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ANNOTATED BIBLIOGRAPHY ON GREAT LAKES HYDROLOGY

by

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ABSTRACT

ANNOTATED BIBLIOGRAPHY ON GREAT LAKES HYDROLOGY

This bibliography contains 233 literature references on Great Lakes hydrology. The references are listed alphabetically by author for the following topics: precipitation; evaporation; runoff; lake levels and flows; hydrologic budget; currents, winds, and water temperature; and general.

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PREFACE

Hydrologic data serve as an input to the water resources system of the Great Lakes. In OWRR Project No. B-035-ILL, the objective of the research was to develop a monthly hydrologic budget for the Great Lakes. As a result the following report was produced:

Great Lakes Hydrology by Months, 1946-1965

In OWRR Project B-062-ILL, the objective is to develop deterministic and stochastic models of the hydrology of the Great Lakes. This report is a result of the literature research for these two projects.

In preparing the bibliography, only references which have a direct bearing on research objectives were selected. The bibliography is by no means complete, but it covers most items of basic significance to the subject matter and thus should provide a valuable source of information to anyone interested in Great Lakes hydrology.

There is minimum overlap between this bibliography and two bibliographies* that were recently published by the Office of Water Resources Research. Those bibliographies were produced wholly from the information base comprising only Selected Water Resources Abstracts (SWRA). Evidently the SWRA did not contain the references listed in this bibliography as of May 15, 1972.

Urbana, Illinois
August 1972

Dale D. Meredith

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*Lake Erie: A Bibliography and Lake Ontario: A Bibliography, Water Resources Scientific Information Center, Office of Water Resources Research, U.S. Department of the Interior, Washington, D.C., June, 1972.

TABLE OF CONTENTS

PRECIPITATION

BLUST, F. A., and B. J. DeCooke, Comparison of precipitation on islands of Lake Michigan with precipitation on the perimeter of the lake, J. Geophys. Res., 65, p. 1565-1572, 1960.

A program of precipitation measurement on islands in northeastern Lake Michigan and the lake's perimeter is described. The precipitation on the islands is compared to that on the perimeter of the lake. The results indicate that lake surface precipitation computed from the perimeter stations may be greater than the actual amount in summer and less in winter.

BOCHKOV, A. P., Estimation of precipitation as water balance element, in Symposium on world water balance, I, Pub. No. 92, p. 186-192, Internat. Assoc. Scientific Hydrology, 1970.

Methods for computing average precipitation and snow storage in river basins are described. Also a system applied in the USSR for the correction of measured precipitation which eliminates systematic errors of the gages is described.

BRUNK, I. W., Precipitation estimates in the Great Lakes drainage basin, Monthly Weather Rev., 90, p. 79-82, 1962.

Precipitation estimates from various sources for the different Great Lakes basins are reviewed. The estimates are correlated with the net basin supply values for each basin. The best correspondence between net basin supply and precipitation is indicated for Erie and Ontario and the poorest for Michigan-Huron and Superior.

CANADA, Department of Transport, Meteorological Service of Canada, Meteorological Branch, Temperature and precipitation tables for Ontario, Vol. 4; Quebec, Vol. 5, Toronto, 1967.

CHANGNON, S. A., Jr., Precipitation climatology of Lake Michigan Basin, Bulletin 52, Illinois State Water Survey, Urbana, 1958.

Average annual precipitation over Lake Michigan is 6 percent less than that of the land portion of the basin. The results of this comprehensive study are more valid than those previously reported (which estimate lake and land percipitation as equal) because they are based on more detailed land and lake data and a greater knowledge of lake affects. The best possible measures of average seasonal and average annual percipitation of the lake and the basin are determined from three detailed studies of thunderstorms, hailstorms, and snowfall combined with lake-land ratios (based on wind land data rather than commonly used down wind data). The lake supresses thunderstorm activity by 20 percent in the summer but in the fall increases it by 50 percent and also causes 400 percent more hail days in lower Michigan. Lake affects cause 25 to 100 percent greater snowfall along the eastern shore. Average lake precipitation is 4 percent higher in winter, 7 percent lower in spring and 14 percent lower in summer than basin land precipitation. They are equal in fall.

CHANGNON, S. A., Jr., Effect of Lake Michigan on severe weather, Pub. No. 15, p. 220-234, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1966.

Lake influences were found to effect thunderstorm activity in all four seasons with the greatest changes occurring in the summer and fall seasons. In the summer the lake reduces thunderstorms over the southern portion of the lake more than 20 percent but enhances thunderstorm activity in the northern lake area by 20 percent. During the summer in the southern lake area the lake influences actually increase nocturnal thunderstorm activity but the 30 to 50 percent reductions in thunderstorms in the daylight hours cause a net reduction. In the fall, the lake causes a 40 percent increase in thunderstorm activity in parts of lower Michigan and although this increase occurs during the day, it is most pronounced during the nocturnal hours. The lake also affects the areal distribution of hail storms in the spring, summer and fall seasons. In the summer the lake effects reduce hail frequency throughout lower Michigan with the largest reduction being 60 percent along the eastern lake shore. In the fall the lake influences produce a striking increase in hail in lower Michigan.

CHANGNON, S. A., Jr., The LaPorte weather anomaly-fact or friction?, Bull. Am. Meteorological Soc., 49(1), p. 4-11, 1968.

The 30 to 40 percent increase in precipitation and related phenomena which occurred at Laporte, Indiana since 1925 is discussed. After the question of the authenticity of these increases is imposed, the author assesses the available climatological data and concludes that these significant increases are real and not fictional.

CHANGNON, S. A., Jr., Precipitation from thunderstorms and the snowfall around southern Lake Michigan, Proc. 11th Conf. Great Lakes Res., p. 285-297, Internat. Assoc. Great Lakes Res., 1968.

A meaningful measure of the effect of Lake Michigan on thunderstorms and snowfall is provided by precipitation values. Daily data from 41 stations located around the Lake's southern end were analyzed to provide seasonal and annual statistics on the average amount of precipitation on days with thunderstorms on only the west side of the lower lake, days with measurable snowfall on only the west side, days with thunderstorms only on the east side days with measurable snowfall on only the east side, days with thunderstorms on both sides, and days with measurable snowfall on both sides. On days when thunderstorms occurred on both sides rainfall on the east averaged 12 percent less than on the west. On days when snowfall occurred on both sides the average precipitation on the east was 20 percent greater than on the west. On summer days when thunderstorms occurred on the west and dissipated over the lake the average daily point rainfall on the west was 0.12 in. as compared with 0.03 in. on the east. Conversely when thunderstorms developed over the lake in summer the average point rainfall on the east side was 0.25 in. as compared to 0.15 in. on the west.

CHANGNON, S. A., Jr., and F. A. Huff, Measurement of precipitation over Lake Michigan, Pub. No. 15, p. 235-248, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1966.

Investigations of various radar and climatological methods of determining precipitation over the lake are reported.

DENNISON, F. N., A report on the difference between the precipitation records as taken on the standard Canadian and United States rain gauges," Bull. Am. Meteor. Soc., 22, p. 65-67, 1941.

The U.S. rain gauges catch approximately 3 percent less rainfall than Canadian gauges because of the difference in the heights of the collecting orifices above the soil surface.

EAGLESON, P. S., and R. F. Lariviere, The scale of oceanic influence on continental precipitation, in Symposium on world water balance, I, Pub. No. 92, p. 34-38, Internat. Assoc. Scientific Hydrology, 1970.

The serial correlation coefficient of monthly point precipitation at lag one is examined for a common fifty year period at thirty-seven stations located throughout North America. The results show that the coefficient values are significant along the Pacific Coast and decay in a eastwardly direction becoming insignificant near the Mississippi River.

POTTER, J. G., Water content of freshly fallen snow, Canada, Department of Transport, Meteorological Branch, Circ. 4232, TEC. 569, May 12, 1965.

The development of a method for estimating the water content of snowfall is presented. The performance of the Meteorological Service of Canada standard snow gage is discussed. Also a method is suggested for adjusting early precipitation data for comparison with that dating from the introduction of the snow gage in 1960 as the standard device for measuring the water content of snowfall.

POWERS, C. F., D. L. Jones, and J. C. Ayers, Sources of hydrographic and meteorological data on the Great Lakes, Special Report 8, 183 p., Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1959.

Presents the results of a study designed to locate and determine the extent of records in the Great Lakes Region that would aid in the understanding of Great Lakes hydrography. The questionnaire on meteorological and hydrographic records that was employed in this study is included. Sources and type of data available are emphasized.

U.S. Department of Agriculture, Monthly Precipitation Probabilities by Climatic Division; 23 Eastern states from the Great Lakes to the Gulf Coast, Misc. Pub. 1160, U.S. Gov't. Print. Office, Washington, D.C., 1969.

U.S. Department of the Army, Corps of Engineers, Lake Survey District, Snow depth probability in the Great Lakes Basin, Misc. Paper No. 68-5, Detroit, Mich., 1968.

The results of snow depth probability calculations for selected stations in and near the Great Lakes Basin are presented. The results are in tabular and graphic form and the computations are based on the snow-on-the-ground data at the end of each month.

WEBB, M. S. and D. W. Phillips, The role of lake effect snow storms in the hydrology of Lake Erie, paper presented at the 14th Conf. Great Lakes Res., Toronto, 1971.

The 1931-60 30 year norms of the snow storms in the Lake Erie basin are investigated to determine the distribution of snow over the basin of Lake Erie due to lake effect snow storms. In the Lake Erie basin two lake effect storm sources dominate: Lake Erie and Lake Huron-Georgian Bay.

WEISS, L. W. and R. F. Kresge, Indications of uniformity of shore and offshore precipitation for Lake Michigan, J. Applied Meteorology, 1, p. 271-274, 1962.

The authors present evidence that indicates that the difference in gage catches at Chicago City Office and the "Four-Mile Crib" is due to difference in wind speed effects.

WILLIAMS, G. C., Comparative rainfall study, 68th Street crib and Chicago area, summer and fall 1963, Pub. No. 11, p. 311-320, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

Daily and monthly measured amounts of rainfall at the 68th Street crib were compared with the measured amounts at 23 shore stations for the period July through Oct. 1963. After correcting the crib gage catches for wind, no lake-induced reduction of precipitation falling at the crib could be identified.

EVAPORATION

BROWN, R. A., R. L. Peace, and G. E. McVehil, A study of hydrologic and energy budgets of Lake Erie with emphasis on evaporation measurement, Report RM-2342-0-3, 36 p., Cornell Aeronautical Lab., 1967.

DERECKI, J. A., Variation of Lake Erie evaporation and its causes, Pub. No. 11, p. 217-227, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

Monthly evaporation from Lake Erie was determined by the water budget method for the 1937-1959 period. The component factors of the water budget are briefly examined and discussed. Evaporation rates vary from minus 4 to plus 24 cm per month, and from 53 to 108 cm per year; therefore, the average values are poorly adaptable for hydrological forecast. The variation of evaporation was analyzed statistically and indices of air-water-temperature difference, heat flux by radiation, and humidity were found to be of primary importance while precipitation and wind speed showed only sporatic effect. The climatic factors gave reasonable account for the variation of the monthly evaporation rates during the months having high evaporation and poor account during the low evaporation period. Ground-water was assumed to be negligible and precipitation was determined by multiplying the depth at the perimeter stations by a ratio of island station to perimeter station.

HARBECK, G. E., Jr., A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory, U.S. Geological Survey, Professional Paper 272-E, U.S. Gov't. Print. Office, Washington, D.C., p. 101-105, 1962.

The value of the mass-transfer coefficient, N, in the equation $E = Nu_2(e_o - e_a)$ is determined as a function of surface area for reservoirs ranging from 1 to nearly 30,000 acres.

HARBECK, G. E., Jr., P. E. Dennis, F. W. Kennon, L. J. Anderson, J. J. Marciano, E. R. Anderson, and M. A. Kohler, Water loss investigations: Lake Hefner studies, technical report, U.S. Geolgoical Survey, Professional Paper 269, U.S. Gov't. Print. Office, Washington, D.C., 158 p., 1954.

Using evaporation computed from the water budget as a control, proposed methods and techniques for determining lake evaporation at Lake Hefner, Oklahoma. These methods and techniques included the prediction of water losses by evaporation from climatological and limnological data using mass-transfer and energy-budget theory and techniques for converting evaporation-pan data to estimated lake evaporation.

HUGHES, G. H., Analysis of techniques used to measure evaporation from salton sea, California, U.S. Geol. Surv., Prof. Paper 272-H, U.S. Gov't. Print. Office, Wash. D.C., 1967.

The estimates of evaporation determined by energy-budget, water-budget, and mass-transfer methods are compared . Various possible sources of error are also investigated.

HUNT, I. A., Jr., Evaporation of Lake Ontario, J. Hydraulics Div., Am. Soc. Civil Engrs., 85(HY2), p. 13-33, 1959. Discussion by M. A. Kohler, 85(HY9), p. 109-112, 1959.

Estimates of the evaporation from Lake Ontario are computed by the water-budget and mass-transfer methods. The annual net evaporation from Lake Ontario was found to be about 2 feet.

JONES, D.M.A., Variability of evapotranspiration in Illinois, Circ. 89, Illinois State Water Survey, Urbana, 1966.

The average annual evapotranspiration for the state of Illinois is derived from the average precipitation and the average runoff from 43 stream gaging stations in and around the state. A comparison of three equations for calculating potential evapotranspiration is made. The reasons for selecting the Hamon equation are given. The Hamon equation is tested for applicability to the climate of Illinois by inserting it into a soil moisture accounting procedure and checking the results against measured amounts of soil moisture at three widely dispersed points in the state. The equation is used to calculate the evapotranspiration at 67 temperature measuring stations in the state for an average year, a wet year, and a dry year.

KUZMIN, P. P., Methods for the estimation of evaporation from land, applied in the USSR, in Symposium on world water balance, I, Pub. No. 92, p. 225-231, Internat. Assoc. Scientific Hydrology, 1970.

Climatological and water balance methods for estimation of evaporation from land, snowpack, and swamps applied in the USSR are presented in this paper.

KUZNETSOV, V. I., Experimental investigations and computations of evaporation from water surface, in Symposium on world water balance, I, Pub. No. 92, p. 153-159, Internat. Assoc. Scientific Hydrology, 1970.

A brief description of investigations of evaporation from water surfaces in the USSR is presented in this paper. Information on standard instruments, methods for measurements and computation of evaporation are included.

LAMOREAUX, W. N., Modern evaporation formula adapted to computer use, Monthly Weather Rev., 90, p. 26-28, Jan., 1962.

The graphical solutions for computing pan and lake evaporation are reduced to mathematical expressions adaptable to computer use in terms of readily available input data.

MORTON, F. I., Evaporation from large deep lakes, Water Resources Res., 3(1), p. 181-200, 1967.

Derived insolation and water budget evaporation data for Lake Superior and Lake Ontario are analyzed in terms of both the regional and the water surface energy balances. The result indicates that the seasonal pattern of evaporation is governed by heat storage changes and that these changes are closely associated with atmospheric energy export from the lake. A simple nonlinear regression equation between monthly evaporation and island to mainland temperature differentials is presented. The evaporation from a large deep lake is less than that from a large shallow lake under comparable climatic conditions because substantial atmospheric energy export reduces the energy available for evaporation. Speculative reasoning and evidence is presented to indicate that evaporation from a large deep lake is closely related to the radiant heat transferred to the sky.

MORTON, F. I., Catchment evaporation as manifested in climatologic observations, in Symposium on world water balance, II, Pub. No. 93, p. 421-433, Internat. Assoc. Scientific Hydrology, 1970.

A model is developed which estimates regional evaporation from representative climatological observations. Regional evaporation is defined as the evaporation from the water, soil, and vegetation surfaces of an area so large that transfers of heat and water vapor from the surfaces control the evaporability of the lower atmosphere. Under such conditions, potential evaporation (which is effected by the temperature and humidity of the bottom layer of air) is regarded as a manifestation of the regional evaporation. A formulation of the model is given in which the final equation involves the regional evaporation as a function of seven climatological parameters. Ways of estimating these parameters are included. The model is tested with hydrologic and climatic data from twenty river basins in Canada and Ireland, representing a range in annual runoff of approximately zero to one meter and a range of snow cover duration of about zero to six months. The test results are summarized in a table.

RICHARDS, T. L. and J. R. Irbe, Estimates of monthly evaporation losses from the Great Lakes 1950 to 1968 based on the mass-transfer technique, Proc. 12th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 469-487, 1969.

The meteorological service of Canada is currently making estimates at the end of each month of the monthly evaporation losses from each of the Great Lakes bordering Canada. These estimates are based on mass-transfer techniques using modified wind and vapor pressure data from shore line geological and climatological stations and surface water temperature data from regular airborne radiation thermometer flight and ship surveys. This paper presents a brief review of the technique and provides an estimate of monthly evaporation losses from Lakes Superior, Huron, Erie, and Ontario.

RICHARDS, T. L. and G. K. Rodgers, An investigation of the extremes of annual and monthly evaporation from Lake Ontario, *Pub. No. 11*, p. 283-292, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

Two water budgets, one energy-budget, and five mass-transfer methods are employed to estimate the average monthly evaporation from Lake Ontario. A mass-transfer method was chosen to use the available data to develop monthly and yearly estimates over a substantial number of years. A modified mass-transfer evaporation equation yielded monthly evaporation estimates for Lake Ontario for a 14-year period of record.

RODGERS, G. K. and D. V. Anderson, A preliminary study of the energy budget of Lake Ontario, *J. Fish. Res. Bd. Can.*, *18*(4), p. 617-636, 1961.

Estimates of heat content for Lake Ontario and a preliminary study of its energy budget based on bathythermographic surveys. The imbalance of the energy budget results in heating of lake water from March to August and cooling from September or October to February. The peak heat content lags the peak surface temperature by about one month. The amount of energy advected into the lake is relatively small compared with other terms in the energy-budget. Thus, energy-budget calculations do not depend upon the accuracy with which the water budget is known. Lack of meteorological data over the lake surface is the principal difficulty in applying present techniques for determination of an energy-budget.

SNYDER, F. F., Evaporation on the Great Lakes, *Pub. No. 53*, p. 364-376, Internat. Assoc. Scientific Hydrology, 1960.

A method is developed for computing mean monthly surface water temperatures of deep lakes from air temperatures and a temperature (heat) storage function. Temperature storage factors were determined from antecedent data for Lakes Ontario and Michigan. These factors were adjusted for use on the other lakes. Computed surface water temperatures for the other lakes are compared with recorded average data. Meyer's adaptation of the Dalton's principle is employed to estimate monthly evaporation. Lake Ontario's average monthly evaporation is based on several years of computed monthly evaporation values. This is compared with values derived from antecedent data and values obtained from water balance methods. Then the average monthly evaporation for the other lakes is computed from long term average monthly climatic data. A final comparison of computed values with annual values obtained from water balance studies indicated a possibility of subterranean water movement.

STALL, J. B. and W. J. Roberts, New methods for determining lake evaporation loss, *J. Am. Water Works Assoc.*, *59*(10), p. 1249-1256, 1967.

New methods for determining lake evaporation loss are presented. A conceptual model, pan evaporation techniques, and a lake evaporation nomograph are included.

SUTCLIFFE, J. V. and C. H. Swan, The prediction of actual evaporation in semi-arid areas, in Symposium on world water balance, I, Pub. No. 92, p. 213-224, Internat. Assoc. Scientific Hydrology, 1970.

Some of the problems involved in comparing humid and semi-arid areas, particularly in terms of actual evaporation are illustrated by comparing the two sides of the Alborz range in Iran. Precipitation, evaporation, and water balance are investigated.

YU, S. L. and W. Brutsaert, Generation of an evaporation time series for Lake Ontario, Water Resources Res., 5(4), p. 785-796, 1969.

Monthly mean values of evaporation from Lake Ontario for the period from 1872 to 1965 inclusive were generated by a mass-transfer procedure. Available on-shore recorded meteorological data were adjusted by empirically derived equations to obtain approximate over lake values. The mass-transfer coefficient was calculated by using an equation proposed by Harbeck relating the coefficient to water surface area. A comparison of the generated mass-transfer evaporation data with water budget estimates obtained by Morton revealed that on the average the two methods gave similar results.

YU, S. L. and W. Brusaert, Stochastic aspects of Lake Ontario evaporation, Water Resources Res., 5(6), p. 1256-1266, 1969.

Time series analysis was carried out on long term monthly mean estimates of evaporation from Lake Ontario and on related meteorological parameters. Correlation and spectral analysis showed that the annual cycle was dominate in all time series analyzed. Evaporation is usually high in autumn and winter and low in spring and summer. A warming trend was observed in the air temperature and a drying trend in the relative humidity series. Except for the wind speed, no significant trend was found for the other time series. Cross-correlation and cross-spectral analysis showed a close relationship between evaporation anomalies and the anomalies of the other parameters. A first-order Markov model adequately described the evaporation, air temperature and relative humidity anomalies, whereas a second-order model fitted the anomalies of wind speed and water surface temperature. Morton's water budget method yields higher evaporation estimates in the summer and lower estimates in the winter than the mass-transfer estimates.

RUNOFF

BROWZIN, B. S., On classification of rivers in the Great Lakes-St. Lawrence Basin, Pub. No. 9, p. 86-92, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1962.

A dimensionless hydrograph, for each of several rivers in the Great Lakes Basin, is obtained by dividing the average monthly flow for each month for the period of record by the average flow for the period. Climatic factors, primarily the yearly amount and seasonal distribution of precipitation and the temperatures, and factors such as relief, soils, vegetation, and regulation by lakes and swamps are believed to be factors which cause particular dimensionless hydrograph characteristics. Specific types of the regimes discovered and their area distribution on the basis of hydrographs only are presented.

BROWZIN, B. S., Seasonal variations of flow and classification of rivers in the Great Lakes-St. Lawrence Basin, Pub. No. 11, p. 179-204, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

The hydrologic type of rivers is described in the index hydrograph which represents the graph of monthly dimensionless coefficients. The monthly dimensionless coefficient is defined by the average flow of a particular month for the period of observation divided by the yearly mean flow for the same period. The index hydrograph reflects factors of river flow, climate, relief, and the surface as well as subsurface properties of the drainage area. In the plains, the dimensionless hydrograph is primarily a function of the climate, and secondly a result of soil conditions.

Three different types of precipitation: oceanic, continental, and transient (oceanic with continental tendency) changing from one type to another from the east to the west were determined. The basin was divided into three thermal-climatic subzones: cold, temperate, and warm. Precipitation and temperature, due to the introduced definitions with their numerical characteristics, aided in the analysis and determination of the various types of river flow expressed in terms of monthly flow coefficients.

BROWZIN, B. S., Annual runoff in the Great Lakes-St. Lawrence Basin, Pub. No. 15, p. 203-219, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1966.

The annual runoff in the Great Lakes-St. Lawrence basin, expressed in terms of unit runoff, increases from the southwest to the northeast approximately six times. This is an unusual characteristic of a river basin. Precipitation and its seasonal distribution as well as mean annual temperature vary considerably but not gradually from the middle west portion of the basin to the Atlantic coast. Frequency analysis based on available data at gaging stations located in various climatic zones of the basin indicate that the frequency distribution of the annual runoff is moderate to low as compared with other basins with similar geographic conditions.

CANADA, Department of Energy, Mines & Resources, Inland Waters Branch, Surface water data reference index, Ottawa, Queen's Printer and Controller of Stationary, Ottawa, 1968.

This is a tabulation of stations showing station number, name, drainage area, discharge records, type of gage, operation, and notes. The stations have been plotted on maps of scale 1 inch equals approximately 32 miles, or larger where there is a concentration of stations. These stations are also listed by station number and the names of rivers and lakes for which data are available are given in an alphabetical index. These stations are differentiated as to whether they measure stream flow, sediment, or water level only.

CANADA, Department of Energy, Mines, and Resources, Inland Waters Branch, Ottawa, Canada, Surface water data, St. Lawrence and Southern Hudson Bay drainage:

Climatic years 1945-1946 and 1946-1947, Water Resources Paper No. 99, 1950.

Climatic years 1947-1948 and 1948-1949, Water Resources Paper No. 103, 1952.

Climatic years 1949-1950 and 1950-1951, Water Resources Paper No. 107, 1954.

Climatic years 1951-1952 and 1952-1953, Water Resources Paper No. 115, 1959.

Climatic years 1955-1956 and 1956-1957, Water Resources Paper No. 119, 1960.

Water year 1957-58, Water Resources Paper No. 126, 1962.

Water year 1958-59, Water Resources Paper No. 129, n.d.

Water year 1959-60, Water Resources Paper No. 133, 1963.

Water year 1960-61, Water Resources Paper No. 137, 1964.

Water year 1961-62, Water Resources Paper No. 140, 1964.

Water year 1962-63, Water Resources Paper No. 143, 1965.

Water year 1963-64, Water Resources Paper No. 147, 1966.

These reports contain the streamflow records for the gaged stations in Canada.

Surface water data, Ontario,

Water year 1965, 1965.

Water year 1966, 1968.

These reports contain the streamflow records for the gaged stations in Ontario, Canada.

HIDORE, J. J., Length of record and reliability of annual runoff means, J. Hydrology, 1, p. 344-354, 1963.

Streamflow records of 31 streams throughout the United States were investigated to determine the reliability of annual runoff means that are derived from records of short duration. Short-term means of 1, 3, 5, 10, 15, 20, 30, and 40 years are compared to the fifty year mean. Maximum deviations below and above the fifty year mean were computed. The variation from stream to stream of the extent to which the short-term means differ from the fifty year mean and the rate at which the observed mean converges to the long-term mean was studied. There is considerable risk involved in employing means from only several years of records. For ten year records, the deviation of the mean is considerable, i.e. at least 30 percent in most cases. For records greater than 10 years the deviation decreases rather slowly.

LIEBSCHER, H., A method for runoff-mapping from precipitation and air temperature data, in Symposium on world water balance, I, Pub. No. 93, p. 115-121, Internat. Assoc. Scientific Hydrology, 1970.

A simple method for obtaining runoff maps from precipitation and air temperature data is described. This method has been applied in the Federal Republic of Germany.

PENTLAND, R. L., Runoff characteristics in the Great Lakes Basin, Proc. 11th Conf. Great Lakes Res., p. 326-359, Internat. Assoc. Great Lakes Res., 1968.

Maps showing the distribution of runoff for the entire Great Lakes Basin on a monthly and annual basis are presented. Computerized methods have made possible the utilization of more than 250 hydrometric stations within and surrounding the basin to construct the 13 runoff maps. A graphical representation of the area runoff distribution for the sub-basin is also presented. A general discussion of the effects of the climatological and physical features in relation to the runoff characteristics is included.

SANDERSON, M., Variability of annual runoff in the Lake Ontario Basin, Water Resources Res., 7(3), p. 554-565, 1971.

A computer program using the Thornthwaite-Mather water balance model for estimating point runoff from climatic data is employed to estimate monthly and annual runoff for some 81 stations in and near the basin with records of 15 to 136 years. Average annual values of runoff are computed and mapped and compared with other estimates of runoff in the Lake Ontario Basin. The results show normal distribution in all cases independent of the length of record. The hypothesis of normality is accepted, and the standard deviation of runoff is calculated for each station. The probability of annual runoff values is shown in two maps of plus and minus two standard deviations.

U.S. Department of the Interior, Geological Survey, Index of surface water records to September 30, 1967, Pt. 4, St. Lawrence River Basin, by B. A. Anderson and C. B. Ham, Geol. Surv. Circ. 574, U.S. Gov't. Print. Office, Washington, D.C., 1968.

The streamflow and reservoir stations in the St. Lawrence River basin for which records have been or are to be published in reports of the Geological Survey for periods through September 30, 1967, are listed. In addition to the continuous record gaging stations, this index includes crest gage and low flow partial record stations. A continuous record station is a gaging station on a stream or reservoir for which the discharges, stages, or contents are published on a daily, weekly, or monthly basis for a continuous period of time. A crest stage partial record station is a streamflow station for which only the annual maximum discharge is published over a period of years for use in flood flow analysis. A low flow partial record station is a streamflow station for which only discharge measurements made at base flow, when streamflow is primarily from groundwater storage, are published.

U.S. Department of the Interior, Geological Survey, Water Resources Div., Compilation of records of surface waters of the United States through September 1950, Pt. 4, St. Lawrence River Basin, Water Supply Paper 1307, 1958, October 1950 to September 1960, Water Supply Paper 1727, U.S. Gov't. Print. Office, Washington, D.C., 1964.

These reports contain monthly and yearly summaries of streamflow records in the St. Lawrence River Basin for the periods indicated.

Compilation of records of surface waters of the United States through September 1950, Pt. 5, Hudson Bay and upper Mississippi River Basins, Water Supply Paper 1308, 1959, October 1950 to September 1960, Water Supply Paper 1728, U.S. Gov't. Print. Office, Washington, D.C., 1964.

These reports contain monthly and yearly summaries of streamflow records in the Hudson Bay and upper Mississippi River basins for the periods indicated.

Surface water records of Illinois, 1961, 1962, 1963, 1964.

Water Resources data for Illinois, Pt. 1, Surface water records, 1965.

Surface water records of Indiana, 1961, 1962, 1963, 1964.

Water Resources data for Indiana, Pt. 1, Surface water records, 1965.

Surface water records of Michigan, 1961, 1962, 1963, 1964.

Water Resources data for Michigan, Pt. 1, Surface water records, 1965.

Surface water records of Minnesota, 1961, 1962, 1963, 1964.

Water resources data for Minnesota, Pt. 1, Surface water records, 1965.

Surface water records of New York, 1961, 1962, 1963, 1964.

Water Resources data for New York, Pt. 1, Surface water records, 1965.

U.S. Department of the Interior (cont'd)

Surface water records of Ohio, 1961, 1962, 1963, 1964.

Water resources data for Ohio, Pt. 1, Surface water records, 1965.

Surface water records of Pennsylvania, 1961, 1962, 1963, 1964.

Water resources data for Pennsylvania, Pt. 1, Surface water records, 1965.

Surface water records of Wisconsin, 1961, 1962, 1963, 1964.

Water resources data for Wisconsin, Pt. 1, Surface water records, 1965.

These reports contain daily streamflow records.

U.S. Department of the Interior, Geological Survey, Magnitude and frequency of floods in the United States: Pt. 4, St. Lawrence River Basin, Water Supply Paper 1677, U.S. Gov't. Print. Office, Washington, D.C., 1965.

Flood magnitude-frequency relations pertaining to streams in the St. Lawrence River basin are presented. Flood stages and discharges for gaging stations with 5 or more years of record are listed. Also included are tables yielding information for maximum known floods at these stations and for annual floods at miscellaneous sites and short-term gaging stations.

GROUNDWATER

BERGSTROM, R. E. and G. F. Hanson, Groundwater supplies in Wisconsin and Illinois adjacent to Lake Michigan, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 251-268, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The status of groundwater supplies in Wisconsin and Illinois adjacent to Lake Michigan is reviewed. The groundwater usage is tabulated for 10 Illinois and 17 Wisconsin counties. The glacial deposits and underlying bedrock of this area are described. Several tables and maps are included. The existing aquifers in eastern Wisconsin and northeastern Illinois are reviewed in detail. A gross water budget of the Lake Michigan-Huron drainage basin suggests that stream and lake shore discharge which involves a large groundwater contribution, approximately equals evaporation from the lakes. It is also mentioned that groundwater is related to the lakes by the fact that the extent to which groundwater will be employed for future municipal and industrial supplies will affect the trend of water supply demands from the lakes.

BIBLIOGRAPHY of the groundwater resources of New York through 1967, Bull. 66, New York Water Resources Commission, 1969.

CANADA Geological Survey, Groundwater in Canada, Economic geology report 24, St. Lawrence lowlands hydrogeological region, p. 98-119, Canadian Shield hydrogeological region, p. 120-130, 1967.

HAEFELI, C. J., Regional groundwater flow between Lake Simcoe and Lake Ontario, Tech. Bull. No. 23, Department of Energy, Mines, and Resources, Inland Waters Branch, Ottawa, Canada, 1970.

The thickness of the quanternary deposits varies considerably between Lake Ontario and Lake Simcoe. Apart from the well defined bedrock channels which are covered by up to 700 ft of overburden regional extensive well defined aquifers do not exist. The general pattern of quanternary deposits is a body of very low permeability with enclosed high permeable lenses of various sizes. Most of the pumping tests show impermeable boundary conditions.

The configuration of the water table corresponds generally with the topography. Piezometric, hydrogeochemical and mathematical analysis demonstrate the non-existence of major seepage from Lake Simcoe into the Lake Ontario basin. The groundwater divide coincides approximately with the basin boundary in the quanternary deposits as well as in the different underlying bedrock formations.

INDIANA Division of Water Resources, Groundwater levels in Indiana, 1955-62, Bull. 30, 1966.

INDIANA Division of Water Resources, Geohydrology and groundwater of ... County Indiana, Bull. No. 31, Lake; No. 32, Porter and LaPorte; No. 33, St. Joseph, 1968.

Reports of the groundwater investigations of Lake, Porter, LaPorte, and St. Joseph Counties are presented. Aquifer location, groundwater hydrology, groundwater geology, groundwater recharge and discharge, safe yield of wells, and the development of the groundwater resources are presented and discussed.

INDIANA Division of Water Resources, Water resources of ... County with imphasis on groundwater availability, county studies issued include Grant, Hendricks, Tippon, 1968.

KNOPLYANTSEV, A. A., Evaluation of the groundwater balance of large territories, in Symposium on world water balance, I, Pub. No. 92, p. 71-77, Internat. Assoc. Scientific Hydrology, 1970.

The evaluation of the groundwater balance of large territories is presented. The problems involved are mentioned. To properly evaluate the groundwater balance, the following three things are necessary: the observation records of the groundwater regime, theoretically well-founded information of the change in the groundwater regime in area, and the methods of cartographic characteristics of changes in the groundwater balance on the territory.

MICHIGAN Division of Geological Survey, Summary of groundwater conditions in Michigan.

1957 to 1963 issued as a numbered series in its water supply reports, 1964 to date as annuals. County studies issued in its water investigation series.

MINNESOTA Geological Survey, Groundwater contribution to streamflow and its relation to basin characteristics in Minnesota, Report of Investigation No. 6, 1967.

NEW YORK Water Resources Commission, Groundwater resources of the Mansema-Waddington area, St. Lawrence County, New York with emphasis of St. Lawrence on groundwater, Bull. GW-47, Ontario County, Bull. GW-48, 1962.

OHIO Division of Water, Groundwater levels in Ohio, October 1959-September 1964, Bull. 41, 1965.

OSTRY, R. C., Hydrogeology of the Forty Mile Creek drainage basin on the south shore of Lake Ontario, Proc. 14th Conf. Great Lakes Res., p. 368-386, Internat. Assoc. Great Lakes Res., 1971.

The results of field investigation of geology, groundwater levels, and groundwater quality to assess the groundwater contribution to Lake Ontario from the Niagara Peninsula is presented. The Forty Mile Creek drainage basin is considered to be typical of the groundwater regime of the Peninsula. Physiography, climate and geology of the basin are described. Hydrogeological aspects of the basin are detailed. From this investigation, it is estimated that approximately one-half cfs of groundwater is being directly discharged into Lake Ontario from the Niagara Peninsula.

RUSSELL, R. R., Groundwater levels in Illinois through 1961, Report of Investigation 45, Illinois State Water Survey, Urbana, 1963.

Systematic measurements of groundwater levels in Illinois were started in the early 1930's in the Chicago region. Measurements were made in 220 observation wells in 42 counties in 1961. Groundwater level trends in Illinois through 1961 are summarized. Water level data in the form of hydrographs for wells with 1 or more years of record, descriptive data for observation wells, a brief summary of geohydrologic and climatologic conditions in Illinois, and discussions and illustrations concerning the significance of water level fluctuations are included.

U.S. Department of the Interior, Geological Survey, Water Resources Div., Groundwater levels in the United States: Northeastern States, Water Supply Paper No. 1404 covers 1955; No. 1537 covers 1956-57; No. 1782 covers 1958-62; No. 1977 covers 1963-67, U.S. Gov't. Print. Office, Washington, D.C.

Groundwater levels in Connecticut, Delaware, Indiana, Maine, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, and Rhode Island for 1955 through 1967 are reported. Groundwater levels are recorded for each county and the highest water level on the 5th, 10th, 15th, 20th, 25th, and last day of every month is tabulated.

WATT, A. K., Surface and groundwater supplies in Ontario, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 269-276, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The surface water and groundwater supplies of Ontario are reviewed. Ontario has an area of 412,582 square and has a wide range of geologic conditions accounting for a wide range in the quality and quantity of its water supplies.

Although present water sources appear adequate, rapid residential and industrial development in several areas has contributed to water supply problems. The Water Resource Commission, which has general controls over water supply and pollution in Canada, and its recent actions are reviewed. Also the public water supply systems of the province are surveyed. Water

WATT, A. K. (cont'd)

supply conditions are poorest in those counties adjoining Lake Erie and parts of Lake Huron and Lake Ontario. A pipeline project is discussed and additional projects are under consideration. In conclusion, the high cost of piping water from the Great Lakes to inland districts in Southern Ontario is the prinicpal deterrent at the present for many municipalities with water supply problems.

WISCONSIN Geological and Natural History Survey, Trends in groundwater levels in Wisconsin through 1966, Information Circ. 9, 1967.

LAKE LEVELS AND FLOWS

ALBERY, A. C. R., Stabilization of the Great Lakes combined with a continental water service, Preprint No. EIC 66 Denver 6, ASME-EIC Fluids Engineering Conference, Denver Colorado, the Engineering Institute of Canada, Montreal, 25-27 April, 1966.

The cost and benefits of stabilization by means of new inflows and outflows are discussed. With continuous new outflows of either 20,000 or 40,000 cfs and varying inflows up to either 40,000 or 80,000 cfs, the extreme range of lake Michigan-Huron (based on the period 1920-1965) could be reduced from 5.7 ft to 4.4 or 3.5 ft respectively. Less variable flow out of Lake Michigan-Huron would be advantageous to downstream navigation and power interests. Large quantities of water could be made available for export without endangering the long-term interest of Canada.

BAJORUNAS, L., Natural regulation of the Great Lakes, Pub. No. 10, p. 183-190, Great Lakes Res. Div., Univ. Michigan, 1963.

Methods and equations are presented to evaluate the natural adjustment of lake levels and outflows to variations in water supply and the inflow or outflow corrections by man. Two examples are shown.

BEETON, A. M., and H. B. Rosenberg, Studies and research needed in regulation of the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, Engineering Institute of Canada and American Society of Civil Engineers, p. 311-342, June 24-26, 1968.

This paper consists of three major sections: socio-economics, hydrology and water resources development, and biological and limnological aspects. To date, we have not been able to forecast effectively supplies more than one month in the future, but forecasts of 1, 2, or even 3 years in the future are needed for full utilization of the storage potential of the Great Lakes.

The section on socio-economics covers population pressure, shore property development, water supply and waste disposal, hydroelectric power aspects, navigation, and diversion.

The hydrology and water resources studies section includes forecasting and simulation, long term trends, weather modification and evaporation control, and heat and its importance. The biological aspects of the regulation of the Great Lakes section includes extent and importance of shallow water areas, effects of changes in lake levels, effect of flow regulation, and the summary.

BRUNK, I. W., Precipitation and the levels of Lakes Michigan and Huron, J. Geophys. Res. 64(10), p. 1591-1595, 1959.

Linear regression of the levels of Lakes Michigan and Huron on precipitation indicated a computable relationship and also an apparent lag between precipitation and its effect. When land area precipitation only was considered, a correlation of lake level with four year precipitation data gave a correlation coefficient of 0.69. Correlation of the difference in annual mean levels and precipitation indicated a correlation coefficient of 0.68.

In order to include the effect of additional variables, a correlation of net basin supply and water year precipitation on a two year basis was made. A correlation coefficient of 0.79 was obtained and a lag between precipitation and its effect was again indicated. Seasonal changes in level were correlated with monthly precipitation values. Finally, it is pointed out that geological conditions in the Michigan-Huron basin provide a physical reason for the indicated lag between the precipitation and its effect.

BRUNK, I. W., Changes in the levels of Lakes Michigan and Huron, J. Geophysical Res., 66(10), p. 3329-3335, 1961, Discussion by H. F. Lawhead, p. 4324-4329, 1961; and also in Pub. No. 7, p. 71-78, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1961.

Ten year overlapping averages of mean annual levels of the Great Lakes for the period 1860-1960 indicate peaks in the levels of most of the lakes in the 1880's and around 1950. The level of Michigan-Huron averaged more than 1.5 ft lower in the 10 year period ending 1955 than in a similar period ending 1887. It is concluded that it is possible that natural and artificial changes in the natural outlet control system of Lake Huron have been responsible for practically all of this observed drop in Michigan-Huron levels in the 68 year period.

Lawhead claims that no more than half of the reduction in lake level is due to down cutting and that a similar amount should be attributed to changes in the precipitation pattern between the test periods 1878-1887 and 1946-1955.

BRUNK, I. W., Additional evidence of lowering of Lake Michigan-Huron, Pub. No. 10, p. 191-203, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1963.

Comparisons of the relations between precipitation, net basin supply, and discharge for several of the Great Lakes are used to show that there are discrepancies between the modern data and that of the last century. These comparisons suggest that the quality of the discharge data from Lake Erie in the last century is only slightly inferior to modern data, but that the discharge values given for Michigan and Huron are excessive by significant amounts in many years prior to about 1900. A reexamination of precipitation estimates for the early period suggested that the estimates for the Michigan-Huron watershed were also too large during the early years. These findings support the earlier conclusion of Brunk: that most of the decrease in the levels of Lake Michigan-Huron was due to down cutting of the outlet channel of the lake.

BRUNK, I. W., Evaluation of channel changes in St. Clair and Detroit Rivers, _Water Resources Res._, _4_(6), p. 1335-1346, 1968.

Extensive improvements for navigation have been made in the St. Clair-Detroit river (SCDR). It is shown that channel changes have lowered the level of Lake Michigan-Huron by about 2 ft and consequently bring about the lowest levels of record in 1964 and 1965. The unrecognized changes in the regimen of the SCDR before 1900 have also resulted in the determination of flows that are much too large. The discharge of Lake Erie and the precipitation of the Erie basin are used to derive more reasonable estimates of the flow of the SCDR before 1900.

CANADA, Department of Energy, Mines and Resources, Inland Waters Branch, Water levels 1966, _Vol. 1-Inland_, Ottawa, 1967.

This is a compilation of water levels of the Great Lakes and St. Lawrence River System recorded from 67 gages operated by the Canadian Hydrographic Service. Contained herein are daily mean levels; annual summary which includes yearly mean, highest and lowest levels during the year, and highest and lowest daily means for each month of the year; extreme levels which includes the highest and lowest levels ever recorded and the highest and lowest daily, monthly, and yearly means ever recorded; frequency distribution of daily mean levels; monthly and yearly summaries; supplementary data; related data, publications, and reports; and hydrographs (from 1860 to 1966) of monthly and yearly mean levels for the Great Lakes, Lake St. Francis, and Lake St. Louis.

CANADA, Department of Energy, Mines and Resources, Marine Science Branch, Monthly and yearly mean levels, _Vol. 1-Inland_, Tides and water levels, Ottawa, 1971.

This is a tabulation of monthly and yearly mean levels with ten year and all time averages recorded at all past and present, permanent (inland) water level gages of Canada. All elevations are in feet and are in reference to the International Great Lakes Datum, 1955. Data from 38 stations on the Great Lakes are included.

CANADA, Department of Transport, Meteorological Service, Meteorological Branch, Meteorological factors affecting Great Lakes water levels, _Circ. 4182-Tech. Paper 553_, 1965.

CLARK, R. H., and G. S. Cavadias, A stochastic approach to the development of a regulation plan for the Great Lakes, _Proc. Internat. Hydrology Symp. 1_, p. 430-442, Sept. 6-8, 1967, Fort Collins, Colorado, Colorado State Univ., Fort Collins, 1967; Discussion in _2_, p. 307-309.

A multi-variant model proposed by Fiering was used in the simulation of net basin supplies to all the Great Lakes. This analysis was based on the assumption that there was no long term trend in the supplies and that the available record could be used as a basis for estimating the parameters of the generating processes. The sequences generated were subjected to several tests in order to verify whether or not the properties of the recorded supplies are conserved. The simulated supplies are used as a guide in evaluating the performance of preliminary regulation plans.

DeCOOKE, B. G., Forecasting Great Lakes levels, Pub. No. 7, p. 79-84, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1961.

A method of forecasting end of month levels for 6 months in the future is presented. Since all factors affecting the runoff are not easily measurable, indices were employed to represent these variables. The arithmatic average of selected stations was used as the index for precipitation. The end of month flows from selected tributary streams were used as the index to represent interflow, groundwater movement, and channel storage. The index of the amount of snow melt during the current month was selected as a current monthly temperature. Precipitation and temperature over the basin were selected as the indexes of the loss of water due to soil moisture recharge. Monthly mean air temperature was an index for evapotranspiration losses. Multiple linear regression equations for computing monthly runoff into Lake Ontario were developed using the above indices. The development of the forecast method on Lake Superior, Michigan, Huron, and Erie consisted of establishing a point-weight system based on the monthly coefficient of multiple correlation and estimating above and below normal point ranges for the system. These point ranges were then used to select a monthly supply from a table which was based on a net basin supplies of record.

The forecasting system which was outlined above is employed by the Lake Survey to determine the supply used in forecasting the end of first month level for each of the Great Lakes. The forecast for the end of second through sixth month levels employ the average net basin supply of the period of record for each month at the forecasted level.

A comparison of errors for this system and the previous system for forecasting levels is given.

DeCOOKE, B. G., Research aspects of Lake Ontario regulation, Pub. No. 10, p. 173-182, Great Lakes Res. Div., Univ. Michigan, 1963.

A summary of present (1963) and future studies on Lake Ontario regulation is presented.

DeCOOKE, B. G., and E. Megerian, Forecasting the levels of the Great Lakes, Water Resources Res., 3(2), p. 397-403, 1967.

A description is given of the U.S. Lake Survey method of forecasting water levels of the Great Lakes. The method in general, consists of determining a level for each month of a 6 month forecast period on each of the Great Lakes by routing a predicted volume of water (net basin supply) to each of the Great Lake basins. The technique employed in prediction of the volume of the water consists of using multiple linear regression based upon U.S. Weather Bureau precipitation and temperature data as predictors for the first month and trend predictors for the second through the sixth month. This technique results in forecasting of lake levels on the average from 15 to 40 percent closer to the recorded lake levels than the technique that utilizes the long-term average volume of water as the basis for projection.

DeCOOKE, B. G., Control of Great Lakes levels, J. Am. Water Works Assoc., 59(6), p. 689-698, 1967.

A brief description of the system of lakes and rivers, the natural regulation of the lakes, a description of the factors affecting the levels of the Great Lakes, a description of the diversions of water to and from the lakes through man-made channels, a brief description of the zoned type regulation plan on Lake Superior and the fixed rule curve type on Lake Ontario, and some of the economic reasons for lake regulation are presented.

DeCOOKE, B. G., Great Lakes regulation, Proc. 11th Conf. Great Lakes Res., p. 627-639, Internat. Assoc. Great Lakes Res., 1968.

A brief description of the physical characteristics and of the hydraulic and hydrology of the Great Lakes system is presented along with a summary of the regulation studies conducted during the past half century. The technique employed to develop current operational regulation plans on the lakes, the latest international studies for regulation of the entire Great Lakes, and the problems of special interests encountered therein are described. The discussion of the derivation of basic data (e.g. levels, flows, supplies, etc.), uniform basic comparisons employed in these studies, requirements of regulations, various approaches to regulation, and methods of evaluating results are included.

The basic data required for regulation studies include: the recorded level and outflows of Lakes Superior, Michigan-Huron, Erie, Ontario, and St. Louis; and the recorded monthly mean diversions of water into Lake Superior, out of Lake Michigan at Chicago, and out of Lake Erie to the Welland Canal.

DeCOOKE, B. G., The Great Lakes water levels problem, Limnos, 1(1), The Great Lakes Foundation, Ann Arbor, Michigan, 1968.

DeCOOKE, B. G., Regulation of Great Lakes levels and flows, Proc. of Great Lakes Water Resources Conf., Toronto, Canada, p. 249-276, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

A brief description of the physical characteristics as well as the hydraulics and hydrology of the Great Lakes System is presented. Included are tables of average lake levels, outflows, runoff, precipitation, and evaporation. The rule-and-limitation approach to planned development (a plan tailored to the past sequence of the water supplies) and the probabilistic and stochastic approach (a plan which gives consideration to the variability of future water supplies) are described and compared. A description and example of the regulation plans presently in operation on Lake Superior and Lake Ontario are included. The author concludes that it is extremely difficult to improve on the natural regulation of the system. However, from an engineering standpoint, the regulation of the entire system is feasible but has not yet been economically justified.

DOHLER, G. C., and R.J.D. MacKenzie, A discussion on the interpretation of high and low water datum planes in the Great Lakes, Proc. 12th Conf. Great Lakes Res., p. 415-440, Internat. Assoc. Great Lakes Res., 1969.

The purpose of high and low water datum planes are examined and defined and the criteria which could meet these requirements are established. All available water level data are analyzed and techniques developed for the selection of appropriate datum planes.

FREEMAN, J. R., Regulation of elevation and discharge of the Great Lakes, report to the Sanitary District, 548 p., Chicago, Illinois, 1926.

The regulation of the Great Lakes is discussed in detail. Hydrological and meteorological phenomena are considered. The effect of diversions by the Chicago Sanitary District and the design of gates, sluices, locks, and so on in the Niagara and St. Clair Rivers are also included.

GALLAGHER, E. J., Levels of the Great Lakes, in The Great Lakes in Michigan, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, June 1955.

GBUREK, W. J., and G. T. Berry, Prediction of Lake Superior monthly inflow using precipitation, temperature, and inflow records, Proc. 10th Conf. Great Lakes Res., p. 197-207, Internat. Assoc. Great Lakes Res., 1967.

Multiple regression analysis is applied to basin wide precipitation, temperature, and antecedent inflow data to obtain predictions of monthly Lake Superior inflows. Accuracy of these predictions is expressed in terms of correlation coefficients, F-values, and standard errors of prediction.

When using 6, 12, and 24 month antecedent precipitation, temperature, and inflow data with multiple regression analysis to predict Lake Superior supplies one month in advance, the 6 month data results in the most accurate, reliable forecast technique derived. This technique gives an average monthly forecast error of 33,900 cfs over an arbitrary 3 year period (1950-1952). Simply using the past average of recorded monthly inflows as a predictor over the same period gives an average error of prediction of 41,700 cfs.

Including a completely accurate 1 month forecast of precipitation and temperature in a 6 month antecedent prediction technique reduces the average monthly error to 18,000 cfs. An average monthly supply error of 18,000 cfs represents about 25 percent of the total average supply error. In reducing the error to 18,000 cfs value, data were admitted from the same month for which the prediction was made. It is clear, therefore, that the regression equations are not equivalent to functional relationships. Perhaps transforms of the variable analyzed and addition of other variables such as net radiation, wind speeds, and humidity would reduce the estimating error still further.

HINEY, R. A., Optimum regulation of the level of the Great Lakes, Proc. 12th Conf. Great Lakes Res., p. 449-468, Internat. Assoc. Great Lakes Res., 1969.

A dynamic programming algorithm is used to find the optimal regulation plan given objective functions relating dollar losses of each interest to monthly mean lake levels and outflows. The optimum plan minimizes the sum of these objective functions for a given set of inflows and outflow constraints. Inflow sequences consist of both the recorded-adjusted net basin supplies and 390 years of artificial monthly net basin supplies simulated to preserve as nearly as possible the serial and interlake correlations observed during the period of record.

The regulation rules are derived from a multiple regression analysis. The resulting emperical formulas relate the monthly regulated outflow from each lake to significant hydrologic parameters such as antecedent inflows and current lake levels. Comparison of losses incurred with the derived plan to those which will occur for the same inflows and existing conditions will indicate the benefits contributable to the plan.

HOLLMER, A., The effect of sill-type modifications in the Niagara River on Lake Erie water levels, Proc. 10th Conf. Great Lakes Res., p. 208-213, Internat. Assoc. Great Lakes Res., 1967.

The effects of a sill-type structure in the lower Niagara River on Lake Erie water level was determined using the Mannings flow equation assuming gradually varied flow and a standard step method of back water computation in natural channels. A total of 675 different combinations of height, length, and location of sills were considered. It was found that for some sills the low levels could be raised significantly with the corresponding minimum increase in high level. During years of high lake levels, it was shown that it is hydraulically feasible to use the Black Rock canal to augment the discharge capacity of the Niagara River to the extent that the lake levels can be lowered more than they are raised by the sill. It was found possible to raise the lake level for low flows about .72 ft or to decrease the lake level for highest flow for about .02 ft. This latter reduction was using the Black Rock canal to augment discharge capacity.

INTERNATIONAL Great Lakes Levels Board, Interium report to the International Joint Commission on the regulation of the Great Lakes levels, Ottawa, Canada and Washington, D.C., February 1968.

This report describes features of the Lakes that relate to their levels; indicates the interests that make direct use of the lakes and are affected by lake level variations; discusses the problem of regulating the levels by controlling lake outflows; and describes the nature, scope and progress to date of the commission study and how the study is oriented toward a comprehensive consideration of the many facets of the lake regulation problem.

KIRSHNER, L. D., Effects of diversions on the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 277-310, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Effects of diversion on the levels and outflows of lakes connected by channels affected by backwater are discussed. The diversions considered consist of diversions into and out of the drainage basin of the lakes and diversions between the lakes. The histories and features of the five existing diversions in the Great Lakes basin that meet these conditions are outlined. The full effects of such diversions are not immediate upon initiation of the diversion but are progressive over a period of time depending upon the surface areas and the lake level-lake outflow relationship of the lakes involved. This period is about 15 years of Lake Michigan and Lake Huron diversions. The method used by the U.S. Lake Survey to determine the diversions in connection with the studies of the International Joint Commission of the United States and Canada are described. The ultimate effects of the Great Lakes diversions upon their levels and outflows which have already been reached are listed.

KORKIGIAN, I., Effects of gage relocations and changes in harbor configuration on crustal movement rates and water level transfers, paper presented at 15th Conf. Great Lakes Res., Madison, Wisconsin, April, 1972.

The relocation of the reference gage and the recording gage and changes in the harbor configuration are indicated as changes that are important and that must be accounted for in determining actual crustal movement rates, in water level transfers, and in other hydraulic and hydrologic studies.

KU, L. F., Spectra of monthly mean water level in the Great Lakes, Proc. 13th Conf. Great Lakes Res., p. 844-861, Internat. Assoc. Great Lakes Res., 1970.

The historical monthly mean data of water level at several stations in the Great Lakes are checked by comparison between stations. The analysis includes computation of the spectra, and co-spectra of the data, and the estimation of the amplitude and phase of the periodic components by least squares.

LAIDLY, W. T., Regimen of the Great Lakes and fluctuations of lake levels, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 91-106, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The significant aspects of the regimen of the Great Lakes system are the vast natural reservoirs of the lakes, the small difference in elevation among Lakes Michigan, Huron and Erie, and the generally wide and deep outflow rivers of all the lakes.

Lake level fluctuations are classified as seasonal, long period, and short period. Also, natural and artificial factors which affect the lake levels are mentioned.

The method by which the Lake survey forecasts Great Lakes levels each month for a six-month period is briefly presented.

LAWHEAD, H. F., Regulation of water levels in Great Lakes, _J. Am. Water Works Assoc._, _57_(6), p. 715-721, 1965.

Variations in the levels of the Great Lakes and the problems of regulating the lake levels are discussed. Water diversions, effects of regulation, and benefits of regulation are included.

LEPOSKY, G., Lake Michigan on rise, _American_, Chicago, Illinois, December 27, 1968.

This is a news article on the fact that in December of 1968 the water level in Lake Michigan was rising. It contains a brief discussion of what causes the fluctuations in the lake and the reservoir effect of the Great Lakes.

LIU, P. C., Statistics of Great Lakes levels, _Proc. 13th Conf. Great Lakes Res._, p. 360-368, Internat. Assoc. Great Lakes Res., 1970.

Using records of monthly mean water levels for the Great Lakes from 1860 to the present, the probability distribution of annual as well as monthly mean water level data is determined to be substantially Gaussian with the exception of monthly Lake Michigan-Huron data. However, a modified Gaussian distribution using the successive terms of a Gram-Charlier series significantly improves the presentation of the data of all the lakes including Lake Michigan-Huron. The long term linear trend of this data was found to be insignificant and the time series can be considered as weekly stationary in a broad sense.

Spectral analysis of monthly water level data in the frequency range between 0 and 6 cycles per year reveals that significant peaks of annual and semi-annual cycles exist in all the lakes. Spectra obtained by taking differences between the monthly data and the long term average for the same months on the other hand do not contain any prominent peaks. Spectral analysis of annual water level data in the frequency range between 0 and 1/2 cycles per year shows the existence of peaks that would suggest long term periodic cycles of 8 years.

MEGERIAN, E., Forecasting Great Lakes levels second through sixth month, _Pub. No. 11_, p. 238-253, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

The method for forecasting second through sixth month lake levels depends heavily on the trend analysis and assumes that net basin supplies are the result of four forces: trend, seasonal variation, cycles, and random fluctuations. A time series analysis was applied to a set of net basin supply data in order to isolate these individual factors, which are considered to be independent.

Lake Michigan is the lake studied and the resulting equation is:

$$NBS = T \times S \times C \times I$$

where NBS is the result net basin supply, T is the combination of primary and secondary trends, S is computed seasonal variations, C is computed cyclic variations, and I is irregular or random fluctuations. Primary trend is a long term and secondary trend is a short term. A sample calculation is shown to illustrate the method.

ORDON, C. J., Stage-fall-discharge relationships in connecting channels, Pub. No. 13, p. 342-348, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1965.

A theoretical temperature correction factor is presented for the stage-fall-discharge relationships. A possible weed correction curve is presented for one reach. Evidence is presented that suggests that the flow in most of the connecting channels of the Great Lakes waterways are nonuniform with draw down curves rather than backwater curves.

PATTERSON, T. M., and H. F. Lawhead, History and present status of regulation and regulation studies of water levels and flows on the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 201-228, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Quantitative and timing problems and conflicts that are associated with the growing use and multiple purpose uses of the water resources of the Great Lakes and connecting channels and that may be susceptible to composite improvement through artificial controls and regulations of the levels and outflows are discussed. Regulation studies of the past are reviewed, the progress and application of methods and plans with respect to Lake Superior and Lake Ontario are presented and the international nature of controlling the levels of the Great Lakes is discussed. The purposes of the studies which the governments of Canada and the United States have placed in the hands of the International Joint Commission are outlined.

PIERCE, D. M., and J. E. Vogt, Method for predicting Michigan-Huron Lake level fluctuations, J. Am. Water Works Assoc., 45, p. 502-520, 1953.

A method for predicting Michigan-Huron Lake levels is presented. Physical characteristics of the Michigan-Huron Lake system, the natural and artificial forces that can effect lake level fluctuations, and the economic consequences of lake level fluctuations are discussed. Michigan-Huron Lake level data for 1860-1950 are used in the study.

PLATZMAN, G. W., and D. B. Rao, Spectra of Lake Erie water levels, J. Geophys. Res., 69(12), p. 2525-2535, 1964.

Variance and covariance spectra of Lake Erie hourly scaled water levels are presented and analyzed with resolution 0.1 cycle per day in the frequency range of 0 to 8 cycles per day. The analysis involved data obtained from thirteen lake-level recording stations in the 6-month "summer" period from April through September 1959 and for a select number of stations, the 6-month period from October, 1958 through March, 1959.

PLATZMAN, G. W., The daily variation of water level on Lake Erie, J. Geophys. Res., 71(10), p 2471-2483, 1966.

The daily variation of the water level of Lake Erie is investigated. Particular attention is given to determining the extent that this variation can be accounted for by a corresponding daily variation of wind stress.

The daily variation is computed from 6 months of hourly data at several lake-level recording stations on Lake Erie. The results are consistent with the hypothesis that the 24-hr constituent of the lake level variation is caused almost entirely by wind stress. On the other hand, the 12-hr constituent is affected substantially by the gravitational tidal force as well as by wind stress. The affect of the atmospheric pressure-gradient force is negligible in both cases. Also an earth-tide correction is applied to the semidiurnal response by means of Jeffrey's values for the Love numbers.

QUINN, F. H., Stage fall discharge equations for the connecting channels of the Great Lakes, Pub. No. 11, p. 267-282, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

A method for determining the stage-fall-discharge equations assuming steady varied flow conditions is presented to determine the flows and effects of regimen changes on the connecting channels of the Great Lakes. Studies should be made on the reaches of the channel under consideration to determine fall, mean bottom elevation, and existing channel controls within the reach. Previous studies have indicated that the fall-stage exponents should be determined for each reach and should not be assumed. A sample derivation for the Detroit River is presented.

SMITH, R. H., and I. E. Conner, Potential benefits of Great Lakes levels and flow regulation, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 229-248, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Examples are presented to illustrate what regulation of Lake Ontario has accomplished since it was implemented in 1960. The regulation results have been optimized through the use of operational discretion.

Using the Lake Ontario experience as a base, it is speculated that while regulation of the remaining Great Lakes is theoretically possible, the benefits to be obtained would be less than expected. The size of the remaining lakes makes more accurate weather forecasting vital to provide the time needed for meaningful transfer of water from lake to lake. Finally the controlled structures and channel enlargements needed for regulation will be quite expensive and these costs should be weighed realistically against the probable benefits to be obtained.

U.S. Army Engineer Division, North Central, Water levels of the Great Lakes report on lake regulation, Chicago, Illinois, December 1965.

Main Report

Information on the Great Lakes system, the development of tentative regulation study plans, the estimated cost of regulatory works considered, and partial evaluation in monetary terms of the effects of tentative regulation plans on U.S. interests is presented.

Appendix A: Hydraulics and hydrology

Hydrology of the Great Lakes as it is presently known is presented with particular reference to the effect on lake levels and outflows of the contributory hydrologic factors. Variations in lake levels, the natural and artificial factors effecting the levels, studies for forecasting the levels, and the method of treating the hydrologic factors in calculations for lake regulation studies are discussed.

Appendix B: Lake regulation

A study plan for the regulation of Lake Superior, two study plans for the regulation of Lake Michigan-Huron, and a study plan for the regulation of Lake Erie that is integrated with the regulation of Lake Ontario are presented. The presentation includes information on the development of study plans by appropriate reference to the preliminary plans. It includes the results of the study plans in terms of the effects on lake levels and outflows of regulation in accordance with the plan.

Appendix C: Affect of lake regulation on shore property

Available information on past damages that resulted from lake surface activities and from regulations of the lake levels is reviewed. Regulation would be such that the range of fluctuation would be narrowed by reducing the higher lake levels and rising the lower levels. An estimate of the monetary value of this effect is presented as a measure of the benefits to shore property on lake level regulation. A detailed evaluation of benefits to shore property is presented. The benefits that would result from an increased recreational capacity of existing public beaches due to Lake Erie regulation are included. This detailed evaluation is used as a basis for estimating similar benefits from Lakes Michigan-Huron regulation.

Appendix D: Affect of lake regulation on navigation

The estimate of the effect on navigation of regulating the level of Lakes Erie and Michigan-Huron under the plans considered for these two lakes is presented. Also presented is an evaluation of effects on commercial and recreational navigation resulting from the study plan for Lake Erie regulation. Also, estimates are developed of the general magnitude of effect on navigation of regulating Lake Michigan-Huron on the study plans for that lake.

Appendix E: Affects on Niagara power of regulating Lake Erie

The benefits to United States hydroelectric power production at Niagara that would be made possible by regulating Lake Erie in accordance with a considered regulation plan are determined. For their realization, the

benefits would require the installation of power units in addition to those presently existing. The cost of additional power units are estimated and the value of the benefits reduced by the cost of required units. Similar benefits occurring to Canada would be made possible by regulating the Lakes. However, the study herein is limited generally to the effects on United States power.

Appendix F: Regulatory works

Regulatory works for controlling outflows from Lake Michigan-Huron through the St. Clair-Detroit River system and for controlling the outflows from Lake Erie through the Niagara River are discussed.

The considered works are described in detail and estimates of the cost of providing the works are developed. Preliminary investigations of the regulation of Lake Michigan-Huron have indicated that the cost of regulatory works in the lake outlet far outweigh the benefits in the regulation of the lake, while such studies of the regulation of Lake Erie have indicated a possibility of economic justification. For this reason plans of regulatory works that would be situated in the St. Clair-Detroit River system are presented in somewhat less detail than those that would be situated in the Niagara River. However, plans for works in the St. Clair-Detroit River system have been studied sufficiently to provide cost data that is adequate for an analyses of the economics of regulating Lake Michigan-Huron.

U.S. Congress, House, Water levels of the Great Lakes - local flood protection projects, House Doc. No. 424, 83rd Congress, 2nd Sess., U.S. Gov't. Print. Office, Washington, D.C., May 26, 1954.

This is an interim survey report on the relation between water levels of the Great Lakes and local flood protection projects. The purpose of this report was to give consideration to the advisability of adopting local flood protection projects at some of the areas which have been damaged severely by inundation as a result of fluctuations in the levels of the Great Lakes. Basic physical and economic data is presented. Hydrology and lake level fluctuations are discussed. Existing federal and non-federal flood control projects are reviewed. Flood control problems in seven areas are detailed. Plans of improvement along with economic analyses are included. Recommendations are made.

U.S. Congress, Senate, Effects of an additional diversion of water from Lake Michigan at Chicago, Senate Doc. No. 28, 85th Congress, 1st Sess., U.S. Gov't. Print. Office, Washington, D.C., 11 January 1957.

U.S. Dept. of Commerce, National Ocean Survey, Lake Survey Center, Monthly bulletin of lake levels for (monthly).

Lake level information is presented in this monthly bulletin. Graphs are included for Lakes Erie, Ontario, Superior, Michigan-Huron and St. Clair. Shown are: recorded levels for previous and current year to date, probable levels for next six months, long term average, last 10-year average, and extreme high and low levels.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Lake Survey Center, Great Lakes Water Levels 1860-1970, Detroit, Michigan, April 1971.

Lake Survey Center Great Lakes water level gage records for 52 stations are tabulated for 1860 to 1970. Monthly and annual average levels are tabulated. Also included are the average monthly average levels, highest and lowest monthly average levels for the period of record, and the average monthly average levels for the period 1960 through 1970.

YU, K-H, W. H. Graf, and G. Levine, The effect of ice on the roughness coefficient of the St. Clair River, _Proc. 11th Conf. Great Lakes Res._, p. 668-680, Internat. Assoc. Great Lakes Res., 1968.

A semi-emperical relationship between the roughness coefficient associated with ice covered flow and that of open water flow is developed. This relationship is compared with existing relationships utilizing data from the St. Clair River. This new relationship more adequately satisfied limiting boundary conditions while providing essentially the same results as other methods within the range of flows of the St. Clair. The results show a decrease in the overall Manning's n with increasing depth of flow and greater n with ice covered flow.

HYDROLOGIC BUDGET

BROWZIN, B. S., Monthly water balance in tributary watersheds of the Great Lakes-St. Lawrence River Basin as influenced by climatic factors, in Symposium on world water balance, II, Pub. No. 93, p. 479-493, Internat. Assoc. Scientific Hydrology, 1970.

The results of an investigation of the water balance of four tributary watersheds of the Great Lakes-St. Lawrence River basin, each with different climates are discussed. The four watersheds selected are: St. Louis River, Winooski River, Cayuga Creek, and Huron River. The St. Louis River basin (northwest shores of Lake Superior) has a pure snow type hydrology in pronounced continental climate. The Winooski River basin (near Lake Champlain) has a pure snow type hydrology in a continental climate with considerable oceanic influence. The Cayuga Creek basin (near the Niagara River) has a mixed type, pluvial snow hydrology and oceanic type climate. The Huron River basin (in southern Michigan) has a pluvial snow hydrology and a transition type climate. A monthly balance for each of the basins was made for the period 1950-1960, calculation of the balance was made by determining three componenets independently: precipitation, runoff, and evaporation. Evaporation was evaluated with the use of Thornthwaite's method. Conclusions are drawn from the budgeting.

BRUCE, J. P. and G. K. Rodgers, Water balance of the Great Lakes system, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 41-69, Am. Assoc. Advancement Science, Washington, D.C., 1962.

An in-depth analysis of the water balance of the Great Lakes system is presented. The value of accurate information on the magnitudes of the water balance components is noted. The time and space variations of these components are also noted. Gross annual water budget figures are presented which indicate that about one-third of the precipitation falling on the whole basin eventually shows up as flow in the St. Lawrence River.

A short discussion of trends in the water balance componenets on Lake Erie and of the complex interrelationships between these factors through lake water temperatures and the radiation balance is given. Lake surface precipitation and evaporation are considered in more detail. Also three methods of estimating lake surface precipitation (water budget, gage networks, and weather radar) are critically reviewed.

BRUNK, I. W., Hydrology of Lakes Erie and Ontario, Pub. No. 11, p. 205-216, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

Significant differences are observed in the hydrologic characteristics of the Erie and Ontario basins. In the Erie basin only about one third of the precipitation becomes streamflow. This is apparently the lowest portion for any of the Great Lakes basins. In the Ontario basin the streamflow is equivalent to approximately one half of the precipitation. Factors other than climate are thought to be responsible for these differences in hydrologic characteristics. There is a large variation among the various river basins

BRUNK, I. W. (cont'd)

which drain into Erie and Ontario and also in the months of the year in the percentages of the precipitation which flows into the lakes. The monthly extremes for Erie range from 75 percent in March to only 8 percent in September. For Ontario the values are 117 percent in April and 17 percent in August. The water area of Lake Erie makes little contribution to the total water supply of the Great Lakes because the average annual evaporation of approximately 34 inches is about the same as the average annual precipitation on the water surface of the lake. The average monthly evaporation from Lake Erie is largest in October about 6-1/2 inches. For Lake Ontario the apparent average annual evaporation is between 29 and 30 inches. Evaporation was computed as runoff from the land (streamflow) plus precipitation on the surface of the lake minus net basin supply.

COORDINATING Committee on Great Lakes Basic Hydraulic and Hydrologic Data, Lake Ontario outflows, 1860-1954, Water Resources Branch, Ottawa, Ontario and United States Lake Survey, Detroit, Michigan, 1958.

The outflow from Lake Ontario for the period 1860-1954 on the basis of information from U.S. and Canadian sources is reported.

COORDINATING Committee on Great Lakes Basic Hydraulic and Hydrologic Data, Lake Erie outflow, 1860-1964, Water Resources Branch, Ottawa, Ontario and United States Lake Survey, Detroit, Michigan, June 1965, also AD 625-918, Clearinghouse FSTI, Springfield, Virginia.

The outflow for the above dates from Lake Erie on the basis of information from U.S. and Canadian sources is reported.

CRAWFORD, L. C., Hydrology of Lake Erie and tributaries, Lake Erie Pollution Studies-Final Report, p. 19-28, Chapter 2, Ohio Department of Natural Resources, 1953.

FERGUSON, H. L. and D. G. Schaefer, Feasibility studies for the IFYGL atmospheric water balance project, Proc. 14th Conf. Great Lakes Res., p. 438-453, Internat. Assoc. Great Lakes Res., 1971.

A study of atmospheric water budget over Lake Ontario is one of the major meteorological projects proposed for the International Field Year on the Great Lakes (IFYGL). Feasibility studies for this project are presented. The project involves the application of observations of atmospheric moisture storage and atmospheric moisture flux divergence, together with precipitation data, to obtain independent estimates of lake evaporation. This method has not yet been applied to areas as small as Lake Ontario for periods as short as one month. Presented are three feasibility studies as carried out by the Canadian Meteorological Service to aid in the optimum planning of the project.

HORTON, R. E. and C. E. Grunsky, Hydrology of the Great Lakes, report of the Engineering Board of Review, Part III, Appendix II, Chicago, Illinois, 432 p., 1927.

This is a portion (Part III-Appendix II) of a report by the Engineering Board of Review of the Sanitary District of Chicago on the lake lowering controversy and a program of remedial measures. This portion deals solely with the hydrological aspects of the Great Lakes. The following topics are included: tilting of land surface, deforestation, lake outlet changes, diversions, rainfall, lake surface evaporation, inflow, outflow, and inflow-outflow relations.

INTERNATIONAL Association of Scientific Hydrology, in Symposium on world water balance, I and II, Pub. Nos. 92 and 93, 1970.

Sixty-two papers concerning world water balance and related topics are included in these publications.

JONES, D.M.A. and D. D. Meredith, Great Lakes hydrology by months, 1946-1965, Research Report No. 53, Water Resources Center, Univ. Illinois, Urbana, 1972, also in Proc. 15th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., 1972.

Monthly estimates of precipitation on each lake, evaporation from each lake surface, and runoff into each lake from surrounding land areas are developed for the Great Lakes for calendar years 1946 through 1965.

MALHOTRA, G. P. and P. Bock, Hydrologic budget of North America and sub-regions formulated using atmosphere vapor flux data, in Symposium on world water balance, II, Pub. No. 93, p. 501-523, Internat. Assoc. Scientific Hydrology, 1970.

Atmospheric vapor flux data is employed to formulate a hydrologic budget of North American regions. Previous investigations using atmospheric vapor flux are briefly reviewed. The data employed in this study included the mean monthly vertically integrated distribution of flux divergence and precipitable water, regional averages of runoff, and isohyetal averages of precipitation for the 5-year period from May 1958 to April 1963. A water budget was formulated for three regions: Eastern, Central, Western. The results indicate that the patterns of monthly evapotranspiration and storage as computed from atmospheric data become questionable as the size of the area is reduced below about 200,000 mi^2.

MEGERIAN, E. and R. L. Pentland, Simulation of Great Lakes basin water supplies, Water Resources Res., 4(1), p. 11-17, 1968.

The basic concept utilized in this simulation study is to evaluate statistically the recorded supplies to isolate the two components assumed to constitute the basin water supply: 1) That portion of supply that is considered owing to the random interaction of unpredictable meteorological elements

and 2) That portion of the supply that is the result of the existence due to natural storage of the lake soil, bedrock, and snow over the drainage basin. In the study consideration was also given to the relationship between supplies and neighboring basins. These factors were used to formulate mathematical models for simulation of supplies to all of the Great Lakes simultaneously. Extensive statistical tests have been used to insure that the statistical parameters and the time series characteristics of the simulated data resemble those of the recorded data.

MICHIGAN Water Resources Commission, Water resource conditions and uses in the ... river basin, 1961 (reports include Huron, AuSable, Maumee, Raisin, Lake Huron, Lower Grande).

These reports consist of a compilation and analysis of available data of the ... river basin in Michigan. Data was procured from the USGS, U.S. Weather Bureau, Michigan Department of Health, Michigan Department of Conservation, etc. The body of these reports generally involve three topics: hydrology, water use, and resource improvement.

MORTON, F. I. and H. B. Rosenberg, Hydrology of Lake Ontario, J. Hydraulics Div., Am. Soc. Civil Engrs., 85(HY5), p. 1-29, 1959.

A description of the physical and climatological features of the Lake Ontario basin is presented. The effects of climate and topography on the supply of water into Lake Ontario are discussed. Short and long term records of flows and supplies to Lake Ontario are related to the factors causing variation in the amount of water supplied. Detailed descriptions of the source of supply are made in relation to seasonal and aerial distribution of precipitation, temperature, and runoff.

From this study of the hydrology of Lake Ontario, it has been determined that the water supply of Lake Ontario has two principle components. The outflows from Lake Erie provide a very large and stable base flow to Lake Ontario which increases or decreases predictably in response to long term changes in hydrologic conditions on the upper Great Lakes. Although the ratio of the variations is small in terms of mean outflow, the long term variations do represent an extremely large volume of water, and that local water supply, although small in proportion to the outflow from Lake Erie, contributes more to the variations of both net total water supply and water level of Lake Ontario. Although the average seasonal distribution of precipitation for the drainage basin is very uniform, other factors cause the net local water supplies to vary widely. These factors are the variation in the aerial distribution of precipitation on the local drainage basin, the seasonal variation of water losses, the effect of the winter temperature variations on the accumulation of snow, and the effect of the seasonal variations of the precipitation-evaporation balance on the lake which intensifies the effect of seasonal variations of the land runoff. In addition to yielding an understanding of the water supplies of Lake Ontario, the results of the studies have indicated that the possibility of making accurate long range forecast of water supply is rather remote. Precipitation and runoff maps for seasonal values are presented. The year is divided into quarters.

PETTIS, C. R. and H. C. Hickman, Hydrology of the Great Lakes: A Symposium, Trans. Am. Soc. Civil Engrs., 105, p. 795-849, 1940.

Typical quantitative analysis as applied to Lake Superior, (C. R. Pettis), p. 795-806.

A method of making a quantitative analysis of the hydrology of the Great Lakes is illustrated by a detailed study of Lake Superior. Several assumptions are made to estimate the evaporation from the lake surface. Knowing the evaporation, the groundwater flow into the lake and the land losses (abstractions) are computed. It is concluded that the evaporation and the underground flow are greater, and the land losses are less, than the present (1939) generally accepted values.

Evaporation experiments, (H. C. Hickman), p. 807-817.

Evaporation experiments that were conducted at Duluth, Kewaunee, Detroit, and Buffalo, for the purposes of establishing a basis for estimating the evaporation from the water surfaces of the Great Lakes are discussed. Evaporation pan techniques were employed to determine the evaporation. The data obtained covered an extremely wide variety of air temperature, water temperature, and wind velocity combinations. It is assumed that the lake evaporation is equal to the evaporation from the experimental pans for like air temperature, water temperature, and wind velocity. The collected data were analyzed and plotted on two charts, from which an estimate of monthly or daily evaporation from the Great Lakes can be made. In these charts it is assumed that the relative humidity and barometric pressure over the lakes is equal to the average of the values at the four stations. These experiments indicate that the effect of wind on evaporation is not reflected in the common evaporation formula.

Discussions, (A. A. Young, A. J. Cooper, Jr., A. F. Meyer, S. T. Harding, O. E. Meinzer, R. W. Davenport, G. H. Hickox, C. R. Pettis, and H. C. Hickman), p. 818-849.

SANDERSON, M. E., The 1958-1963 water balance of the Lake Erie basin, Pub. No. 15, p. 274-282, Great Lakes Res. Div., Univ. Michigan, 1966, also A climatic water balance of the Lake Erie basin, 1958-1963, Pub. in Climatology, 19(1), C. W. Thornthwaite Associates Laboratory of Climatology, Elmer, New Jersey, 1966.

A climatic water balance method is used to determine monthly runoff at 133 climatic stations in the Lake Erie basin. An isopleth mapping technique is used to estimate total runoff. Monthly overwater precipitation is similarly estimated using data from perimeter stations. Monthly net lake evaporation is obtained as a remainder in the water balance when precipitation and runoff fail to meet the needs of lake evaporation and water withdrawn from the Great Lake system.

Groundwater is assumed negligible. The precipitation on the lake was determined by extrapolating the apparent precipitation pattern from the land surface. Monthly values of potential evapotranspiration, soil moisture storage, and runoff in the five year study period were computed by the

SANDERSON, M. E. (cont'd)

Thornthwaite method for the 133 stations in the watershed. Computed runoff was plotted on contoured base maps and monthly isopleth maps were drawn. The volume runoff for each month was determined by taking the area of each strip between successive isopleths on the map and multiplying by the average depth of runoff in the strips.

SANDERSON, M. E. and D. W. Phillips, Average annual water surplus in Canada, Climatological Studies No. 9, Department of Transport, Meteorological Branch, Toronto, Canada, 71 p., 1967.

Average annual runoff of Canada is determined. Since streamflow gaging stations are either scarce or have only a short period of record, long term records of about 800 climatic stations are utilized. The method of average annual surplus determination is explained. Canada was divided into six geographic regions: Maritime Provinces, Quebec and Newfoundland, Ontario, Prairie Provinces, British Columbia, and Northwest Territories and Yukon Territory. Maps of the location of climatic stations and drainage basins, and the water surplus are included for each of the geographic areas.

U.S. Lake Survey, Total atmospheric water vapor aloft over the Great Lakes Basin, Res. Report No. 5-3, April, 1967.

In this report values of atmospheric water vapor aloft over the Great Lakes Basin are estimated from surface moisture values for 29 stations in the basin employing empirical equations developed at three reporting radiosonde stations. Isoline charts are constructed and indicate that the amount of water vapor aloft always decreases from the southern to the northern portions of the basin. The isoline charts also show that a secondary increase exists from east to west over the basin. The highest mean value computed was 2.97 cm in August at Toledo, Ohio; the lowest computed was 0.26 cm in January at Armstrong, Ontario.

VIKULINA, Z. A., Methods for the computation of water balance of reservoirs, in Symposium on world water balance, II, Pub. No. 93, p. 295-299, Internat. Assoc. Scientific Hydrology, 1970.

Methods for the study and computation of water balance of reservoirs in the USSR are presented. A water balance equation for a short time interval is presented. All components of the water balance (i.e., inflow, outflow, evaporation, precipitation, etc.) are estimated independently, on the basis of appropriate data. Also included is an analysis of the errors involved in the water balance computation.

WITHERSPOON, D. F., A hydrologic model of the Lake Ontario local drainage basin, Tech. Bull. No. 31, 12 p., Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, Canada, 1970, also in Internat. Conf. Water for Peace, Vol. 3, p. 343-351, 1967.

A hydrologic model based on the water and energy balances is proposed for the Lake Ontario local drainage basin (27,100 sq mi, comprising the entire local contributing area except for the lakes water surface area of 7,500 sq mi). Using hypotheses which provide estimates of the actual regional evaporation, regional moisture values are obtained, which when routed through linear storages simulate the measured monthly outflows for the land area.

For evaporation computations, the monthly climatological variables of temperature, wind, humidity, and sunshine are used. Snowfall data were also used. Precipitation values were determined and used.

Since the model required verification, the inflow to the lake from the local contributing area was estimated. Gaged representative basins were used to extrapolate the runoff distribution to ungaged areas. The totals of the gaged runoff and the estimated runoff of ungaged areas were computed on a monthly basis and used as the value of the local inflow.

WITHERSPOON, D. F., Storage in the water balance of the Lake Ontario basin, in Symposium on world water balance, II, Pub. No. 93, p. 283-388, Internat. Assoc. Scientific Hydrology, July 1970.

Using a hydrologic model based on a water balance, the annual run of storage and its extremes are studied to determine the significance of this factor in the balance of a large land basin of 27,100 sq mi which contributes to the local inflow of Lake Ontario. Estimates obtained are reasonable when compared with values estimated from the physical and hydrologic characteristics of the basin. These estimates demonstrate the relative importance of storage to the month by month hydrology of the basin. The storage on the basin is approximately equivalent in volume to that available within the range of stage of Lake Ontario available by international agreement by Canada and the United States.

ANDERSON, D. V. and G. K. Rodgers, A synoptic survey of Lake Superior, Pub. No. 10, p. 79-89, Great Lakes Research Div., Univ. Michigan, 1963.

The results from a synoptic cruise (5-10 September 1959) are presented.

AYERS, J. C., Currents and related problems at Metropolitan Beach, Lake St. Clair, Special Report No. 20, Great Lakes Research Div., Univ. Michigan, Ann Arbor, 1964.

Specific problems at Metropolitan Beach, Lake St. Clair arising from alongshore water currents, currents outside the beach area, and the winds that provide driving force for both currents are described and discussed. Modeling of the currents aided the study.

AYERS, J. C., D. V. Anderson, D. C. Chandler, and G. H. Lauff, Currents and water masses of Lake Huron (1954 Synoptic Surveys), Tech. Paper No. 1, Great Lakes Res. Institute, Univ. Michigan, Ann Arbor, February 1956.

The results of three synoptic surveys (28 and 29 June, 27 July, and 25 August 1954) are presented. In each survey more than 80 stations were occupied. Data obtained included temperature, magnesium, silicone, calcium, and conductivity in both horizontal and vertical distributions. The horizontal distributions of transparency and relative humidity were measured and drift bottles were released. Surface currents and probable directions of bottom currents were computed.

AYERS, J. C., D. C. Chandler, G. H. Lauff, C. F. Powers, and E. B. Henson, Currents and water masses of Lake Michigan, Pub. No. 3, Great Lakes Res. Institute, Univ. Michigan, Ann Arbor, 1958.

The results of four synoptic studies (28 and 29 June and 9 and 10 August 1955) of Lake Michigan are presented. In each study 40 or more complete stations and 50 or more temperature stations were occupied.

Data obtained included transparency, temperature, calcium, sodium, silica, wind, sea state, weather, cloud cover, and relative humidity at known height above water. Drift bottles were released at each complete station. The dynamic height method was used to compute surface currents and probable direction of bottom currents.

BARRIENTOS, C. S., An objective method for forecasting winds over Lake Erie Lake Ontario, Proc. 14th Conf. Great Lakes Res., p. 401-411, Internat. Assoc. Great Lakes Res., 1971.

An objective method for forecasting surface winds over Lake Ontario and Lake Erie is presented. The data employed in the development of the method consists of 1000-mb geostrophic wind and sea-level pressure forecasts from the Subsynoptic Advection Model for eight United States cities near the two lakes

BARRIENTOS, C. S. (cont'd)

and recorded marine observations made by anemometer-equipped vessels during the 1968 boating season. Two sets of regression equations for predicting wind speed are derived by employing screening regression. The first regression equation gives wind speed by vectoral addition of two directional components; the second yields wind speeds directly. By comparing the two methods, it is evident that wind speed forecasts made by vectorally adding components are negatively biased. The resulting operational program is characterized, and verifications based on the 1969 observations are discussed.

BENNETT, J. R., Thermally driven currents during the spring and fall transition periods, Proc. 14th Conf. Great Lakes Res., p. 535-544, Internat. Assoc. Great Lakes Res., 1970.

The use of numerical model to study thermally driven lake currents during a transition to stratification is presented. The Boussines approximation is an important assumption in this model. There are six model equations, and certain boundary conditions are imposed.

The model predicts that the motion is confined primarily to the stratified region of the lake. There a geostrophic current parallel to the shore is the predominant characteristic. A smaller circulation, with upswelling in shallow regions and a broad zone of sinking motion centered about the 4°C isotherm, is found to be significant in redistributing the heat gained through the surface.

BIRCHFIELD, G. E., Response of a circular model Great Lake to a suddenly imposed wind stress, J. Geophysical Res., 74(23), p. 5547-5554, 1969.

This paper points out several errors in the paper by Csanady, 1968, which are listed and the corrected solution and conclusions are presented.

CHURCH, P. E., The annual temperature cycle in Lake Michigan, Am. Geophys. Union Trans. 27, p. 109-110, February 1946.

Summarizes 2,000 bathythermograph observations from 110 lake crossings into brief discussions of the temperature changes in the lake through the year.

CSANADY, G. T., Motions in a model Great Lake due to a suddenly imposed wind, J. Geophysical Res., 73(20), p. 6435-6447, 1968.

A solution is presented for the initial value problem that arises when a uniform wind stress is suddenly imposed on the surface of a circular, constant depth, two layer lake that has similar characteristics to the Great Lakes under summer conditions. Even with this minimum number of dynamically significant features in the theoretical model, a number of experimentally found features in the behavior of the Great Lakes are reproduced in a realistic way, the most important being large thermocline movements near the shores, coastal jets, rotary currents in the central portion, standing internal waves of long wave length and large amplitude, standing surface seiches, and rotating surface and internal seiches. This model is a closed basin, two layer structure, with constant coriolis parameter.

CSANADY, G. T., Wind driven summer circulation in the Great Lakes, _J. Geophysical Res._, _73_(8), p. 2579-2589, 1968.

Simplified models of wind driven forces are considered in the two layer circular basin "Model Great Lake" introduced in an earlier paper. Under summer conditions, when a thermocline is present, both a uniform, steady wind and a uniform wind varying periodically in time produce a frictionless lake response characterized by strong boundary currents and pronounced thermocline movements in the shore zone. The length scale determining the width of this shore zone is the "Radius of Deformation," typically three miles. Observations on Lakes Huron, Michigan, and Ontario show such motions to be present near the shores.

HACHEY, H. B., Vertical temperature distribution in the Great Lakes, _J. Fish. Res. Bd. Can._, _9_(7), p. 325-328, 1952.

Temperature observations in June, July, and August 1948 indicate that: (1) the maximum depth of the thermocline does not exceed 50 feet, (2) the temperature gradient within the thermocline may be as much as 26°F in 10 feet, (3) the thickness of the surface layer varies considerably with time and position, and can under certain circumstances be entirely removed from the area, and (4) the temperature of the deeper waters approximates to that of the maximum density of fresh water.

HAMBLIN, P. F., Circulation and water movement in Lake Erie, _Scientific Series No. 7_, Inland Waters Branch, Depart. Energy, Mines and Resources, Ottawa, Canada, 1971.

HARLEMAN, D.R.F., R. M. Bunker, and J. B. Hall, Circulation and thermocline development in a rotating lake model, _Pub. No. 11_, p. 340-356, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1964.

Results from a study of a very small, highly idealized rotating model of Lake Michigan are presented. The model used in this study was considerably smaller than that recommended in a previous feasibility study. Theoretical considerations for the temperature effects, coriolis force, wind effects, hydrologic effects, and modeling considerations are given. Natural model relationships are given. The experimental equipment is described. The experimental procedure is described and results and conclusions are summarized. The length ratio is 1 to 500,000 and the depth ratio is 1 to 1,000. The horizontal length of the model is 3.28 feet and the average model depth is .27 feet.

LAUFF, G. H., Some aspects of the physical limnology of Grand Traverse Bay, _Pub. No. 2_, Great Lakes Res. Institute, Univ. Michigan, Ann Arbor, June 1957.

The results of a limnological survey on 30-31 July 1954 of Grand Traverse Bay in northern Lake Michigan are presented. A bathymetric chart of the bay has been prepared along with data concerning the area and volume of the bay. The surface and subsurface distributional patterns of several parameters including water transparency, temperature, and dissolved silica and magnesium are described. Some aspects of the distribution and character of the sediments of the bay are correlated with the activity of surface and subsurface currents.

LEMIRE, F., Winds on the Great Lakes, Canada Dept. Transport, Meteorological Branch, CIR. 3560, TEC. 380, 1961.

MALONE, F. D., An analysis of current measurement in Lake Michigan, J. Geophys. Res., 73(22), p. 7065-7081, 1968.

Current meter records, collected from Lake Michigan during the Great Lakes-Illinois River Basins project (GLIRB) are studied using harmonic, spectral, and cross-spectral analysis techniques. Major peaks in the velocity spectra are located near the local inertia frequency during the thermocline season. Cross-spectra between the velocity components at different depths yield high coherences (0.9) near the inertia frequency and show that the velocity components are approximately 180° out of phase above and below the thermocline. The current meter records from the mouth of Green Bay and the Straight of Mackinac are dominated by periods of 12 and about 15 hours, respectively.

MILLAR, F. G., Surface temperatures on the Great Lakes, J. Fish. Res. Bd. Can., 9(7), p. 329-376, 1952.

The water temperature of the Great Lakes was recorded for five to ten years with thermographs that were installed on the condenser intakes of several steamships. Averages are presented in tables, maps, and diagrams. The temperature varies over a lake surface in a manner determined by depths and currents. Standard deviations and serial correlations are found for some data.

MILLER, G. S., Currents at Toledo Harbor, U.S. Lake Survey, Misc. Paper 69-5, Detroit, 1968.

The results of an investigation of currents at Toledo Harbor, Ohio, that was conducted from May through November 1966 employing Eulerian and Langrangian techniques are presented. Wind tides, seiches, and river discharge are the driving forces which produce currents in the harbor. The current is a reversing type except during periods of high river outflow. Histograms indicated that approximately 10 percent of the time the current speed is greater than 15cm/sec. Spectoral analysis of current speed indicated that the peaks correspond to the modes of the seiches. Drogue tracks show that the mid-channel current is up to 2.5 times greater than that recorded near the channel edge. Also it is noted that opposing currents are occasionally observed due to wind induced surface currents.

NOBLE, V. E., Winter temperature structure of Lake Michigan, Pub. No. 13, p. 334-341, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1965.

Buoy data were used to compute the heat storage in Lake Michigan during the winter seasons 1962-63 and 1963-64. The lake was totally covered with ice during the 1962-63 season and nearly ice-free during 1963-64. It is suggested that the fall temperature profiles in deep water may be used as an indicator of the amount of ice cover to be expected during the winter.

NOBLE, V. E., Vertical current structure in the Great Lakes, Special Report No. 27, Great Lakes Res. Div., Univ. Michigan, 1966.

The transient feature of the vertical profile of horizontal currents in the Great Lakes under the influence of the wind stress are described. Data were obtained from a buoy station in Lake Michigan. An attempt to apply an Ekman-type model (of current dynamics) failed while a geostrophic eddy model was verified.

PASKAUSKY, D. F., Winter circulation of Lake Ontario, Proc. 14th Conf. on Great Lakes Res., p. 593-606, Internat. Assoc. Great Lakes Res., 1971.

In winter Lake Ontario is a barotropic or homogeneous fluid circulation mode. A barotropic, prognostic, numerical circulation model, which includes topographic, inertial, lateral and bottom friction, and wind stress terms, is applied to Lake Ontario. The circulation pattern is determined for two cases; first with river inflow and outflow only and second with both river flow and a wind field that could be produced by a meteorological-pressure area to the southwest of the lake. Development of a model is based on the following conditions and/or assumptions: (1) the fluid is considered homogeneous and incompressible, (2) the bottom and boundaries of the basin other than openings are considered impermeable, (3) the local horizontal component of the earth's rotation is neglected, (4) inflow and outflow are normal to the cross-section of the ports, (5) bottom friction is proportional to the velocity, (6) lateral friction torque is taken proportional to the horizontal Laplacian of the velocity, (7) the vertical velocity is zero at the sea surface and the bottom is a stream function, and (8) the stream function is fixed on all boundaries.

RICHARDS, G. L. and J. P. Fortin, An evaluation of the lake-land vapor pressure relationship for the Great Lakes, Pub. No. 9, p. 103-110, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1962.

An evaluation of the land-lake vapor pressure relationship for the Great Lakes is presented. This involves the determination of the humidity ratio. Method of determinations, results, and applications are discussed.

RODGERS, G. K., The thermal bar in the Laurentian Great Lakes, Pub. No. 13, p. 358-363, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1965.

The progress of stratification in a large lake in the temperate zone is presented.

RODGERS, G. K., The thermal bar in Lake Ontario, spring 1965 and winter 1965-1966, Pub. No. 15, p. 369-374, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1966.

The movement of the thermal bar is documented for the spring condition, and current measurements taken in the bar are shown.

RODGERS, G. K., Field investigation of the thermal bar in Lake Ontario: precision temperature measurements, _Proc. 14th Conf. Great Lakes Res._, p. 618-624, Internat. Assoc. Great Lakes Res., 1971.

Field investigations during nine surveys in the spring of 1970 consisted of measuring temperature profiles at 30 to 60 stations in the eastern half of the lake. Previously reported patterns of heat content change were confirmed.

RODGERS, G. K. and D. V. Anderson, The thermal structure of Lake Ontario, _Pub. No. 10_, p. 59-69, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1963.

A selection of data obtained from 21 surveys of Lake Ontario in 1958, 1959, 1960, and 1961 is presented. A description of the characteristic average thermal structure of Lake Ontario is presented.

SCOTT, J. T., P. Jekel, and M. W. Fenlon, Transport in the baroclinic coastal current near the south shore of Lake Ontario in early summer, _Proc. 14th Conf. Great Lakes Res._, p. 640-653, Internat. Assoc. Great Lakes Res., 1971.

In early summer the currents along the south shore of Lake Ontario are primarily baroclinic and concentrate in a narrow band or coastal jet. These boundary modified coastal currents are generally set up by the relatively strong wind following the passage of summer cyclones and cold fronts. A study of the transport and pattern of the coastal current which resulted from a typical summer storm in July 1970 is described.

SMITH, N. P. and R. A. Ragotzkie, Some characteristics of temperature recorder time series from Lake Superior, _Proc. 14th Conf. Great Lakes Res._, p. 670-676, Internat. Assoc. Great Lakes Res., 1971.

Half-hourly temperature data collected at five levels in southeastern Lake Superior from early June to mid October 1967 are used to compute daily averages, standard deviations, daily temperature ranges, and relative energy density and coherence spectra.

THE thermal current structure in Lake Michigan: A theoretical and observational model study, _Special Report No. 43_, Great Lakes Res. Div., Univ. Michigan, 1969.

OHIO Division of Geological Survey, Water masses and their movement in western Lake Erie, _Report of Investigation No. 74_, 1969.

WEBB, M. S., Monthly mean surface temperatures for Lake Ontario as determined by aerial survey, Water Resources Res., 6(3), p. 943-956, 1970.

Preliminary patterns of monthly mean surface water temperatures for Lake Ontario basin on 36 airborne radiation themometer surveys over a 3 year period are presented. Temperature values of each of the 86 points in a grid have been plotted against calendar date and an average temperature curve has been produced for each point. Values for the middle of each month have been determined by interpolation and used to produce a pattern for each month. The patterns are briefly compared with Miller's. These monthly values are considered tentative, and plans are to continue the surveys in order to update the patterns.

YU, S. L. and W. Brutsaert, Estimation of near surface water temperatures on Lake Ontario, Proc. 11th Conf. Great Lakes Res., p. 512-523, Internat. Assoc. Great Lakes Res., 1968.

Near-surface water temperature was assumed to be a function of the air temperature and sunshine percentage data observed at four periphical stations. Time series and regression analyses were performed and different estimation equations were compared. It was found that there was practically no correlation between water temperature and sunshine anamolies, and that water temperatures could be estimated with an average coefficient of determination of 0.44 by using the present and the past 2 to 4 months of air temperature data.

GENERAL

ACKERMANN, W. C., Implications of the Maris Report, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 343-360, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Judge Albert B. Maris was appointed special master by the U.S. Supreme Court to hear the testimony and prepare and recommend decree in the extended legislation revolving around the Chicago diversion from Lake Michigan. The decree set definite limits on the water that can be diverted at Chicago until it can be shown that every reasonable alternative has been exploited. In view of possible future diversions in other states the Illinois situation probably has great interest as a president. Interest in Canada is probably equal to that in the United States.

ALBERY, A.C.R., Some technical and economical aspects of continental water schemes, addressed to Ontario Municipal Water Association, Gibb, Underwood & McLellen, Toronto, Ontario, March 25, 1968.

Canada's water resources are outlined against a world background, some of the schemes proposed for continental water development are described, the probable cost of water delivered to the U. S. border is estimated, and the possibility of a market for water in the United States at the price at which it could be delivered is discussed.

ANALYSIS of water and water related research requirements in the Great Lakes region, Council on Economic Growth, Technology, and Public Policy of the Committee on Institutional Cooperation for the Director, Office of Water Resources Research, Department of the Interior, Washington, D.C., Univ. Michigan, Ann Arbor, June, 1968.

Investigators interested in water and water related research in the Great Lakes region considered applicable research requirements and methodologies, with special emphasis on the applications of systems analysis and modeling. Representatives of many disciplines, from major midwestern universities, water resources centers, and federal agencies, met in two working conferences and on numerous other occasions to discuss a framework for research activities which appear necessary to comprehensive water management and related development in the Great Lakes region.

This report indicates the focus placed by researchers of many disciplines upon a systems analysis model of the Great Lakes. Early in the study it was determined that a water quantity model of the entire system is necessary and feasible. Attempts at a water quality model for the Great Lakes region on a subregional, subsystem basis, with subregional groupings anticipated as available data and systems technology permit, are also presented. The need for a regional economic growth model, water related information systems, and a gaming simulating model for research on relevant institutions is described. The research efforts to supplement and support the water quantity and water quality subsystems are specified, and priorities among these are suggested. The

ANALYSIS of water and water related research requirements in the Great Lakes region (cont'd)

Appendices to the report contains papers contributed to the study, proceedings of the working conferences, names of conference participants, a listing of responses by conference participants and their colleagues to a questionnaire on research activities needed in the Great Lakes region, and other supplementary materials.

ANDERSON, D. V., Recirculation of water in the Great Lakes, Bull. Internat. Assoc. Scientific Hydrology, 11(4), p. 5-7, December 1966.

The possibility of recirculating water from Lake Ontario to Georgian Bay is discussed; only 25 miles separate Lake Ontario from the Georgian Bay divide, but a 330 feet difference in elevation exists. Some light is shed on the benefits and problems of such a development.

AYERS, J. C., Great Lakes waters, their circulation and physical and chemical characteristics, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 70-90, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The circulation of the Great Lakes consists of horizontal surface current, horizontal deep currents, and vertical water movements. The relationship of these is also mentioned.

Concerning the physical characteristics, the following aspects are presented along with graphs and tables: cyclic phenomena, annual water temperature cycle, air temperature-water temperature cycle, difference of land and lake precipitation, lake level cycles, tides, and seiches.

Turbidity, silica, iron, calcium, magnesium, sodium, carbonate, bicarbonate, sulfate, nitrate, chloride, and dissolved solids are discussed for each lake.

AYERS, J. C. and J. E. Kerrigan, Preliminary research design for the water quality subsystem of the Great Lakes region, Appendix F in Analysis of water and water related research requirements in the Great Lakes region, p. 87-96, Council on Economic Growth, Technology, and Public Policy of the Committee on Institutional Cooperation for the Director, Office of Water Resources Research, Department of the Interior, Washington, D.C., Univ. Michigan, Ann Arbor, June 1968.

An approach designed to quantify the quality interrelationships between local areas lake by lake and to describe the nature and alternative courses of action that may take place within a localized region or local sector is outlined.

BEETON, A. M. and D. C. Chandler, The St. Lawrence Great Lakes, Chapter 19 in Limnology in North America, edited by David Frey, p. 535-558, The University of Wisconsin Press, Madison, 1963.

A general introduction to the Great Lakes is presented. The characteristics of the Great Lakes and a history of limnological research on the lakes are included. The history of research includes a brief description of the missions and facilities of the agencies and institutions involved in research on the Great Lakes in 1963. The discusssion is oriented mainly toward biological and limnological studies.

BUTRICO, F. A., C. J. Touhill, and I. L. Whitman, Resource Management in the Great Lakes Basin, 190 p., Heath Lexington Books, D. C. Heath and Company, Lexington, Massachusetts, 1971.

The material in this book was prepared by the staff of the Battell Columbus and Battell Northwest Laboratories of Battell Memorial Institute.

This book is a genral survey of research needs in the Great Lakes basin. The identification of problems include water quality; water levels and inter-basin transfer; ecological imbalances; institutional problems; economic and social problems; financing; and public involvement. The proposed research program to accomplish the understanding and management of these problems include technical-economic analysis, social-economic analysis, institutional analysis, and the development of International Great Lakes Center. There are six appendices which comprise two-thirds of the book. They are Water Pollution in the Great Lakes Basin, Great Lakes Ecology, Biological and Chemical Sub-Models, Advances in Computer Technology, A Method for Estimating Recreation Benefits, and Political Theory for Institutional Analysis.

CAIN, S. A., The use of the Great Lakes for recreation, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 213-238, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The resources available, including Great Lake areas and shoreline, and the proportions of the latter in public ownership are tabulated. Statistics of population growth, participation in various recreational activities, and revenues derived from such activities are also tabulated. Among the recreational activities discussed are hunting, fishing, boating, and camping and swimming at the many State Parks. It is concluded that recreation of this type provided by the Great Lakes is a fundamental and integral part of the present life styles, and that acquisition and maintenance of the means for such recreation must be treated on a par with more familiar and more easily quantified economic developments.

CAIN, S. A., Conflicts of recreation and other uses of the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 121-144, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

The alewife explosion is used as an example for demonstrating the conflicts which arise from the use of the lakes for recreation and commerical fishing and other uses.

CLARK, A. H. and E. R. Officer, Land use pattern, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 141-156, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The following figures, all pertaining to the Great Lakes basin, are included: land use, population density of 1950, rate of population change from 1930 to 1960, ratio of rates of population change for 1930 to 1950, and ratio of rates of population change for 1940 to 1960. It is noted that in the land use patterns, population density, and rates of population change strong constrasts exists between the northern and southern portions of the Great Lakes basin. Several other conclusions are drawn.

COOLEY, L. E., The diversion of the Waters of the Great Lakes by way of the Sanitary and Ship Canal of Chicago, Clohesey and Co., Chicago, February, 1913.

This is a brief of the facts and issues concerning the request made by the Sanitary District of Chicago to increase the diversion of water to 10,000 cfs through the Chicago Sanitary and Ship Canal. The Secretary of the Army refused this request. The district, canal, and the Great Lakes are described in detail. Cooley (consulting engineer for the Chicago Sanitary District) presents an argument for the permission to increase the diversion to 10,000 cfs.

DAHL, A. H., Water pollution in the Great Lakes, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 277-290, Am. Assoc. Advancement Science, Washington, D.C., 1962.

Current water pollution problems in the Great Lakes basin are reviewed. The Great Lakes are receiving effluents equivalent to the raw wastes of 4.5 million people. Also, 60 percent of the population in the Great Lakes basin rely upon the lakes for water supply. Industrial wastes add greatly to the pollution of the lakes.

Growth of population and industry and the increased metropolitanism are overtaxing the current facilities and knowledge of waste treatment. Even with the best known treatment facilities, plant effluents are rendering receiving streams and lakes impaired for further use. Chicago, for example, despite its up-to-date sewerage system, discharges wastes containing 1,800 tons of solids daily. This is not uncommon for such large metropolitan areas. Many beaches have been closed. The opening of the St. Lawrence Seaway has caused increased concern particularly in harbor cities where ships dispose of sewage and garbage. In conclusion, research along with research funds is needed to properly treat and dispose of the wastewater in the Great Lakes system.

DEININGER, R. A., Preliminary research design of the water quality subsystem of the Great Lakes, Appendix E in Water and water related research requirements in the Great Lakes region, p. 81-86, Council on Economic Growth, Technology, and Public Policy of the Committee on Institutional Cooperation for the Director, Office of Water Resources Research, Department of the Interior, Washington, D.C., Univ. Michigan, Ann Arbor, June, 1968.

A brief summary of the average inputs and outputs of the Great Lakes, based on data from the U.S. Lake Survey is presented along with a brief discussion of the data collection, and the formulation and verification of mathematical models.

DOHLER, G. C., The adoption of the international Great Lakes datum 1955, Canadian Hydrographic Service, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa, 1961.

The various reasons why the Canadian Hydrographic Service changed the datum of reference of all the water level and bench mark elevations in the area between Father Point, Quebec, and Port Author, Ontario, to the International Great Lakes Datum (1955) (IGLD 1955) are presented. Also the establishment of this datum is described in general terms.

EDWARDS, E. E. and E. J. Lowe, References on the Great Lakes-St. Lawrence Waterway Project, U.S. Dept. of Agriculture Library, Biographical Contribution No. 30, Washington, D.C., October, 1936.

A compilation of references on the Great Lakes-St. Lawrence River Project is presented. This work contains more than 900 entries and an index.

ENGINEERING Institute of Canada and American Society of Civil Engineers, Proc. Great Lakes Water Resources Conf., Toronto, Ontario, June 24-26, 1968.

This is the proceedings of a conference covering multiple uses of the Great Lakes, water use conflicts, regulation of the lakes, and water quality in the lakes.

EXPLORATION of collateral data potentiality applicable to Great Lakes Hydrography and Fisheries, Phase II, Final Report, Great Lakes Res. Institute, Univ. Michigan, Ann Arbor, 1959.

This is part of a three phase study carried out by the U.S. Fish and Wildlife Service. The objectives of Phase II were to carry out a pilot study in which data from onshore and near shore sources were tried for compatibility with offshore cruise data; to determine which data sources were most nearly represented of open-lake conditions; and to assess methodologies, instrumentations, and other aspects influencing the accuracy and/or representatives of the data. These objectives were attained and the final report of the results is presented.

GAMET, M. B., Nature of use and consumption of Great Lakes water for domestic and industrial purposes, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 239-250, Am. Assoc. Advancement Science, Washington, D.C., 1962.

Great Lakes water demand is compared to the national water demand. It is estimated that the full development of water resources will be reached by about 1980 and beyond that year, recycling of water will be required to meet all water demands.

In the Great Lakes region more than 16 million people are supplied with Great Lakes water through treatment plant facilities with combined capacities of over 4,000 mgd. Tables contained in this paper illustrate consumptions of Great Lakes water and the population served in all near-by states and the Province of Ontario. For five states, more than 90 percent of their total water supply is for industrial use.

A few of the problems to be encountered are brought up with special note given to increased pollution of the Great Lakes by municipal and industrial wastes.

GREAT Lakes Basin Commission, Long-range schedules of priorities for water and related land resources programs, Ann Arbor, Michigan, June, 1970.

This bulletin is an annual report to assess and establish priorities of future programs for the development, conservation and utilization of water and related land resources beginning with Fiscal Year 1972. This report attempts to establish a basis for the coordination and scheduling of programs relating to the collection and analysis of data, the investigation of programs, and the implementation of programs. Ideally, the participating eight states and nine federal agencies will apply these guidelines to solve problems associated with water and related land resources in the Great Lakes basin.

Characteristic features and the conflicting interests in the Great Lakes region are discussed. The problems, needs, and objectives of the Great Lakes system for the planning subareas (i.e. political subdivisions) of each of the basin states are defined. Programs to solve these problems were defined and the program elements, their location, scope, and associated priorities as recommended by the Great Lakes Basin Commission are tabulated.

HAVLICK, S. W., An inventory of needed research activities in the Great Lakes region, Appendix H in Analysis of water and water related research requirements in the Great Lakes region, p. 100-104, Council on Economic Growth, Technology, and Public Policy of the Committee on Institutional Cooperation for the Director, Office of Water Resources Research, Department of the Interior, Washington, D.C., Univ. Michigan, Ann Arbor, June, 1968.

The results of a questionnaire survey to determine research priorities of researchers in the Great Lakes region are presented.

HENSON, E. D. and M. Potash, Lake Champlain in relation to regional water supply, *Proc. 12th Conf. Great Lakes Res.*, p. 441-448, Internat. Assoc. Great Lakes Res., 1969.

Lake Champlain is a deep glacial lake of the St. Lawrence drainage basin. It is the eastern most major contributor of fresh water to the St. Lawrence system before the St. Lawrence becomes brackish. Because of its large size (440 sq. mi.) and considerable depth (400 ft.), Lake Champlain has been singled out as a potential regional water supply for the metropolitan areas of New England and New York City. An analysis had been made of the water budgets of the lake to ascertain its reliability as a major water supply.

The lake has a volume of 912.2 x 10^9 cubic feet. The effluent, the Richelieu River, has a mean outflow of 11,000 cfs which is equivalent to 38 percent of the lake volume. The flow through period amounts to only 2.6 years. The total input ranges from 25 to 55 percent of the lake volume.

Present municipal water use of the lake amounts to 1 percent of the lake volume per year and will increase as the population increases. Lake levels are usually at low stages when regional demands for the water are greatest. It is recommended that water resource planners might look to the more stable supplies of Lake Ontario discharge on its way to the sea as a reliable source of water for the region.

HOUGH, J. L., *Geology of the Great Lakes*, 313 p., University of Illinois Press, Urbana, 1958.

A detailed report on the geology of the Great Lake basin is presented. The Great Lakes region, the present lakes and pre-lake history, methods of dating events of lake history, and history of lake stages are discussed.

HOUGH, J. L., Geologic framework, in Great Lakes Basin, *Pub. No. 71*, edited by J. H. Pincus, p. 3-28, Am. Soc. Advancement Science, Washington, D.C., 1962.

A review of the geologic framework of the Great Lakes is presented. A general description of each of the five Great Lakes along with a map of the bottom topography of each is included.

Bedrock geology of the region is summarized and a generalized geologic map identifying the rock groups is included.

HYDROSCIENCE, Inc., Limnological systems analysis for the Great Lakes, *Summary Report*, Westwood, New Jersey, for the U.S. Great Lakes Basin Commission, Ann Arbor, Michigan, April, 1972.

A preliminary assessment of the feasibility of applying a limnological systems analysis to the Great Lakes is presented. The state-of-art of modeling as it applies to the water resource problems of the Great Lakes is evaluated. Seven major water resources problems are listed and discussed. Existing data is reviewed. The concept of modeling is discussed. Available hydrological balance, ice-heat budget, thermal, lake circulation and mixing, erosion-sediment, eutrophication, dissolved oxygen, ecological, and chemical models are discussed.

INTERAGENCY Committee on Oceanography of the Federal Council for Science and Technology, Aquatic sciences in the Great Lakes area, ICO Informal Report No. 4, Vol. 1, U.S. Department of Commerce, Office of Regional Economic Development for the ICO, U.S. Gov't, Print. Office, Washington, D.C., May, 1966.

A narrative summary of Great Lakes activity categorized by sponsor is presented.

KEHR, W. Q. and C. R. Owndey, Water resources problems of Great Lakes, J. Am. Water Works Assoc., 5(9), p. 1167-1172, 1964.

Water resources problems of the Great Lakes are reviewed. Among those mentioned are water quantity, water availability, industrial usage, buildup of dissolved solids, over fertilization, urban pollution, and vessel waste pollution.

LAARMAN, J. P., Internationally coordinated physical data of the Great Lakes, Lake Survey District, Corps of Engineers, Detroit, Michigan, 1965.

The aspects of internationally coordinated physical data of the Great Lakes are discussed and defined. Physical data are international in scope when they are derived from the basic environmental data of the Great Lakes, employed in projects that affect the water laws of the Great Lakes basins, and applied to structural design or physical environmental features of the Great Lakes.

Established needs of internationally coordinated data, two dynamic forms of internationally coordinated data, and two classified formalities of internationally coordinated data are discussed.

The structure and accomplishments of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data and Vertical Control, Lake Levels, Physical Data, and River Flow Subcommittees are mentioned.

Three types of coordination projects are recognized depending upon the relative importance of data and methods. In a Type I project, data is precedent over methods. In a Type II project, data and methods are of equal importance. In a Type III project, method has precedence over data.

The steps necessary in the proper coordination of data are exemplified by three practical applications.

LEE, T. R. and A. Beaulieu, A water use map of the Great Lakes Basin, Proc. 14th Conf. Great Lakes Res., p. 677-680, Internat. Assoc. Great Lakes Res., 1971.

A map of water use behavior in the Great Lakes basin is discussed. The map is an attempt to bring together and put into meaningful form a large variety of information on water use from many fragmentary sources. All water use phenomena are shown on the map. Relevant characteristics of the water resource and social and economic system are shown. The water related activities portrayed include shoreline use, waste loads, fisheries, irrigation, thermal loadings and electrical generation. The map is available at cost from the Department of Energy, Mines, and Resources, Canada.

LYON, W. A., Water conflicts on Lake Erie, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 115-120, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

The water quality problems of Lake Erie are due to excessive pollution, particularly over fertilization of the lake and exploitation of the fisheries resource without consideration for a favorable fish balance. Public statements about the lake's depth are overly pessimistic and tend to depress the recreation and tourist economy of the lake. Improvement in water quality of the lake should be taken in three steps: (1) Implementation of the pollution abatement program development by the Federal Government and International Joint Commission; (2) Development of conceptual policy framework based on a model of the lake which considers ecologic hydrologic and biochemical and other subsystems operative in the lake and relates pollution abatement to result in water quality and use improvements including cost; (3) Improvement of fisheries.

MacDOWELL, J. and J. Bolsenga, A synoptic study for evaluating the role of the Great Lakes, in Symposium of world water balance, II, Pub. No. 93, p. 281, Internat. Assoc. Scientific Hydrology, 1970.

A summary of a study designed to facilitate the management of the Great Lakes is presented. The study involves a large scale coordination and concentration of research effort (the International Field Year for the Great Lakes) to more readily define the water balance and associated lake-air interactions of the Great Lakes and to provide the basic data to improve mathematical models of physical limnology and meteorological phenomena.

MacLAREN, J. W. and R. F. Clevenger, New requirement in water resources planning on the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 361-392, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Present conditions on the Great Lakes including the complexity and interaffect of the various uses of the resource and the type of action that will be required to introduce appropriate planning to permit the optimum development of resources on both sides of the border are discussed. Recommendations are made for the organizational procedures necessary to implement the study in the plan including reference to the roles of the recently established Great Lakes Basin Commission and the continuing role of the International Joint Commission.

MacNISH, C. F. and H. F. Lawhead, History of the development of the use of the Great Lakes and present problems, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 1-48, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

Past and current problems and coordination efforts are reviewed. The results of international cooperation, understanding, and agreement are described. The authors conclude that the most effective solution of the Great Lakes problems must involve an interdisciplinary approach. A bibliography of source material referred to in the preparation of the paper is provided.

MacKAY, W. R., Commerical navigation on the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 89-114, Engineering Institute of Canada and Society of Civil Engineers, June 24-26, 1968.

The growth of commercial navigation in the Great Lakes and St. Lawrence System from 1678 to the present is traced and the relationship of the development of the canals with development and growth of navigation is outlined.

The possibilities for future expansion resulting from development of potash deposits in Saskatchewan and the ever increasing grain and iron ore traffic and the expansion of overseas trade are mentioned.

MARIS, A. B., Report of Special Master, Wisconsin Et. al. vs. Illinois Et. al., December, 1966.

This is a summary of four hearings dealing with the Great Lakes in the October Term 1966 in the Supreme Court of the United States. They are:

(1) States of Wisconsin, Minnesota, Ohio, and Pennsylvania vs. State of Illinois and the Metropolitan Sanitary District of Greater Chicago;

(2) State of Michigan vs. State of Illinois and the Metropolitan Sanitary District of Greater Chicago;

(3) State of New York vs. State of Illinois and the Metropolitan Sanitary District of Greater Chicago; and

(4) State of Illinois vs. State of Michigan, Ohio, Pennsylvania, Minnesota, New York, and Wisconsin.

MEREDITH, D. D., Water systems modeling, Appendix C in Analysis of water and water related research requirements in the Great Lakes region, p. 61-77, Council on Economic Growth, Technology, and Public Policy of the Committee on Institutional Cooperation for the Director, Office of Water Resources Research, Department of the Interior, Washington, D.C., Univ. Michigan, Ann Arbor, June, 1968.

A review of the state-of-the-art in system model building that would be applicable to a Great Lakes area system model is presented. The models discussed are: the New York metropolitan region study, by the graduate school

MEREDITH, D. D. (cont'd)

of public administration Harvard University; the upper midwest economic study, jointly undertaken by the upper midwest research and development council and University of Minnesota; the Ohio River basin study by Arthur D. Little for the U.S. Army Corps of Engineers; the California development model for the state of California; the OAHU Hawaii model for the state of Hawaii; the Leheigh basin simulation model by the Harvard water program, Harvard University; the Susquehana River basin model by Battelle Memorial Institute; a regional economic simulation model by the southeastern Wisconsin regional planning committee; and the METRO model developed by the Tricounty Regional Planning Commission, Lansing, Michigan. This is followed by some alternative approaches to the development of the Great Lakes area systems model itself.

MEREDITH, D. D. and B. B. Ewing, Systems approach to the evaluation of benefits from improved Great Lakes water quality, _Proc. 12th Conf. Great Lakes Res._, p. 843-870, Internat. Assoc. Great Lakes Res., 1969.

A systems approach to the evaluation of benefits that would accrue due to an improvement in the quality of the water in the Great Lakes is outlined. The basic approach for analysis of municipal and industrial water supply, recreational use, and commercial fishing involves following a change in water quality through a sequence of interrelationships to arrive at an estimate of annual benefits. The difficulties encountered in determining the benefits are discussed. A mathematical model which can be solved to determine the benefits for a change in water quality when the level of water quality before and after the improvement is known is presented. The model is applicable to all uses.

MILENBRUCH, C. W. and R. C. Stuart, Development of the transportation network, in Great Lakes Basin, _Pub. No. 71_, edited by H. J. Pincus, p. 157-191, Am. Assoc. Advancement Science, Washington, D.C., 1962.

A review of the development, form the 18th century to the present, of the Great Lakes region transportation network is presented. The current metropolitan centers and larger cities on the Great Lakes grew out of the waterways transportation pattern of the French and Indian period. The Erie, Ohio, Athens, Miami, and the Illinois and Michigan Canals, all pre 1850, are mentioned. The railway and transportation era, 1850 to 1920, is discussed and several illustrations are included. Also, the development of the highways and an integrated transportation network from 1920 to 1960 is discussed.

The concept of urban growth being directly related to the quality of regional transportation is verified. The six metropolitan cities which dominate the Great Lakes (Buffalo, Cleveland, Chicago, Detroit, Milwaukee, and Toledo) are discussed.

O'CONNOR, D. J. and J. A. Mueller, Water quality model of chlorides in Great Lakes, J. Sanitary Engineering Div., Am. Soc. Civil Engineers, 96(SA4), p. 955-975, 1970.

The increase in the concentration of conservative substances in the Great Lakes is described by a simple time variable equation. The concentration of chlorides is related to the fresh water flow, the volumes of the lakes, and the various sources--municipal, industrial, natural background, and road de-icing. The increase in concentration since 1900 is presented and projections are made of anticipated concentrations based on various assumptions of control.

PENTLAND, R. L. and N. E. Eryuzler, A dynamic programming algorithm for the operation of the Great Lakes, Reprint Series No. 53, Inland Waters Branch, Department of Energy, Mines, and Resources, Ottawa, Canada, 1969.

The application of a dynamic programming algorithm to develop a plan for the Great Lakes which would produce the most beneficial levels and outflows for the conflicting interests within the basin is presented. The scope of this problem is discussed. Due to the magnitude of the investigation, various approximations were used in the development of the algorithm. Methods used to reduce computing costs to acceptable levels are discussed.

PINCUS, H. J., (ed) Great Lakes Basin, Pub. No. 71, Am. Soc. Advancement of Science, Washington, D.C., 1962.

Fifteen papers presented at a symposium of the American Society for the Advancement of Science meeting at Chicago on December 29-30, 1959, are included. Three main areas are discussed: natural setting, man's adaptation in the basin, and utilization of water.

PINCUS, H. J., Recession of Great Lake shorelines, in Great Lake Basin, Pub. No. 71, edited by H. J. Pincus, p. 123-140, Am. Assoc. Advancement Science, Washington, D.C., 1962.

A fundamental difference between shoreline recession and erosion is stated. An explanation is given for the 13 factors contributing to recession and erosion. They are water waves, currents, wind, surface runoff, groundwater flow, raindrop impact, frost action, gouging of shore material by lake ice, mechanical consequences of chemical weathering, composition of shore material, vegetation, lake levels, and shore protection structures. Interaction of these factors and counter factors are discussed.

POLICASTRO, A. J., State-of-the-art of analytical modeling of heated effluent dispersion in large lakes, paper presented at 15th Conf. Great Lakes Res., at Madison, Wisconsin, Internat. Assoc. Great Lakes Res., Argonne National Lab., Argonne, Ill., April, 1972.

This is a state-of-the-art report which identifies and contrasts available mathematical models for predicting thermal plume dispersion in large

POLICASTRO, A. J. (cont'd)

lakes. Eight far-field models, four jet regime models, and three complete field models are reviewed and critically evaluated. The first section of this paper describes and analyzes each model. The second section contrasts the models on an issue by issue basis. The models are compared with respect to the method of analytical approach, dimensionality, ambient cross flow, wind stress considerations, buoyancy ambient stratification, surface heat loss, shoreline and bottom effects, discharge position and configuration, flow establishment considerations, availability of computer routines, and whether the models have been applied to field or laboratory data or both.

POSTON, H. W., Great Lakes water supply - the years ahead, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 291-300, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The use of the Great Lakes for future water supply purposes is discussed. As the water demand over the country becomes more acute, more and more attention will be directed toward the Great Lakes. It is roughly estimated that domestic water demand will double and industrial water demand will triple by 1980.

Water quality and pollution enter into this discussion. Efficient treatment and disposal techniques along with good sound planning is needed. Essentially in order to utilize the Great Lakes for future needs, the groundwork must be laid today.

POTOS, C., Hypolimnetic oxygen depletion mechanisms in Lake Erie, Proc. 13th Conf. Great Lakes Res., p. 707-714, Internat. Assoc. Great Lakes Res., 1970.

The correlation of the measured positive depletion of oxygen in the summer of 1968 in the Lake Erie Central Basin with existing sediment and hypolimniom oxygen demand is presented.

POWERS, W. E., Drainage and climate, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 29-40, Am. Assoc. Advancement Science, Washington, D.C., 1962.

Outstanding characteristics of the Great Lakes basin are the relatively large surface water area, obscure boundaries, absence of major tributaries, and nearness of the basin divide to the lakes at several points. The lake plains and drainage pattern within the basin are also discussed.

Climate is severe and continental with a great deal of precipitation with the maximum occurring during the warmer months. Usually lake levels are at a maximum in the late spring or early summer due to melting snow and precipitation. Ice formations are also mentioned.

Current geological processes affecting the Great Lakes drainage basin include gentle regional warping, erosion of shorelines and channels, and dune building. Climatic fluctuations are also important features that cannot be de-emphasized.

QUINLAN, D. W., Conflicts arising from the use of shore property of the Great Lakes, Proc. Great Lakes Water Resources Conf., Toronto, Canada, p. 145-154, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

The continuing conflict between urban and industrial expansion and open land use, between agricultural and industrial use, and between commercial-industrial development and the pressing requirement for more and more recreational facilities in the Great Lakes region are described. It is concluded that since there will continue to be conflicts in the future, with increased development and changes in land use, it is essential that adequate land use planning be carried out to insure maximum benefits to all users of the resources of the Great Lakes.

SMITH, H. A., Hydro-electro power development on the Great Lake system, Proc. Great Lakes Water Resources Conf., Toronto, p. 49-88, Engineering Institute of Canada and American Society of Civil Engineers, June 24-26, 1968.

A history of hydro-electric power development on the Great Lakes is presented. The types of benefits to other interests are discussed. The desirability and possibilities of additional hydro-electric power development on the Great Lakes is reviewed.

TOWER, K. G., Hydroelectric power in the Great Lakes-St. Lawrence Basin, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 195-212, Am. Assoc. Advancement Science, Washington, D.C., 1962.

The developed and undeveloped hydroelectric power in the Great Lakes-St. Lawrence basin is discussed. The hydroelectric power potential of streams tributary to the Great Lakes is tabulated. Already 790,000 kilowatts of capacity are developed and it is estimated that 880,000 kilowatts of capacity are still undeveloped. Values for developed and undeveloped hydroelectric power are also given for the interconnecting lake channels, St. Lawrence River, and its tributaries. The United States hydroelectric potential, both developed and undeveloped, is tabulated for each state with a total U.S. hydroelectric potential being 5,814,000 kilowatts of which 2,210,000 are presently developed.

U.S. Department of the Army, Corps of Engineers, Lake Survey District, Great Lakes ice cover winter _____, Basic data reports, Detroit, Michigan, Annual since 1965.

The data related to the formation, thickness, distribution, movement, and decay of the ice in the Great Lakes is presented annually as a U.S. Lake Survey research report. Ice charts are included.

U.S. Department of the Army, Corps of Engineers, Lake Survey District, U.S. Lake Survey gage replacement and improvement program, Detroit, Michigan, April, 1966.

This brochure describes the existing water level gages on the Great Lakes for the United States portion. It also gives the locations of the gages, and also proposes a replacement and improvement program for upgrading the lake level recorders on the Great Lakes.

U.S. Department of the Army, Corps of Engineers, Lake Survey District, The use of geopotential heights for Great Lakes vertical datum, Misc. Paper 68-6, Detroit, Michigan, 1968.

U.S. Congress, Senate, St. Lawrence Seaway Manual, by A. Waley, Sen. Doc. No. 165, 83rd Congress, 2nd Session, U.S. Gov't. Print. Office, Washington, D.C., 1955.

A compilation of documents on the Great Lakes Seaway Project and correlated power development is presented. This report was designed to answer the many questions in connection with the seaway's past, present, and future.

U.S. Great Lakes Basin Commission, Interim bibliography Part I: Issuing agencies and authors; Part II: Title arrangement, Ann Arbor, 1969.

These publications represent a listing of the holdings of the Great Lakes Basin Library.

U.S. Great Lakes Basin Commission, Great Lakes Basin library book catalog, Ann Arbor, Michigan, 1969.

This is a listing of the trade books presently (1969) in the Great Lakes Basin Library. The arrangement is both by author and by title.

U.S. Great Lakes Basin Commission and Great Lakes Panel on the Committee on Multiple Use of the Coastal Zone, National Council on the Rain Resources and Engineering Development, Great Lakes institutions; A survey of institutions concerned with the water and related resources in the Great Lakes Basin, U.S. Gov't. Print. Office Washington, D.C., June, 1969.

The first section contains resumes of institutions that have programs or responsibility of some aspect of the Great Lakes. The addresses of these institutions and others are listed in Appendix A. The addresses of institutions having planning or coordinating responsibilities are listed in Appendix B. A partial listing of useful publications concerning the Great Lakes is given in Appendix C.

VERDUIN, J., Energy flow through biotic systems of western Lake Erie, in Great Lakes Basin, Pub. No. 71, edited by H. J. Pincus, p. 107-122, Am. Assoc. Advancement Science, Washington, D.C., 1962.

Some of the aspects and consequences of an intensive twelve year study of energy flow through the natural occurring communities of western Lake Erie are discussed. Such subjects as seiche-generated turbulence, phytoplankton, light supply, photosynthesis, and the transfer coefficient across the air-water boundary, all in relation to the shallow waters of western Lake Erie, are presented.

ZUMBERGE, J. H., Bibliography of published geologic papers and unpublished theses of the Great Lakes and their drainage basins, 1950 through 1958, Pub. No. 4, p. 51-59, Great Lakes Res. Div., Univ. Michigan, Ann Arbor, 1960.