the Lake Meteorology programme:

(1) the collecting of meteorological data in support of the projects in other disciplines—the various components of the radiation budget; the temporal and spatial distribution of precipitation; wind over the water, etc.;

(2) the estimating of evaporation from the lake surface—through calculation of the atmospheric water budget (described in more detail below); by mass-transfer using data from the land basin; by mass-transfer using observations from the buoy network;

(3) the study of mesoscale weather systems which are either created through the existence of the lake, or suffer structural changes over the lake—lake breeze, land breeze, lake-effect snowstorms, air-mass modifications, and so on;

(4) the study of the surface climate of the air over the lake, and mesoscale variations in the climate of the near-shore basin.

Water Movements

While ancillary studies such as surface wave generation by wind were undertaken, the main thrust of the Water Movement Programme was towards phenomena which required a large, whole-lake, coordinated approach. Of major interest in this category were internal waves, large-scale diffusion processes, thermal structure during upwelling events, lake-level transfers across the lake due to meteorological factors (including storm surges), and near-shore velocity and temperature profiles.

Biology and Chemistry

Clearly, these two aspects must be treated jointly. Under the general heading of 'Materials Balance', individual tasks included: suspended and dissolved inputs to the lake; the release and uptake of phosphorus by bottom sediments; nitrogen fixation; the flow of hazardous materials,

including the degree of concentration of pesticides through the food chain to birds' eggs; the oxygen demand of sediments; and the modelling of eutrophication. Tasks that were principally biological were addressed to: the status of fish populations, especially the relative abundance and seasonal changes in the distribution of stocks, with feeding studies to assess materials circulation; rates of production of various zooplankton species, food uptake rates and energy utilization, turnover time; and the status of benthic invertibrates. These studies were supplemented by a number of additional tasks, particularly: measurement of chlorophyll and algal species composition; algal nutrient availability; optical properties of the lake water; bioassays of phytoplankton nutrients, especially for cladophora; detailed biological and chemical studies of various near-shore areas and embayments; and the impact of discharges on the near-shore biology and chemistry.

The above is not a complete summary of the tasks related to this critical aspect of the lake. It serves only to provide an overview of the scope of the biological and chemical studies which were added to the IFYGL when the planning for the latter was well advanced. It is a tribute to those directly concerned with these matters that such a comprehensive programme could be organized and implemented at such short notice.

The Evaporation Synthesis Programme

As will have been noted in the brief outlines above, there is a considerable emphasis on evaporation from the lake surface. This quantity is being estimated by several different approaches—as a residual in the energy budget; as a residual in the terrestrial water budget; through the atmospheric water budget; and by two or three variations of the bulk aerodynamic method. A special task group has been formed to study the various results and to produce a series of 'best estimates' of evaporation for various time periods. These figures may then be used to reconsider the individual estimates that had been made. In particular, it is hoped to be able to

(1) 'calibrate' the bulk aerodynamic calculations to permit better estimates to be made operationally in the future; and

(2) re-evaluate some of the terms in the energy and water budgets by using the improved evaporation estimate in the relevant balance equations. Both activities will be of importance for those interested in forecasting lake levels and ice formation and decay in large lakes in temperate latitudes.

Atmospheric Water Budget

One of the more ambitious undertakings of special interest to meteorologists and others concerned with evaporation was the Atmospheric Water Budget Project. The approach had been used elsewhere but never for such a small area.

The task involved the calculating of the total heat budget of the troposphere over the lake. Then, by making assumptions about liquid and solid water advected across the lake boundary in clouds and precipitation, the moisture flux divergence could be estimated. Provided the calculations and estimates were good, an excellent measure of evaporation could be obtained.

Based on a careful analysis of potential errors and three feasibility studies (Ferguson and O'Neill, 1968; O'Neill and Ferguson, 1971; Ferguson and Schaefer, 1971), the following experimental design evolved:

(1) the high evaporation period of mid-September through mid-December was chosen;

(2) six rawinsonde stations were established around the shore of the lake, carefully sited for this project;

(3) a sounding system was chosen with the following features:

(a) winds were calculated from positions determined using radio signals from a navigational aid facility—this improved the accuracy of the winds over those that would have been found by standard radio-direction-finding or secondary radar techniques;

(b) the sensing elements in the sondes were individually (rather than batch) calibrated;

(c) the electronic components in the sondes were of guaranteed precision;

(d) the sensors were sampled at 0·8 s intervals, providing far more vertical resolution than standard sondes;

(e) data were digitized and recorded on computer-compatible magnetic tape for automatic processing (for safety, the analogue signals were recorded on charts also);

(4) for three intervals (Oct. 2–18; Oct. 30–Nov. 14; Nov. 21–Dec. 10), eight flights per day were made from each site; for the rest of the period, two flights per day were made from each site;

(5) some supporting observations were made occasionally by aircraft.

Needless to say, many problems arose during the experiment. However, those involved are very pleased with the operational phase and are eagerly awaiting the early results of the analysis phase. It seems certain that, quite apart from the calculation of the heat and moisture budgets, the data will provide the opportunity for detailed investigation of the smaller scales of atmospheric structure to an extent which is unique.

A complete description of the programme and the instrumentation involved will soon be available in a Technical Report titled 'IFYGL Radiosonde System Operation'.

Concluding Remarks

It will be one or two years before some of the major budgets and syntheses will have progressed to the point where the results are ready for presentation to the scientific community at large. The IFYGL Steering Committee wishes to thank the organizers of this symposium for the opportunity to describe the programme, and to alert the participants to the forthcoming presentation of some exciting results. Those of us who have been involved in the planning and data-gathering phases of IFYGL are eagerly awaiting the opportunity to begin the analysis of the data which will soon be available from the official archives.

It is felt that IFYGL will make three major contributions to the scientific community:

(1) Many future models of limnological processes may be tested on the extensive physical and biological data sets that have been gathered.

(2) the results of the analysis and simulation programme should be applicable in many ways to other large lakes in temperate latitudes, and perhaps more broadly than that;

(3) the age of large international and inter-disciplinary geophysical programmes is upon us, and many lessons may be learned from the experience of those who have planned and carried out IFYGL.

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