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GREAT LAKES HYDROLOGY BY MONTHS, 1946-1965

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ABSTRACT

GREAT LAKES HYDROLOGY BY MONTHS, 1946-1965

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. Overlake precipitation is estimated by extrapolation of the land isohyetal patterns multiplied by lake-land ratios as established from island-shore stations. Evaporation by months is calculated using the mass transfer method. An isopleth mapping technique is used to estimate the runoff. The net basin supply for a lake is equal to the total runoff plus the precipitation on the lake surface minus the evaporation from the lake surface. The monthly and annual net basin supplies for each lake are determined from the estimated values of runoff, precipitation, and evaporation and are compared with the monthly and annual net basin supplies as reported by the U.S. Army Corps of Engineers. The estimated 20 year mean annual net basin supply for all lakes is about 6 per cent less than the value reported by the U.S. Army Corps of Engineers.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Great Lakes are the earth's greatest expanse of fresh water. The five Great Lakes in order of descending elevation are Superior, Michigan, Huron, Erie, and Ontario. The drainage area of this system is approximately 295,000 square miles (764,000 km^2). The dimensions of the Great Lakes are given in Table 1 and a map of the Great Lakes drainage basin is shown in Fig. 1.

From the conservation of matter principle, a water balance equation can be written for each lake as follows

$$\Delta S = P + R - E + I - O \pm D \pm G \tag{1}$$

where ΔS is the change in amount of water stored in the lake, plus if supplies exceed removals, minus if removals exceed supplies; P is the amount of precipitation on lake's surface; R is the amount of runoff into the lake from the surrounding land area; E is the amount of evaporation from the lake's surface; I is the amount of inflow from the upstream lake; O is the amount of outflow from the lake through its natural outlet; D is the amount of diversion, plus if into lake, minus if out of lake; and G is the amount of groundwater flow entering or leaving the lake. All variables are expressed in the same units and for the same period of time. Obviously, any variable may be equal to zero for a lake where it is not pertinent.

The Tides and Water Levels Section, Marine Sciences Branch, Department of Energy, Mines and Resources, Canada and the Lake Survey Center, National Ocean Survey, United States Department of Commerce

TABLE 1. Dimensions of the Great Lakes.

Lake	Length[a] (mi)[c]	Breadth[a] (mi)[c]	Area[a] Water Sur. (mi^2)[d]	Area[a] Drainage (cfs)[e]	Average Discharge[b] 1946-1965 (cfs)[e]	Max. Depth[a] (ft)[f]	Mean Depth[a] (ft)[f]
Superior	350	160	31,820	80,000	78,000	1,333	487
Michigan	307	118	22,400	67,860		923	276
Huron	206	183	23,010	72,620	St. Clair 182,000	750	195
St. Clair	26	24	490	7,430	Detroit 186,000	21	10
Erie	241	57	9,930	32,490	Niagara 198,000	210	58
Ontario	193	53	7,520	34,800	St.Lawrence 239,000	802	283

[a]Source: U.S. Army Engineer Division, North Central (1965a)

[b]Source: From data supplied by U.S. Department of Commerce, Lake Survey Center, (Personal Communication, 1972)

[c]1 mile (mi) = 1.61 Kilometers (km)

[d]1 square mile (mi^2) = 2.59 square kilometers (km^2)

[e]1 cubic foot per second (cfs) = 0.028 cubic meters per second (m^3/sec)

[f]1 foot (ft) = 0.305 meters (m)

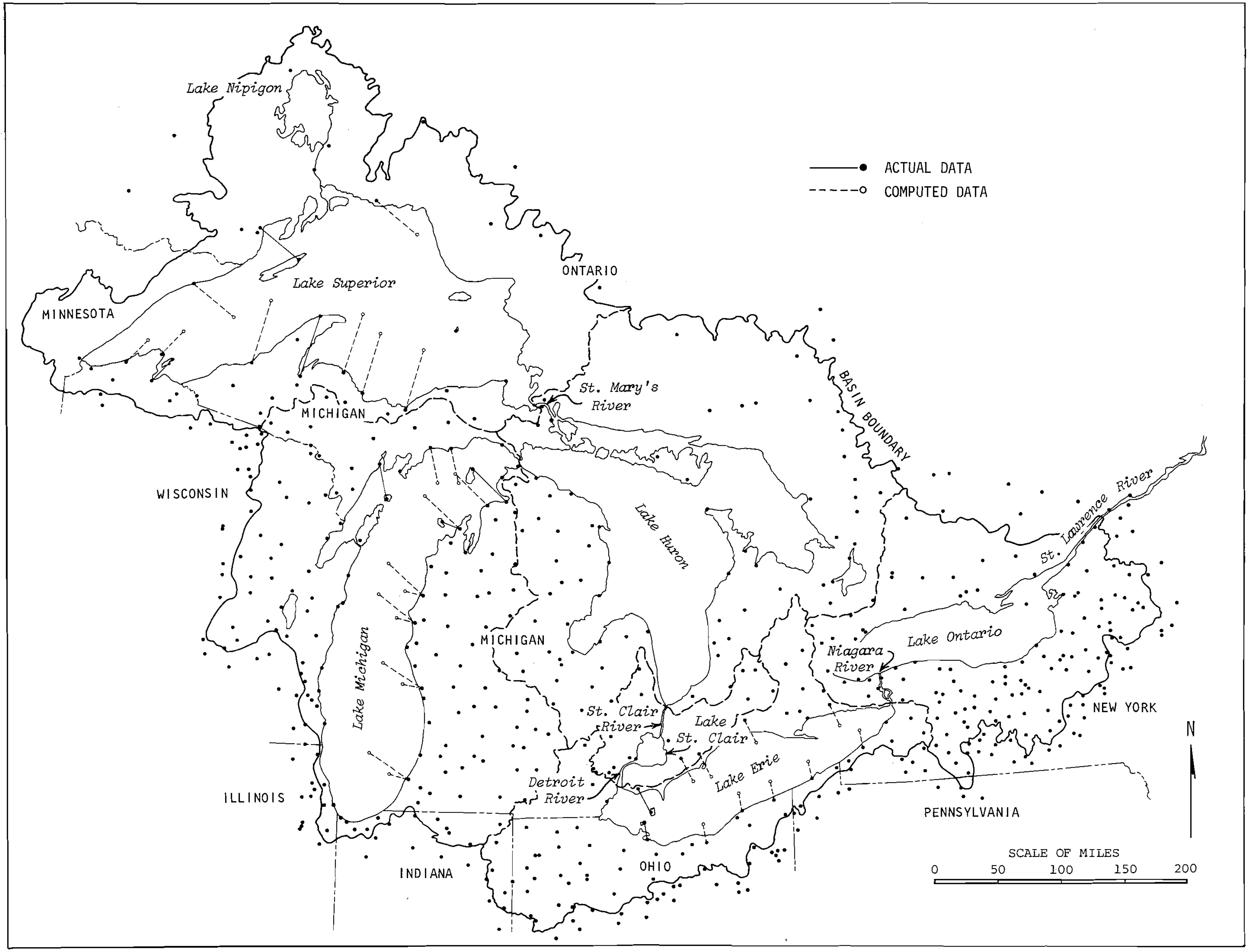

Figure 1. Great Lakes drainage basin showing drainage area for each lake, the location of precipitation stations, and the location of island-shore stations.

maintain water level gages on the Great Lakes, rivers which connect the lakes, and channels in which water is diverted into or out of the lakes. The change in amount of water stored in a lake is calculated from the area of the lake and the measured change in the elevation of the water surface over a period of time. The amount of inflow from the upstream lake, outflow from the lake through its natural outlet, and diversions into and out of the lake are determined from the water level records and rating curves which give the relationship between the amount of flow past a point and the surface elevation of the water at that point.

The present study was undertaken to determine the magnitude of the precipitation on the lake, evaporation from the lake surface, and runoff into the lake from surrounding land areas for each of the Great Lakes for each month of calendar years 1946 through 1965.

PRECIPITATION ON THE LAKES

It has usually been assumed that the lake surfaces have received the same depth of precipitation as measured at sites along the lakes shores (Brunk, 1962; Weiss and Kresge, 1962). After a study of available records of precipitation and precipitation types over the lake and the adjacent land areas, Changnon (1968) reported that the annual average precipitation over Lake Michigan is 29.6 in. (75.2 cm) which is 6 percent less than the precipitation over the land portion of the basin. He concluded that the lake suppresses summertime thundershowers by 20 percent, but enhances winter snowfall along the eastern shore by 25 to 100 percent. Although some of the snow falls on the lake surface, most of the increase is on the downwind shores with the net result that there is a greater decrease in precipitation on the lake in the warm months than there is an increase in the winter months. These Lake Michigan precipitation amounts are presented as seasonal and annual averages. Changnon's work is extended here to all of the Great Lakes for individual months for calendar years 1946 through 1965.

The monthly precipitation data for 840 United States reporting stations in and around the Great Lakes basin were obtained on punched cards or magnetic tape from the National Climatic Center, National Oceanic and Atmospheric Administration. The data for 130 Canadian stations were obtained on magnetic tape from the Meteorological Service of Canada. Some of the data was not used. When two or more stations were located close together, usually within the same city, only the data for the station with the longer record was used. The locations of the stations for which data were used in the study are shown in Fig. 1.

The monthly precipitation data was plotted onto a common base map. Isohyets were interpolated from the station values at spacings determined by the range of values for each monthly chart. Usually, isohyets were drawn at one-inch (2.54 cm) intervals with the 0.5-inch (1.27 cm) and zero isohyets drawn where applicable. Far more data points (stations) were used in this study than have been used in any previous study. This is reflected in the detail of the isohyets. The pattern of the isohyets over the land determined the pattern of isohyets over the lakes near the shores, but the pattern of isohyets over the lakes was determined by two methods. Deep, large lakes gain and lose heat very slowly, the rate of heat exchange with the atmosphere being a function of the configuration of the lake with the prevailing winds, the intensity of the winds, the contrast in temperature between the lake and the overlying air mass, the amount of cloudiness, and the contrast in vapor pressure between the lake surface and the overlying air. These factors cause the individual lakes in the Great Lakes system to adjust to the climate of the surrounding land at varying rates in both time and space. Since the contrasts in temperature, atmospheric stability, and moisture between the lakes and the surrounding land determine the difference in precipitation between the lakes and the land, these factors have been taken into account qualitatively in the drawing of the isohyets over the lake surfaces. Quantitatively, ratios between observed monthly mean values of precipitation at island and peninsular stations were established with coastal stations and these ratios were then applied to values at other coastal stations along the same side of the lake in order to obtain values representative of the rainfall to be expected further out over the lake surface. This extrapolation procedure was only appropriate for Lakes Superior, Michigan, and Erie because these lakes have islands or peninsulas with precipitation stations on them which can be paired with coastal stations in order to determine the ratios. The ratios for the station pairs on each lake for the individual months are shown in Table 2. The geographic locations of the station pairs are shown in Fig. 1. Extrapolation of the ratios was applied only to coastal stations which could be expected to be influenced by the same atmospheric flow conditions which affected the stations which were used to establish the ratio. Thus, the ratio extrapolations were restricted in use to the lake for which they were calculated and to the same coast from which the ratios were obtained. Fig. 1 has upon it the pairs of coastal stations and points to which extrapolations of the precipitation values were made.

The isohyets as drawn for July, 1964, are shown in Fig. 2. The areas between the isohyets were planimetered and the average precipitation was determined for each lake for each of the 240 months. The results are given in Tables 3 through 8 with the 20-year average for each month, the annual totals, and the annual average precipitation over the 20-year period. During that period Lake Superior had the least annual average precipitation with 28.35 inches (72.01 cm) and Lake Erie averaged the most with 32.79 inches (83.29 cm). The seasonal average precipitation on each lake is given in Table 9. Here it will be noted that the largest seasonal amount again occurs on Lake Erie in the spring, but that Lake Superior has almost as large an amount in the summer. This is an illustration of the lag in the seasons between the more northerly, deep lake and the more southerly, shallow lake. The lowest average seasonal amount falls on Lakes Michigan in the winter. The low winter precipitation on Lake Michigan is probably due to the north-south orientation of the major axis of this narrow lake and the fact that the prevailing winds in the winter are from the west. There is no lake of major size upwind from Lake Michigan when the winds are out of the west and, thus, there is no adequate moisture supply for generation of overlake precipitation in the winter.

TABLE 2. Monthly lake/land precipitation ratios

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
LAKE ERIE											
Pelee Island, Ontario/Harrow, Ontario											
1.120	0.840	0.958	1.129	1.168	1.101	1.184	0.978	0.985	0.948	0.896	0.865
Gibralter Island, Ohio/Sandusky, Ohio											
0.851	0.833	0.838	0.882	0.910	0.818	0.816	0.947	0.782	1.088	0.846	0.762
LAKE MICHIGAN											
North Manitou Island, Mich./Sutton, Mich.											
0.690	0.568	0.951	0.822	1.149	0.939	0.978	1.319	1.178	0.952	0.832	0.677
Beaver Island, Mich./Petosky, Mich.											
0.638	0.736	0.815	1.014	1.183	0.983	0.952	0.979	0.911	1.042	0.954	0.809
Washington Island, Mich./Escanaba, Mich.											
0.950	0.785	1.480	1.030	1.015	0.953	1.075	1.053	1.048	1.201	1.033	0.928
LAKE SUPERIOR											
Madeline Island, Wisc./Ashland, Wisc.											
1.512	1.283	0.974	0.907	1.009	0.844	0.932	1.007	0.955	0.925	1.042	1.305
Eagle Harbor, Mich./L'Anse, Mich.											
1.669	1.212	1.256	0.714	0.793	0.702	0.559	0.850	0.951	0.880	0.830	1.208
Mott Island, Mich./Port Arthur, Ontario											
				0.815	0.935	1.128	0.912	0.975	1.202		

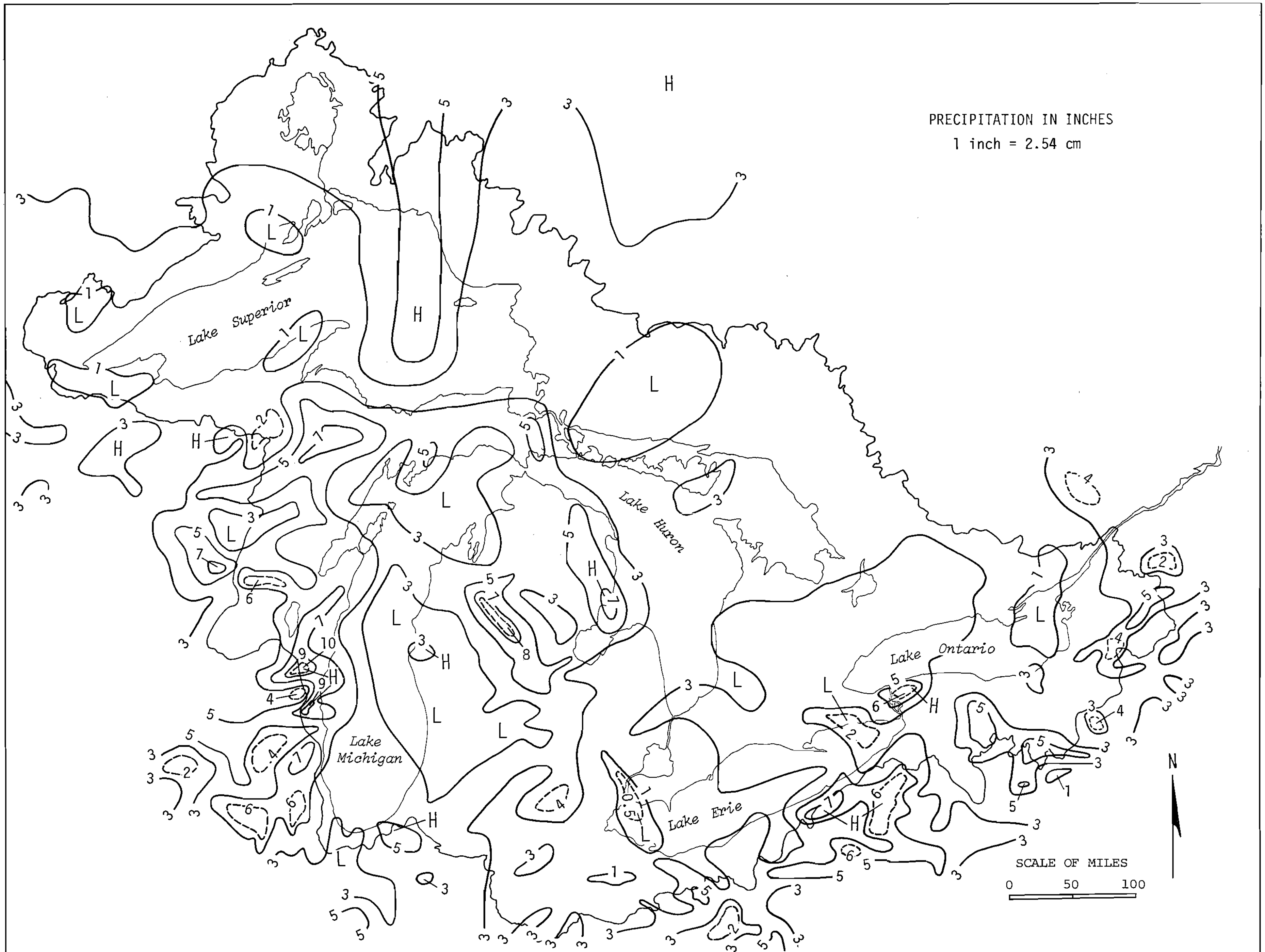

Figure 2. Isohyets for July, 1964.

TABLE 3. Precipitation on Lake Superior (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	2.71	1.64	1.59	1.34	3.01	3.85	1.74	2.88	3.21	3.00	2.56	2.08	29.61
1947	0.86	1.68	0.79	3.12	2.80	4.42	1.67	2.60	3.07	0.74	3.27	1.56	26.58
1948	1.42	1.02	1.78	2.36	0.68	2.14	3.32	2.31	1.09	1.23	3.58	1.88	22.81
1949	2.36	1.20	1.67	0.49	3.12	4.38	5.13	1.62	2.94	3.43	2.79	1.50	30.63
1950	3.32	1.64	2.15	2.88	3.55	3.26	4.14	3.24	2.01	1.52	3.98	2.37	34.06
1951	1.37	2.10	2.55	2.26	2.10	4.69	2.10	4.50	4.72	3.02	1.96	1.88	33.25
1952	2.09	0.64	1.64	1.58	2.22	4.36	4.30	3.33	1.29	1.06	2.09	1.33	25.93
1953	1.64	1.69	1.73	2.06	4.29	3.68	3.96	3.09	2.91	1.05	2.31	2.23	30.64
1954	2.18	1.33	1.79	3.43	3.78	2.42	1.08	1.97	3.32	2.22	0.71	0.86	25.09
1955	1.71	1.44	2.84	1.88	3.16	2.24	3.86	3.22	3.49	3.92	2.70	2.21	32.67
1956	1.16	0.65	0.64	1.56	3.04	2.50	3.16	2.52	2.41	0.81	2.60	1.99	23.04
1957	1.31	1.38	1.38	1.90	2.32	3.40	2.12	1.67	3.67	1.35	4.00	1.56	26.06
1958	1.49	0.93	0.81	1.41	1.89	3.47	3.84	4.20	2.66	1.88	2.93	2.40	27.91
1959	1.50	0.73	1.63	1.22	4.38	2.43	2.44	6.06	4.57	4.15	2.10	1.53	32.74
1960	1.58	0.96	1.13	3.72	3.80	2.07	2.73	2.12	2.72	2.41	3.00	1.61	27.85
1961	0.84	1.32	1.59	1.74	2.40	1.81	1.82	1.32	4.68	2.01	2.11	1.45	23.09
1962	1.51	1.94	0.94	1.67	3.57	1.85	2.18	3.37	3.59	1.25	1.05	1.90	24.82
1963	1.23	1.05	1.70	2.77	1.93	3.49	2.31	2.92	1.87	0.89	1.96	1.83	23.95
1964	1.46	0.86	1.58	3.39	4.93	3.22	2.66	4.81	3.72	1.92	2.24	2.59	33.38
1965	1.52	1.81	1.53	1.68	4.60	2.19	3.10	3.57	5.20	2.18	3.57	1.98	32.93
MEAN	1.66	1.30	1.57	2.12	3.08	3.09	2.88	3.07	3.16	2.00	2.58	1.84	28.35

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 4. Precipitation on Lake Michigan (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	2.01	1.10	1.88	0.78	3.28	2.60	1.38	2.04	2.46	1.84	2.47	2.08	23.92
1947	1.54	0.98	1.46	4.54	5.16	2.93	2.47	1.93	4.29	1.05	2.47	1.25	30.07
1948	1.28	1.50	3.40	2.41	3.32	2.71	1.97	1.68	2.11	1.17	3.48	1.70	26.73
1949	2.04	1.62	1.89	1.64	2.09	2.88	3.61	1.65	2.02	1.77	2.13	2.28	25.62
1950	2.68	1.59	2.47	4.55	1.49	3.00	3.88	2.14	2.61	1.50	2.38	2.26	30.55
1951	1.56	1.53	2.71	3.44	2.29	2.58	4.33	3.36	3.78	4.29	3.10	2.29	35.26
1952	2.02	0.49	2.54	2.26	3.34	2.77	6.13	3.04	1.49	0.77	3.09	1.75	29.69
1953	1.76	2.38	1.66	3.09	2.65	3.52	3.03	2.43	2.22	1.23	1.41	2.05	27.43
1954	1.39	1.66	1.96	4.80	2.84	5.41	3.58	2.76	3.98	4.90	1.55	1.65	36.48
1955	2.34	1.20	1.63	2.67	2.82	2.86	1.82	2.41	1.41	4.05	2.20	1.21	26.62
1956	0.48	0.97	1.73	3.02	3.87	1.95	3.55	3.16	1.09	0.54	1.98	1.34	23.68
1957	1.05	0.74	1.48	3.11	4.56	3.19	2.26	3.03	1.79	2.16	3.60	1.92	28.89
1958	1.13	0.87	0.47	2.06	1.85	2.75	2.55	3.33	3.24	2.13	2.70	1.08	24.16
1959	1.87	1.80	2.61	3.35	3.25	0.97	3.03	5.28	3.69	5.25	2.30	2.28	35.68
1960	2.18	1.96	1.44	3.34	5.45	3.70	3.35	3.88	2.97	2.18	2.32	0.75	33.52
1961	0.55	1.01	2.52	2.41	1.51	2.69	2.66	2.01	7.06	2.71	2.42	1.59	29.14
1962	2.27	1.80	1.35	1.87	2.33	2.20	2.61	2.86	2.60	2.64	1.08	1.74	25.35
1963	1.26	0.87	2.42	1.96	3.06	1.70	2.91	2.70	2.58	1.09	2.57	1.94	25.06
1964	1.47	0.55	2.30	3.61	3.18	1.46	3.52	3.43	4.19	1.01	2.65	1.59	28.96
1965	2.32	1.45	2.26	3.25	2.97	2.41	2.19	4.87	7.50	2.47	2.76	2.62	37.07
MEAN	1.66	1.30	2.01	2.91	3.07	2.71	3.04	2.90	3.15	2.24	2.43	1.77	29.19

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 5. Precipitation on Lake Huron (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	3.35	2.43	1.29	0.81	3.42	2.58	1.33	2.00	2.57	1.38	2.50	3.61	27.27
1947	2.86	1.68	1.91	3.54	4.83	2.23	3.61	1.30	3.91	1.13	3.30	1.80	32.10
1948	2.14	2.04	3.82	2.50	2.08	2.25	1.82	1.08	0.98	1.93	3.91	2.16	26.71
1949	3.25	2.93	1.82	1.47	1.72	3.23	1.89	1.65	2.83	2.04	2.65	4.00	29.48
1950	4.27	3.47	2.91	2.41	0.99	2.56	2.60	3.26	2.48	1.95	3.36	2.40	32.66
1951	2.90	2.52	2.97	4.04	1.19	2.32	4.07	2.58	3.23	4.77	3.87	3.91	38.37
1952	2.94	1.56	2.34	3.18	2.33	2.09	4.29	3.80	2.34	0.74	3.62	2.36	31.59
1953	2.65	2.99	3.25	2.53	3.86	2.13	3.01	2.39	3.70	1.50	2.43	2.99	33.43
1954	2.09	2.51	2.86	4.10	2.06	4.67	1.61	2.31	4.66	5.87	2.53	2.52	37.79
1955	3.26	2.20	2.23	2.56	2.39	1.30	2.50	2.92	0.97	3.79	2.92	2.72	29.76
1956	1.36	2.15	1.87	2.25	3.25	2.92	3.09	3.74	2.69	1.14	2.67	2.79	29.92
1957	2.80	1.51	1.49	2.97	2.64	4.34	2.74	1.28	4.22	3.96	3.04	3.22	34.21
1958	1.93	1.53	0.60	1.40	0.92	2.61	2.59	1.85	3.30	2.18	3.47	3.01	25.39
1959	2.40	2.58	1.58	3.46	3.32	1.56	2.55	4.79	3.76	4.36	4.19	2.69	37.24
1960	2.39	1.84	1.79	2.70	4.09	3.37	2.65	1.58	2.24	2.33	2.93	2.43	30.34
1961	0.92	1.51	2.12	1.55	1.53	3.24	2.36	2.55	4.71	1.73	2.56	2.31	27.09
1962	3.36	2.54	0.59	1.90	2.72	2.49	1.76	2.31	3.74	3.08	1.37	3.18	29.04
1963	2.35	1.26	2.34	2.26	3.47	2.16	2.96	3.37	2.64	1.34	2.36	2.73	29.24
1964	2.07	0.89	1.64	2.56	2.25	1.27	2.59	4.64	3.60	1.70	3.21	3.01	29.43
1965	3.46	3.38	1.54	2.57	2.22	1.78	1.94	3.52	5.63	2.41	3.67	3.06	35.18
MEAN	2.64	2.18	2.05	2.54	2.56	2.55	2.60	2.65	3.21	2.47	3.03	2.84	31.31

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 6. Precipitation on Lake St. Clair (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	1.35	2.20	2.10	0.45	4.10	5.70	0.90	3.85	1.15	2.50	1.20	3.10	28.60
1947	3.30	0.35	2.75	5.20	5.10	2.65	3.00	5.00	3.20	0.90	1.60	2.00	35.05
1948	1.20	3.50	4.00	1.50	5.00	2.70	1.20	1.40	0.95	1.30	3.10	1.50	27.35
1949	2.16	2.00	1.90	1.90	2.50	2.70	3.50	2.40	2.50	4.00	1.00	3.40	29.96
1950	4.00	4.40	2.40	4.20	2.20	2.00	2.50	2.00	2.40	2.90	4.30	2.70	36.00
1951	2.30	2.90	3.00	2.40	2.87	3.20	3.20	2.40	2.12	4.00	3.20	4.00	35.59
1952	3.00	1.40	3.00	3.50	2.20	1.10	2.50	2.00	1.60	1.40	2.50	2.00	26.20
1953	2.10	0.65	2.75	3.10	2.50	3.50	2.40	1.70	1.80	0.70	1.00	2.00	24.20
1954	1.85	4.00	4.40	2.80	1.20	2.00	1.60	3.00	2.50	7.50	1.70	1.70	34.25
1955	1.60	2.50	2.50	2.40	1.30	2.00	2.00	3.30	2.10	3.60	2.80	1.40	27.50
1956	1.20	2.20	4.00	4.20	5.10	3.00	1.50	4.50	0.60	0.70	2.20	1.90	31.10
1957	2.00	2.00	1.40	4.90	2.95	3.20	5.00	2.50	4.50	3.40	2.20	3.70	37.75
1958	0.90	0.73	0.55	1.70	1.30	4.00	2.40	2.30	3.30	1.60	2.80	0.70	22.28
1959	3.00	1.90	2.40	4.00	3.70	0.70	1.40	5.50	3.10	3.90	3.00	3.30	35.90
1960	2.60	2.40	1.30	2.10	2.60	5.30	1.70	2.10	1.20	2.10	0.90	0.75	25.05
1961	0.40	2.50	2.50	4.75	2.30	3.00	2.60	4.40	4.30	1.30	3.10	1.40	32.55
1962	2.20	2.10	0.95	1.30	1.10	5.50	2.40	3.20	2.60	1.50	2.00	1.40	26.25
1963	0.80	0.70	2.60	2.90	2.30	3.00	2.00	2.30	1.70	0.50	1.30	1.20	21.30
1964	2.30	0.80	2.80	4.00	2.00	2.50	1.50	4.50	1.90	0.60	0.90	2.30	26.10
1965	3.20	2.70	2.90	2.50	1.70	2.50	2.40	3.50	3.30	2.60	1.60	4.00	32.90
MEAN	2.07	2.10	2.51	2.99	2.70	3.01	2.28	3.09	2.34	2.35	2.12	2.22	29.79

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 7. Precipitation on Lake Erie (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	1.14	1.08	2.51	0.90	5.23	4.34	2.49	1.99	1.47	3.31	2.29	2.52	29.27
1947	3.93	0.81	2.53	5.37	5.34	3.65	3.56	3.04	2.99	1.25	2.29	2.08	36.84
1948	1.71	2.05	3.71	3.16	4.27	4.45	2.79	2.19	1.51	3.00	3.52	1.71	34.07
1949	3.13	2.33	2.44	2.26	3.04	1.63	3.05	2.49	3.36	1.88	2.45	2.79	30.85
1950	5.46	3.54	3.24	3.87	1.61	2.73	4.22	2.96	2.88	2.52	4.91	2.08	40.02
1951	2.66	2.76	4.12	3.06	2.49	3.52	2.35	1.60	2.53	2.32	3.74	3.26	34.41
1952	3.70	1.71	2.51	2.78	3.52	1.54	2.11	3.70	2.95	1.08	2.39	2.49	30.48
1953	2.82	0.95	2.78	2.58	4.29	2.36	2.19	2.52	2.33	0.82	2.10	2.39	28.13
1954	3.24	2.96	4.41	5.06	1.22	2.11	1.99	2.62	1.72	8.69	2.02	2.00	38.04
1955	2.13	2.21	3.21	3.10	1.95	1.70	1.84	4.26	2.07	5.42	2.92	1.37	32.18
1956	1.90	2.66	3.40	3.77	5.01	3.00	3.23	6.09	2.01	1.04	2.18	2.18	36.47
1957	2.75	2.00	1.45	5.02	3.22	4.78	3.85	2.02	4.06	2.75	2.41	2.79	37.10
1958	1.81	1.07	0.76	2.86	2.05	4.19	3.94	3.93	3.44	2.01	3.38	1.07	30.51
1959	4.29	2.70	2.61	4.04	3.47	1.64	2.65	2.00	2.67	5.29	2.93	2.73	37.02
1960	2.78	2.05	1.39	2.77	3.62	2.97	2.38	2.63	1.39	1.93	1.84	1.04	26.79
1961	0.55	2.96	2.53	6.32	1.98	3.50	3.53	4.20	2.76	1.61	2.41	1.71	34.06
1962	2.93	1.97	1.50	1.53	1.57	3.27	3.01	3.19	3.37	3.03	2.52	2.53	30.42
1963	1.22	0.96	2.77	3.00	2.32	2.00	3.12	2.29	1.44	0.80	2.89	1.75	24.56
1964	2.08	0.90	3.89	4.60	2.37	1.92	2.62	5.67	1.32	1.45	1.26	2.42	30.50
1965	4.31	2.81	2.78	2.04	2.27	2.44	2.86	3.47	2.68	3.40	2.62	2.40	34.08
MEAN	2.73	2.02	2.73	3.40	3.04	2.89	2.89	3.14	2.45	2.68	2.65	2.17	32.79

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 8. Precipitation on Lake Ontario (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	1.71	2.26	1.03	1.18	3.33	2.44	1.91	2.03	2.36	3.81	2.70	3.37	28.13
1947	4.90	1.38	3.90	2.81	4.24	4.73	5.57	1.21	3.10	0.94	2.55	2.39	37.72
1948	1.90	2.78	3.66	2.58	3.37	2.58	2.23	1.39	1.18	2.99	3.47	2.04	30.17
1949	2.73	2.57	1.75	2.60	1.29	0.60	1.68	1.81	3.22	1.44	3.25	3.17	26.11
1950	4.10	3.29	2.77	2.02	1.82	2.29	2.47	3.51	1.59	3.41	3.80	2.22	33.29
1951	2.59	2.64	3.69	4.01	1.66	3.80	4.44	2.56	2.31	1.63	3.40	3.98	36.71
1952	2.58	2.28	2.52	2.36	4.05	0.87	2.44	2.68	2.83	1.95	2.69	2.27	29.52
1953	2.42	1.24	3.31	1.84	4.61	1.16	1.78	2.33	3.03	1.14	1.66	2.37	26.89
1954	2.40	3.01	3.04	4.12	1.05	2.44	0.19	3.35	2.73	3.60	3.44	4.01	33.38
1955	1.55	2.20	3.99	2.52	2.60	6.34	1.33	4.52	2.12	8.57	1.56	1.56	38.86
1956	1.53	2.80	2.74	3.66	4.05	1.14	1.98	3.26	2.52	1.32	2.00	1.91	28.91
1957	2.42	1.79	1.48	2.65	3.05	2.92	1.95	0.92	3.62	1.74	2.04	3.19	27.77
1958	1.76	3.02	0.72	2.42	1.32	2.60	2.59	3.53	3.67	2.32	2.16	1.63	27.74
1959	3.52	2.45	1.94	2.73	1.98	1.37	3.09	1.72	2.03	4.26	2.56	3.99	31.64
1960	2.21	3.26	1.22	2.93	3.56	2.34	1.30	2.07	0.74	2.92	2.06	1.38	25.99
1961	1.09	2.75	2.29	3.70	2.82	3.81	3.05	2.77	1.02	1.45	3.55	1.82	30.12
1962	2.92	3.15	1.07	2.40	2.47	1.90	3.01	3.19	4.86	3.11	1.82	2.83	32.73
1963	1.71	1.51	2.29	2.87	2.92	0.66	1.81	3.60	1.35	0.32	5.36	2.00	26.40
1964	2.29	1.17	3.04	3.11	2.24	1.50	2.47	4.31	0.86	1.45	2.01	2.54	26.99
1965	3.04	3.92	1.91	2.58	0.97	2.03	2.37	4.22	3.60	3.29	3.76	1.53	33.22
MEAN	2.47	2.47	2.42	2.75	2.67	2.38	2.38	2.75	2.44	2.58	2.79	2.51	30.61

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 9. Seasonal average precipitation on lakes for 1946 through 1965 (inches[a]).

	Winter	Spring	Summer	Fall
Lake Superior	4.80	6.77	9.04	7.74
Lake Huron	7.66	7.15	7.80	8.70
Lake Erie	6.92	9.17	8.92	7.78
Lake Ontario	7.45	7.84	7.51	7.83
Lake Michigan	4.73	7.98	8.66	7.82

[a]1 inch (in.) = 2.54 centimeters (cm)

EVAPORATION FROM THE LAKE SURFACES

Several methods have been proposed for calculating the monthly evaporation from the Great Lakes water surfaces. The energy budget method has been found to be an effective method for determining evaporation (Rodgers and Anderson, 1961). The use of this method requires data such as amounts of solar radiation, albedo, and cloudiness, which are not available for all the lakes for the calendar years 1946 through 1965.

The results of the study of lake evaporation performed on Lake Hefner (Harbeck, et al., 1954) has been adapted for use on larger lakes (Harbeck, 1962). Yu and Brutsaert (1969) used the mass-transfer equation proposed by Harbeck (1962) to calculate the evaporation from Lake Ontario. The equation has the form:

$$E = 0.00338A^{-0.05}u_2\,(e_w - e_a) \qquad (2)$$

in which E is the evaporation in inches per day, A is the area in acres, u_2 is the wind velocity in miles per hour 2 meters above the surface, e_w is the saturation vapor pressure at the temperature of the water surface in mb, and e_a is the vapor pressure of the ambient air. They used an average wind velocity obtained at Toronto which was reduced to the 2 meter level by using the one-seventh power law. They used an average wind at 8 meters height obtained at Toronto. The lake surface temperatures were estimated from a regression equation developed for surface water temperature as a function of the mean monthly air temperature. The air vapor pressures were obtained by multiplying the saturation vapor pressure by the average relative humidity at Toronto or Rochester, whichever was the lower.

The area-dependent coefficient assumes a circular lake such that wind direction is unimportant in determing the length of overwater fetch. Obviously, the Great Lakes with the average winds from a westerly direction and Lakes Superior, Erie, and Ontario with their major axis oriented east-west, and Lakes Michigan and Huron with their major axis oriented north-south, will not be influenced as much by the surface area of the individual lakes as they will by the overwater fetch during a particular evaporation period. It seems quite likely that the 'oasis' effect for which the area coefficient is designed to account becomes negligible with lakes as large as the Great Lakes. The air stream in passing over the exposed water surface should reach a state of equilibrium with the water underneath after some distance of travel even though this equilibrium would not be the total wet-bulb saturation at the surface water temperature (Morton, 1967).

Richards and Irbe (1969) have adapted the Lake Hefner equation to the peculiar conditions of the Great Lakes:

$$E = 0.0024\ (e_s - e_{ad} \cdot H)\ (V \cdot R) \qquad (3)$$

in which e_s is the saturation vapor pressure at surface water temperature in inches of mercury, e_{ad} is the vapor pressure of the air over land, H is a monthly humidity ratio determined from historical records, V is the wind velocity in miles per day at 8 meters, and R is the monthly wind ratio as determined from the work of Lemire (1961) and Richards and Fortin (1962). This equation differes from that of Yu and Brutsaert in that there is no area coefficient, but there are corrections (ratios) applied to the wind speed and air vapor pressure which, on the average, effectively increase the coefficient. The ratios applied by Richards and Irbe tend to adjust the basic Lake Hefner equation in the same direction as the area coefficient applied by Yu and Brutsaert. Over the 16-year period from 1950 through 1965 the two methods resulted in the Yu and Brutsaert equation averaging approximately 5 percent more evaporation annually than the Richards and Irbe equation. Since the Richards and Irbe equation indirectly accounts for the size of the individual lakes through ratios with what seems to us as a more realistic method, the Richards and Irbe equation has been used to calculate the evaporation from Lakes Superior, Michigan, Huron, Erie and Ontario for the periods 1946 through 1958, 1946 through 1965, 1946 through 1958, 1946 through 1949, and 1946 through 1949 respectively.

The surface water temperatures used in computing the evaporation from Lake Michigan were determined from the records of intake temperatures at the Muskegon Heights, Michigan, water plant. This intake is approximately 40 feet (12.2 m) beneath the surface. The most likely surface temperature was determined by a modification of a technique due to Richards and Rodgers (1964). A graph of the march of recorded water temperatures with time was plotted. For the part of the year when the temperatures were above the temperature at which water is at its maximum density an envelope curve of maximum temperature was drawn. Similarly, for the part of the year when the temperatures were below the temperature at which water is at its maximum density an evelope curve of minimum temperatures was drawn. The combined curve is assumed to indicate the trend of the surface water temperature for the year. Muskegon Heights is in the southern basin of Lake Michigan and should not be expected to represent the total surface area of the lake. The Muskegon Heights temperatures were averaged and the difference between the average temperature there and

Millar's (1952) average temperature for the entire lake was noted by months. Millar's average monthly temperatures were then altered by the difference between the average monthly and actual monthly values at Muskegon Heights.

A multiple regression analysis revealed that the surface water temperatures for Lakes Erie and Ontario are a function of the average air temperatures of the present and two preceding months. The surface water temperatures reported by Richards and Irbe were used in the analysis. The same relationship was found to be applicable for Lakes Superior and Huron except for the months of January through May for Superior and January and February for Huron. The surface water temperatures for Lakes Superior and Huron in January and February were found to be a function of the air temperatures for the same months. The lack of year-to-year variation of surface temperatures on Lake Superior from March through May dictated the use of mean monthly surface temperatures for those months. The estimated surface water temperatures are listed in Tables 10 through 14.

The stations whose wind, relative humidity, and temperature records were used to calculate the evaporation from the individual lakes are listed in Table 15. Tables 16 through 20 contain the calculated amounts of evaporation from each of the five lakes for the months of the period 1946 through 1965 for which Richards and Irbe did not report evaporation values.

TABLE 10. Lake Superior surface water temperature[a] (°F[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	35.8	32.8	32.0	33.0	35.0	38.8	43.9	55.3	53.9	47.2	41.8	39.0
1947	35.7	32.7	32.0	33.0	35.0	37.2	44.7	62.7	55.8	49.9	43.8	39.4
1948	34.9	31.9	32.0	33.0	35.0	38.5	44.4	57.2	58.4	49.1	43.9	39.3
1949	35.7	32.7	32.0	33.0	35.0	39.0	43.3	54.9	54.5	48.6	42.8	39.3
1950	35.2	32.2	32.0	33.0	35.0	34.4	43.2	51.4	52.7	45.8	42.7	38.8
1951	35.5	32.5	32.0	33.0	34.0	40.0	46.9	54.1	51.1	45.4	41.6	38.5
1952	35.6	32.6	32.0	33.0	35.0	40.0	44.2	52.8	54.9	46.4	42.1	38.5
1953	35.8	32.8	32.0	33.0	35.0	37.7	43.9	57.5	56.1	49.2	43.4	39.6
1954	35.1	32.1	32.0	33.0	35.0	34.7	41.6	53.9	53.6	47.4	42.7	38.8
1955	35.6	32.6	32.0	33.0	35.0	40.0	45.4	59.1	56.7	50.1	43.0	38.7
1956	35.8	32.8	32.0	33.0	35.0	34.3	41.4	49.6	51.8	47.2	43.0	39.3
1957	34.6	31.6	32.0	33.0	35.0	38.9	45.3	57.7	54.1	47.8	42.6	38.8
1958	36.1	33.1	32.0	33.0	35.0	41.2	44.6	57.0	55.5	47.8	43.6	39.0

[a] Values for January, 1959, through December, 1965, are in Richards and Irbe (1969).

[b] °C = 5/9 (°F -32)

TABLE 11. Lake Michigan surface water temperature (°F[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	32.2	32.4	34.9	43.3	49.9	56.9	64.3	66.2	66.4	62.6	54.6	43.0
1947	32.9	32.6	33.2	34.0	45.7	58.3	64.4	68.6	72.6	63.1	50.5	36.6
1948	32.0	32.8	33.2	39.0	44.5	54.1	68.2	71.6	68.6	60.1	52.8	40.5
1949	33.9	32.8	33.6	38.8	54.0	63.2	74.0	74.5	66.5	60.1	51.5	40.1
1950	34.0	32.8	33.1	36.0	47.1	61.3	69.0	70.0	68.4	61.0	50.8	36.4
1951	33.0	33.0	32.5	35.3	50.2	59.4	64.2	65.2	66.0	58.9	46.5	37.7
1952	32.8	32.8	33.5	38.6	48.1	61.1	69.5	71.4	67.8	60.2	51.0	43.4
1953	33.2	32.0	32.2	39.1	47.5	58.4	69.0	75.4	73.0	61.0	50.7	42.5
1954	33.3	34.0	34.2	40.7	46.5	60.4	70.3	70.3	68.5	62.4	52.8	44.5
1955	34.3	33.0	33.2	40.7	52.0	56.6	70.9	75.0	67.2	60.3	50.8	35.4
1956	33.1	32.3	32.7	39.1	49.7	59.4	66.5	71.9	67.2	58.7	51.1	39.9
1957	33.9	32.6	34.2	40.4	48.9	59.8	68.0	67.4	66.2	60.1	48.9	39.7
1958	34.2	33.2	34.5	42.7	50.2	58.7	66.7	68.4	66.3	60.4	52.2	37.7
1959	33.0	32.1	32.6	38.6	54.9	60.8	69.0	71.2	73.0	60.0	45.7	36.8
1960	33.1	33.0	33.1	36.7	51.0	61.6	63.2	70.0	71.0	62.0	51.0	39.0
1961	33.1	33.1	33.7	38.6	48.4	60.0	66.8	70.4	71.8	62.5	53.0	40.7
1962	33.2	33.0	33.5	37.3	51.5	59.0	65.0	70.4	70.0	62.0	52.0	40.1
1963	33.2	33.0	33.0	37.1	48.9	59.4	68.3	75.8	68.5	64.8	56.5	43.0
1964	32.5	32.4	33.0	41.0	52.7	62.0	72.2	70.0	64.6	58.0	53.1	41.2
1965	35.4	33.7	33.0	36.9	49.5	59.5	66.5	67.8	64.0	60.9	52.1	42.0

[a] °C = 5/9 (°F −32)

TABLE 12. Lake Huron surface water temperature[a] (°F[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	38.8	34.9	34.4	37.0	39.3	46.5	59.5	65.1	63.4	55.9	47.6	42.4
1947	38.7	35.0	33.4	32.6	34.3	44.6	57.4	71.5	62.9	61.4	47.2	43.1
1948	37.6	34.9	34.0	34.0	41.1	47.8	61.9	67.5	66.6	57.1	45.2	41.7
1949	39.6	36.0	34.4	34.9	41.7	51.1	59.7	61.4	63.6	57.5	47.6	42.2
1950	39.8	35.4	33.5	32.5	33.7	48.4	57.7	64.8	60.9	54.4	46.5	42.4
1951	38.7	35.5	34.6	34.8	38.7	50.2	62.8	63.0	61.2	53.0	44.9	41.8
1952	39.1	35.9	34.5	33.0	38.1	48.8	60.4	65.6	64.6	52.7	44.4	40.6
1953	39.4	36.1	34.8	35.9	37.6	49.5	58.3	60.3	62.1	57.0	48.0	42.1
1954	38.2	36.7	35.9	34.5	36.1	47.8	53.0	60.0	59.9	54.3	46.8	42.1
1955	38.5	35.4	34.1	34.2	39.9	51.9	71.6	69.8	59.5	57.2	45.6	42.8
1956	38.6	35.7	34.2	33.4	35.1	48.0	55.9	63.4	56.1	53.9	48.6	42.3
1957	37.7	35.9	35.4	35.3	37.5	47.8	56.7	60.0	60.2	54.2	43.2	41.6
1958	38.7	34.7	33.6	34.2	38.5	45.7	64.8	69.5	62.4	56.1	46.7	43.2

[a] Values for January, 1959, through December, 1965, are in Richards and Irbe (1969).

[b] °C = 5/9 (°F -32)

TABLE 13. Lake Erie surface water temperature[a] (°F[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	38.1	36.1	34.2	40.9	50.5	62.2	69.3	71.6	67.3	60.5	50.8	41.0
1947	34.6	32.7	32.2	36.5	46.9	60.8	68.1	73.2	68.8	61.0	49.2	38.4
1948	32.6	32.5	33.1	39.3	49.2	62.2	70.0	72.6	68.3	59.7	49.0	40.0
1949	35.0	33.3	33.7	38.0	49.6	64.7	72.7	73.9	64.9	58.9	49.1	39.9

[a] Values for January, 1950, through December, 1965, are in Richards and Irbe (1969).

[b] °C = 5/9 (°F -32)

TABLE 14. Lake Ontario surface water temperature[a] (°F[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	35.4	34.9	38.7	38.8	45.1	52.3	67.1	65.6	63.9	54.3	45.0	40.6
1947	38.6	35.5	34.2	34.6	39.9	52.5	65.3	73.6	68.8	57.1	44.1	38.9
1948	35.0	33.2	34.8	38.5	43.9	53.7	67.2	69.3	66.1	54.8	44.5	40.5
1949	39.0	37.6	37.5	38.1	42.2	58.5	72.5	73.4	65.6	56.4	43.6	39.8

[a] Values for January, 1950, through December, 1965, are in Richards and Irbe (1969).

[b] °C = 5/9 (°F −32)

TABLE 15. Stations from which data were obtained to calculate evaporation.

Lake Superior		
Duluth, Minn.	Whitefish Point, Mich.	Fort William, Ont.
Grand Marais, Minn.	Sault Ste. Marie, Mich.	Port Arthur, Ont.
Marquette, Mich.	White River, Ont.	Caribou Island, Ont.
Houghton, Mich.	Schreiber, Ont.	Munsing, Mich.
Lake Michigan		
Chicago, Ill.	Green Bay, Wisc.	Muskegon, Mich.
Escanaba, Mich.	Milwaukee, Wisc.	South Bend, Ind.
Lake Huron		
Sault Ste. Marie, Mich.	Gore Bay, Ont.	Muskoka, Ont.
Alpena, Mich.	Wiarton, Ont.	Centralia, Ont.
Detroit, Mich.	Sudbury, Ont.	
Lake Erie		
Detroit, Mich.	Sandusky, Ohio	Long Point, Ont.
Toledo, Ohio	Erie, Pa.	
Cleveland, Ohio	Buffalo, N. Y.	
Lake Ontario		
Rochester, N. Y.	Oswego, N. Y.	Toronto, Ont.
Syracuse, N. Y.	Trenton, Ont.	

TABLE 16. Evaporation from Lake Superior[a] (inches[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	3.95	3.31	0.58	0.31	0.52	-1.34	-2.64	0.10	1.70	1.90	4.28	5.16	17.83
1947	4.41	3.63	1.85	0.83	0.76	-1.76	-3.30	-0.14	2.09	0.59	4.07	4.13	17.16
1948	4.07	3.29	1.85	-0.54	0.45	-1.40	-3.56	-0.55	1.20	2.30	2.74	3.90	13.75
1949	4.46	3.07	2.32	0.09	-0.19	-2.48	-4.05	-0.57	2.77	2.63	4.79	4.85	17.69
1950	5.12	2.83	2.72	1.64	0.35	-2.40	-2.79	-0.43	0.92	0.64	5.08	4.71	18.39
1951	3.68	2.24	1.80	-0.16	-0.70	-1.48	-2.52	-0.55	0.97	1.52	5.04	4.37	14.21
1952	4.02	2.41	1.64	-0.63	-0.60	-2.50	-4.38	-2.00	0.37	3.52	3.24	2.56	7.65
1953	3.58	2.36	1.51	0.63	0.24	-2.58	-2.96	-0.38	2.70	1.93	2.92	4.51	14.46
1954	4.49	1.48	2.86	0.60	0.91	-2.82	-2.61	-0.39	1.17	2.38	3.01	3.12	14.20
1955	3.82	3.05	3.23	-0.78	0.15	-2.14	-3.78	-0.48	3.60	3.31	5.15	5.44	20.57
1956	3.17	3.04	2.59	1.48	1.32	-2.64	-2.49	-1.41	1.79	1.68	4.16	4.53	17.22
1957	5.14	2.87	2.02	0.42	1.06	-1.29	-2.38	1.20	2.29	2.78	4.71	4.45	23.27
1958	3.26	3.98	0.89	0.62	0.86	-0.23	-2.62	0.58	1.81	2.53	4.93	5.59	22.20
1959	5.61	3.92	2.11	0.51	-0.81	-2.49	-3.97	-1.98	0.99	3.84	6.99	3.75	18.47
1960	4.46	3.36	3.16	-0.15	0.12	-1.80	-3.32	-1.80	1.08	2.88	4.59	6.05	18.63
1961	4.71	2.32	1.49	0.69	0.65	-1.71	-3.69	-1.55	1.20	2.54	4.05	4.62	15.32
1962	5.78	3.81	1.53	0.59	-0.78	-1.42	-2.55	-1.39	1.67	1.64	3.77	5.65	18.30
1963	5.92	4.58	2.57	0.03	0.50	-2.61	-3.75	-0.53	0.63	0.03	4.77	5.80	17.94
1964	4.03	3.19	2.98	-0.03	-0.56	-1.29	-2.88	0.78	0.54	1.74	3.96	5.08	17.54
1965	5.43	4.47	2.64	0.21	-0.50	-1.44	-2.48	-1.80	0.87	2.48	5.19	3.94	19.01
MEAN	4.46	3.16	2.12	0.32	0.19	-1.89	-3.14	-0.66	1.52	2.14	4.37	4.61	17.19

[a] Values for January, 1959, through December, 1965, are from Richards and Irbe (1969).

[b] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 17. Evaporation for Lake Michigan (inches[a])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	2.59	2.75	0.57	2.23	2.14	0.12	0.06	3.66	5.68	4.93	6.64	5.91	37.28
1947	2.65	3.80	2.05	-0.65	0.95	1.05	0.30	1.57	8.99	2.87	5.77	2.87	32.22
1948	4.37	2.94	2.02	-0.44	0.82	-0.29	1.02	4.88	5.01	5.15	4.29	4.87	34.64
1949	3.51	2.67	2.09	1.09	1.77	-0.17	0.61	4.63	7.14	3.09	5.41	4.95	36.79
1950	4.04	3.16	3.30	1.53	0.34	0.43	0.84	4.79	5.35	2.92	7.46	3.95	38.11
1951	3.38	2.62	2.31	-0.55	-0.20	-0.08	-1.26	1.24	5.80	2.89	5.40	4.40	25.95
1952	2.55	1.81	1.86	0.32	0.09	-1.05	-0.81	3.63	5.39	8.56	4.85	3.92	31.12
1953	1.91	1.96	0.68	1.76	-0.60	-1.51	0.26	5.66	10.01	3.70	4.08	5.49	33.40
1954	3.54	1.27	3.06	0.80	1.00	-1.44	0.82	3.41	5.35	4.48	4.49	5.63	32.41
1955	3.99	3.04	2.70	-0.51	1.17	-1.15	-1.15	5.59	6.95	3.99	7.05	3.96	35.63
1956	2.79	2.20	2.35	2.48	1.18	-1.09	-0.20	4.08	7.12	2.31	5.41	3.67	32.30
1957	4.91	1.75	2.08	0.33	0.82	-0.75	-0.49	2.42	5.15	4.63	5.00	3.98	29.83
1958	2.93	3.92	1.40	2.85	3.16	1.17	-0.42	3.30	4.55	3.79	6.71	5.40	38.76
1959	4.16	3.02	1.99	1.14	-0.89	-0.32	0.36	3.79	8.71	4.43	4.86	1.59	32.84
1960	2.23	2.88	3.11	-1.06	0.55	0.90	-1.07	2.68	4.62	4.12	4.65	5.73	29.34
1961	3.70	1.58	1.02	1.48	1.92	0.65	-0.51	2.96	6.72	4.75	5.45	5.11	34.83
1962	4.38	3.07	1.53	0.91	-0.50	-0.41	-0.44	3.37	7.27	3.32	4.12	5.33	31.95
1963	3.23	3.92	1.71	0.70	0.64	-0.80	0.27	4.53	5.61	3.27	6.10	6.29	35.47
1964	2.39	2.51	2.20	1.40	0.50	0.35	0.85	4.71	3.43	4.19	4.42	5.34	32.29
1965	4.76	0.17	2.43	0.38	-0.58	0.44	0.29	2.43	2.47	4.77	5.28	3.44	26.28
MEAN	3.40	2.55	2.02	0.81	0.71	-0.20	-0.03	3.67	6.07	4.11	5.37	4.59	33.07

[a] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 18. Evaporation from Lake Huron[a] (inches[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	4.46	3.65	0.02	1.31	1.26	-0.34	0.17	3.17	4.32	4.44	5.15	5.32	32.93
1947	4.64	3.54	2.23	-0.38	-0.86	-1.50	-1.63	1.31	2.95	3.25	4.46	4.57	22.58
1948	4.48	2.87	1.52	-1.99	0.71	-0.99	0.29	1.94	4.32	4.55	1.25	3.79	22.74
1949	4.11	2.58	1.36	-0.55	0.08	-2.53	-1.25	-0.58	7.13	3.49	5.34	3.73	22.91
1950	3.72	2.89	2.77	0.16	-1.79	-1.19	-0.62	2.47	3.17	1.86	4.89	4.55	22.88
1951	3.69	2.48	1.54	-1.83	-1.13	-1.07	0.24	0.83	3.45	2.47	5.42	4.41	20.50
1952	4.02	2.70	2.01	-1.58	-0.79	-1.62	-2.36	1.31	4.42	6.62	2.49	2.27	19.49
1953	3.11	2.34	0.62	-0.11	-1.17	-0.83	-1.07	-0.59	4.53	4.40	3.33	3.71	18.27
1954	4.67	1.77	3.06	-1.19	0.39	-1.75	-1.31	0.52	2.95	2.94	3.71	4.20	19.96
1955	4.38	2.59	2.45	-2.19	-0.26	-0.25	3.47	3.44	3.51	4.44	5.41	6.60	33.59
1956	4.10	2.77	2.26	-0.12	-0.12	-0.98	-1.01	0.60	2.26	2.83	6.07	4.48	23.14
1957	5.98	2.76	2.01	-1.13	0.12	-1.25	-0.76	1.09	3.00	4.24	3.27	4.80	24.13
1958	4.18	4.46	0.74	0.05	1.20	0.16	1.70	5.77	3.66	5.43	5.37	7.06	39.78
1959	4.96	3.64	2.17	-1.20	-0.31	-0.30	1.24	0.93	3.30	5.27	5.40	3.41	28.51
1960	3.94	3.25	2.79	-1.95	-1.09	-0.66	0.31	2.02	2.25	3.97	3.54	6.45	24.82
1961	4.84	2.21	1.86	-0.09	0.81	-1.23	-1.18	3.35	4.29	4.81	4.23	4.53	28.43
1962	5.80	3.92	1.27	2.31	-0.96	-0.69	0.28	2.36	4.38	2.82	4.92	5.89	32.30
1963	5.18	3.86	1.55	-0.72	-0.90	-1.11	-0.43	1.18	3.81	3.72	5.91	6.88	28.93
1964	4.68	3.68	2.02	-0.63	0.37	0.60	-0.06	2.42	1.98	4.46	4.29	5.08	28.89
1965	6.51	4.65	2.26	-0.06	-0.62	0.18	1.12	2.42	2.97	6.26	4.56	2.98	33.23
MEAN	4.57	3.13	1.83	-0.59	-0.25	-0.87	-0.14	1.80	3.63	4.11	4.45	4.74	26.40

[a] Values for January, 1959, through December, 1965, are from Richards and Irbe (1969).

[b] 1 inch (in.) = 2.54 centimeters (cm)

TABLE 19. Evaporation from Lake Erie[a] (inches[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	3.28	2.59	-2.06	0.98	3.56	2.84	2.55	5.81	5.62	6.46	5.44	3.68	40.75
1947	0.97	3.19	1.08	-1.04	1.97	2.23	2.28	1.55	6.27	2.81	6.83	2.35	30.49
1948	2.89	1.86	0.03	-1.74	2.60	2.42	2.18	4.58	5.59	7.79	3.88	2.90	34.98
1949	0.44	0.65	0.67	0.11	2.67	2.55	2.58	5.28	7.07	4.39	5.91	2.77	35.09
1950	0.65	2.44	1.55	-0.39	1.36	3.78	2.20	4.71	3.78	4.22	6.99	3.32	34.61
1951	1.09	1.15	-0.28	-1.44	1.46	2.94	2.51	5.46	6.21	4.37	6.54	2.54	32.55
1952	1.27	0.49	0.03	-1.86	3.26	3.30	3.19	4.68	5.34	10.54	4.17	2.14	36.55
1953	0.34	0.78	-0.47	0.21	1.30	2.55	2.60	4.99	7.29	5.49	4.86	4.31	34.25
1954	2.51	-0.11	1.36	-2.58	3.72	2.28	4.34	5.83	5.76	5.12	4.44	2.76	35.43
1955	2.51	1.04	0.47	-3.00	2.60	3.63	1.40	2.67	5.94	5.61	6.21	2.73	31.81
1956	1.67	1.16	0.84	-0.81	2.82	2.13	1.36	3.47	6.27	4.37	7.38	1.15	31.81
1957	3.16	0.50	0.19	-2.73	2.60	2.34	1.52	5.58	5.31	7.53	5.25	2.48	33.73
1958	2.91	3.44	-0.06	-0.90	3.66	4.32	1.95	5.89	4.56	6.60	6.18	3.97	42.52
1959	2.91	2.24	1.02	-0.90	0.37	3.75	2.42	3.04	4.71	5.80	5.40	1.36	32.12
1960	1.24	2.00	2.54	-3.12	0.62	2.70	2.88	3.63	4.95	8.71	5.28	4.50	35.93
1961	3.04	0.73	-0.12	-0.42	3.19	2.16	1.52	3.50	3.72	6.01	5.28	4.06	32.67
1962	3.47	2.30	0.87	0.03	1.98	2.85	3.32	3.88	7.38	5.83	4.98	3.47	40.36
1963	3.66	3.28	-0.43	0.24	3.81	2.94	3.16	5.52	7.00	5.18	5.88	4.43	44.67
1964	1.27	1.71	0.03	-1.62	2.26	3.12	3.01	5.54	6.81	6.70	5.42	3.87	38.12
1965	2.64	2.27	1.21	-0.66	0.37	2.34	3.02	3.60	3.81	7.30	4.71	1.27	31.88
MEAN	2.10	1.69	0.42	-1.08	2.31	2.86	2.50	4.46	5.67	6.04	5.55	3.00	35.52

[a] Values for January, 1950, through December, 1965, are from Richards and Irbe (1969).

[b] 1 inch (in.) = 2.45 centimeters (1969)

TABLE 20. Evaporation from Lake Ontario[a] (inches[b])

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1946	4.62	4.00	-0.06	0.77	0.73	0.68	2.96	3.11	3.96	4.31	4.51	5.40	34.99
1947	4.43	4.28	1.80	-0.10	-0.07	-1.01	0.46	1.71	4.34	0.37	4.73	3.64	24.58
1948	4.56	2.66	1.39	-0.97	0.27	0.43	1.53	2.31	3.97	3.44	0.98	3.27	23.84
1949	2.99	1.61	2.24	0.02	1.18	1.07	4.28	6.85	5.83	1.63	4.17	2.57	34.44
1950	2.36	3.68	3.19	0.68	-0.24	-0.24	-0.35	1.24	4.82	2.39	4.74	3.76	26.03
1951	3.54	1.96	0.79	-1.80	0.42	0.61	2.50	3.59	3.92	2.33	4.61	3.10	25.57
1952	3.07	2.36	1.73	-0.91	1.96	0.82	2.59	4.62	4.78	7.01	1.58	2.98	32.59
1953	2.89	2.96	1.66	0.74	0.04	-0.06	3.16	4.24	5.08	2.99	3.12	3.94	30.76
1954	3.79	1.38	3.06	-0.10	1.21	0.0	2.89	3.43	4.75	2.12	2.48	3.36	28.37
1955	3.95	2.04	1.82	-2.05	0.19	1.32	2.50	3.90	6.26	3.73	5.36	4.31	33.33
1956	3.25	2.06	2.32	-0.28	1.08	-0.01	2.69	3.78	5.26	2.87	3.94	2.38	29.34
1957	4.30	1.34	1.28	-1.68	0.71	-1.06	0.86	4.42	3.49	4.74	3.53	2.00	23.93
1958	3.56	3.83	0.44	-0.52	0.97	1.19	0.13	2.83	2.50	3.11	4.62	4.72	27.38
1959	4.38	3.46	1.84	-0.82	0.84	0.42	2.11	2.81	5.57	4.00	3.30	2.08	29.99
1960	3.13	2.11	2.80	-2.23	-1.68	0.13	1.54	2.78	3.80	4.10	1.73	4.30	22.51
1961	4.28	1.33	0.68	-1.32	-0.29	-1.44	0.31	1.40	1.88	2.15	3.14	2.95	15.07
1962	4.67	3.07	0.92	-1.19	-1.13	0.48	5.40	4.64	6.61	4.04	3.50	4.33	35.34
1963	4.44	3.70	1.18	-0.08	0.37	0.50	0.84	1.94	4.69	2.72	2.27	4.14	26.71
1964	4.22	3.39	1.83	-0.15	0.22	0.51	1.43	3.72	4.77	4.37	3.75	3.29	31.35
1965	5.02	3.44	1.71	-0.03	-0.56	0.15	1.61	2.73	2.01	5.36	3.21	2.42	27.07
MEAN	3.87	2.73	1.63	-0.60	0.31	0.22	1.97	3.30	4.41	3.39	3.46	3.45	28.16

[a] Values for January, 1950, through December, 1965, are from Richards and Irbe (1969).

[b] 1 inch (in.) = 2.54 centimeters (cm)

RUNOFF INTO LAKES FROM SURROUNDING LAND AREAS

Several investigators have attempted to determine the amount of runoff which enters the Great Lakes from the surrounding land areas. Brunk (1964) studied the 1940-1959 average monthly distribution of the evapotranspiration, streamflow, and precipitation on the lake for Lakes Erie and Ontario. He concluded that topography and absorptive capacity of soils are probably responsible for the wide variations in the percentage of monthly precipitation which flows into the lakes as streamflow from the various river basins.

A map of mean annual runoff in the Great Lakes basin for the period 1931 through 1960 was developed by Browzin (1966). Pentland (1968) presented maps of average monthly and annual runoff for the Great Lakes basin for the base period 1935 through 1964.

Sanderson (1966) used the Thornthwaite water balance technique to estimate monthly point runoff at 133 climatic stations in the Lake Erie basin for the period October, 1958, through September, 1963. An isopleth mapping technique was then used to estimate total monthly runoff into the lake. The Thornthwaite water balance technique was also used for estimating point runoff at 81 climatic stations in and near the Lake Ontario basin (Sanderson, 1971). These runoff values were then used to prepare a map of annual average runoff as well as maps of plus and minus two standard derviations of annual average runoff.

Witherspoon (1970) developed a hydrologic model based on the water and energy balances for the Lake Ontario local drainage basin which included the entire land area of the basin. Using a hypothesis which provided estimates of the actual regional evaporation, regional moisture values were obtained which, when routed, simulate the measured monthly outflows from the land area. The period October, 1935, through September, 1964, was simulated and computed runoff was compared to "measured" runoff. The "measured" runoff was determined by extrapolating the runoff distribution from gaged representative basins to ungaged areas on a monthly basis.

The runoff values desired for this study are the total runoff into each lake from surrounding land areas for each month of calendar years 1946 through 1965. There is approximately 200,000 sq. miles (518,000 km^2) of land area in the Great Lakes basin of which approximately 114,000 sq. miles (295,300 km^2) are in the United States and 86,000 sq. miles (222,700 km^2) are in Canada. For the period 1946 through 1965 approximately 59 percent of the area in the United States was gaged and approximately 30 percent of the area in Canada was gaged. In addition, an additional 10 percent of the area in the United States was gaged for part of the period and about 32 percent of the area in Canada was gaged for part of the period. A summary of the amount of land area for which streamflow records are available is presented in Table 21 for each lake.

A map of the Great Lakes basin was prepared for each month of the period 1946 through 1965 with the amount of runoff from each gaged area during the month plotted at the centroid of the gaged area in units of cfs/sq.mi. A total of 309 station records were used in preparing the maps: 96 complete record stations in the basin, 41 partial record stations in the basin, and 67 complete record stations outside of the basin for the United States; and 28 complete record

TABLE 21. Amount of land area in the Great Lakes basin for which streamflow records are available for the period 1946 through 1965[a].

Lake Basin	Total Land Area (mi^2)[d]	Canada			United States			Percent of Sub-basin gaged	
		Area (mi^2)[d]	Complete[b] (mi^2)[d]	Partial[c] (mi^2)[d]	Area (mi^2)[d]	Complete[b] (mi^2)[d]	Patial[c] (mi^2)[d]	Complete[b]	Partial[c]
Superior	48,180	30,980	6,845	11,318	17,200	6,751	2,084	28.2	27.8
Michigan	45,460				45,460	27,867	5,616	61.3	12.4
Huron	49,610	34,180	11,976	11,692	15,430	7,559	1,875	39.4	27.3
St. Clair	6,940	4,164	519	1,371	2,776	1,394	395	27.6	25.4
Erie	22,560	4,715	1,360	1,406	17,845	12,755	929	62.6	10.4
Ontario	27,280	11,950	4,850	1,859	15,330	10,608	471	56.7	8.5
Total	200,030	85,989	25,550	27,646	114,041	66,934	11,370	46.2	19.5

[a]Complied from Surface Water Data for Ontario, Inland Waters Branch, Department of Energy, Mines and Resources, Canada, and Water Supply Papers, Geological Survey, U.S. Department of Interior, for years 1946 through 1965.

[b]Area for which records are available for the complete period 1946 through 1965.

[c]Area for which records are only available for part of the period 1946 through 1965.

[d]1 square mile (mi^2) = 2.59 square kilometers (km^2).

stations in the basin, 61 partial record stations in the basin, and 16 complete record stations outside of the basin for Canada. Fig. 3 shows the areas for which streamflow records were used in this study

Runoff isopleths were then interpolated from the plotted values at spacings determined from the range of values for each map. The extrapolation of the isopleths over the ungaged areas was made after taking into consideration the distribution of precipitation as indicated by the precipitation map for that month. The runoff isopleths for July, 1964, are presented in Fig. 4. The amount of runoff from the ungaged areas was then obtained by planimetering the areas between the isopleths. The total runoff is the sum of the runoff from the ungaged areas and the runoff from the gaged areas. The amount of runoff into each lake in units of cfs/sq.mi. of surrounding land area for each month of the period 1946 through 1965 is presented in Tables 22 through 27.

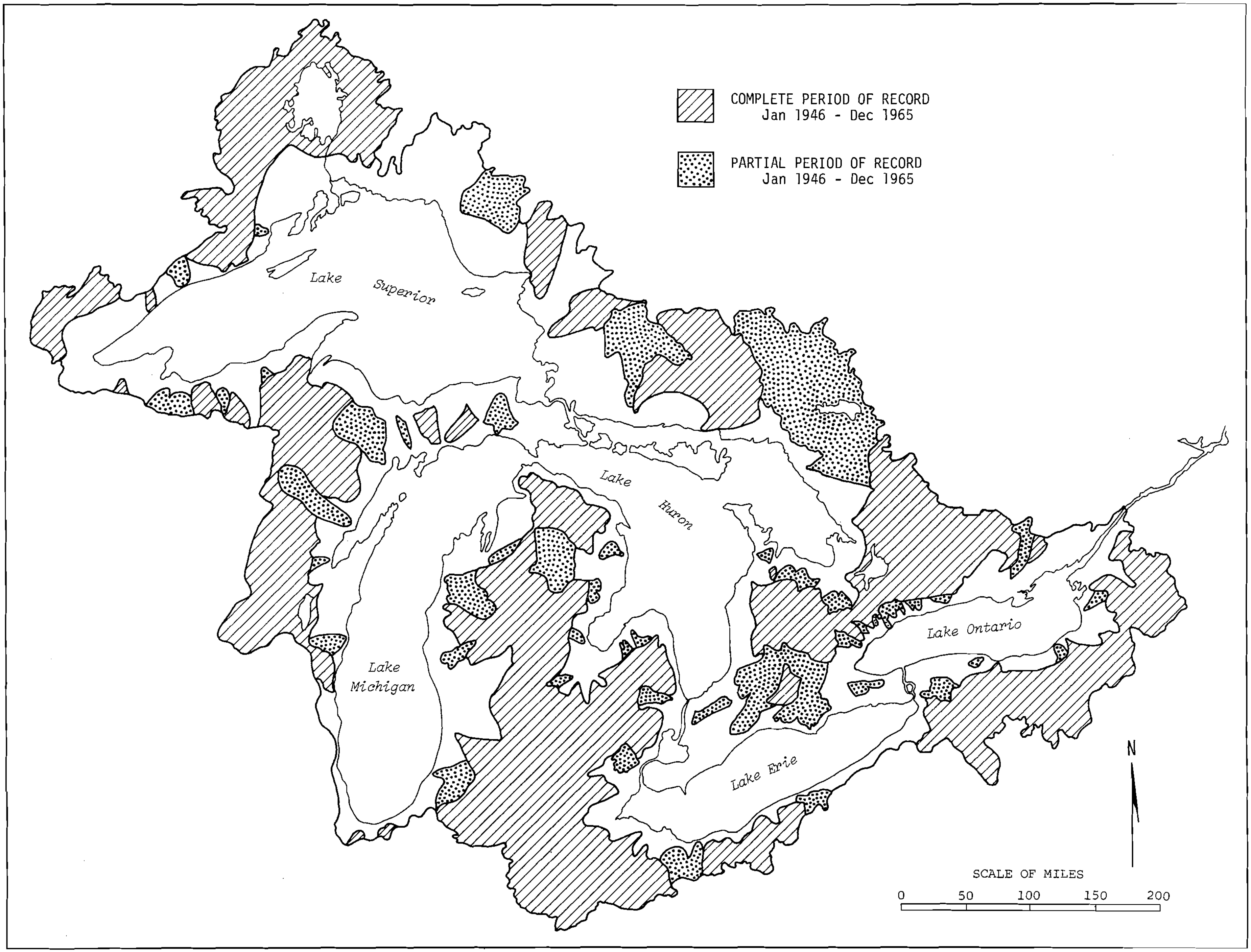

Figure 3. Areas for which streamflow records are available for period 1946 through 1965.

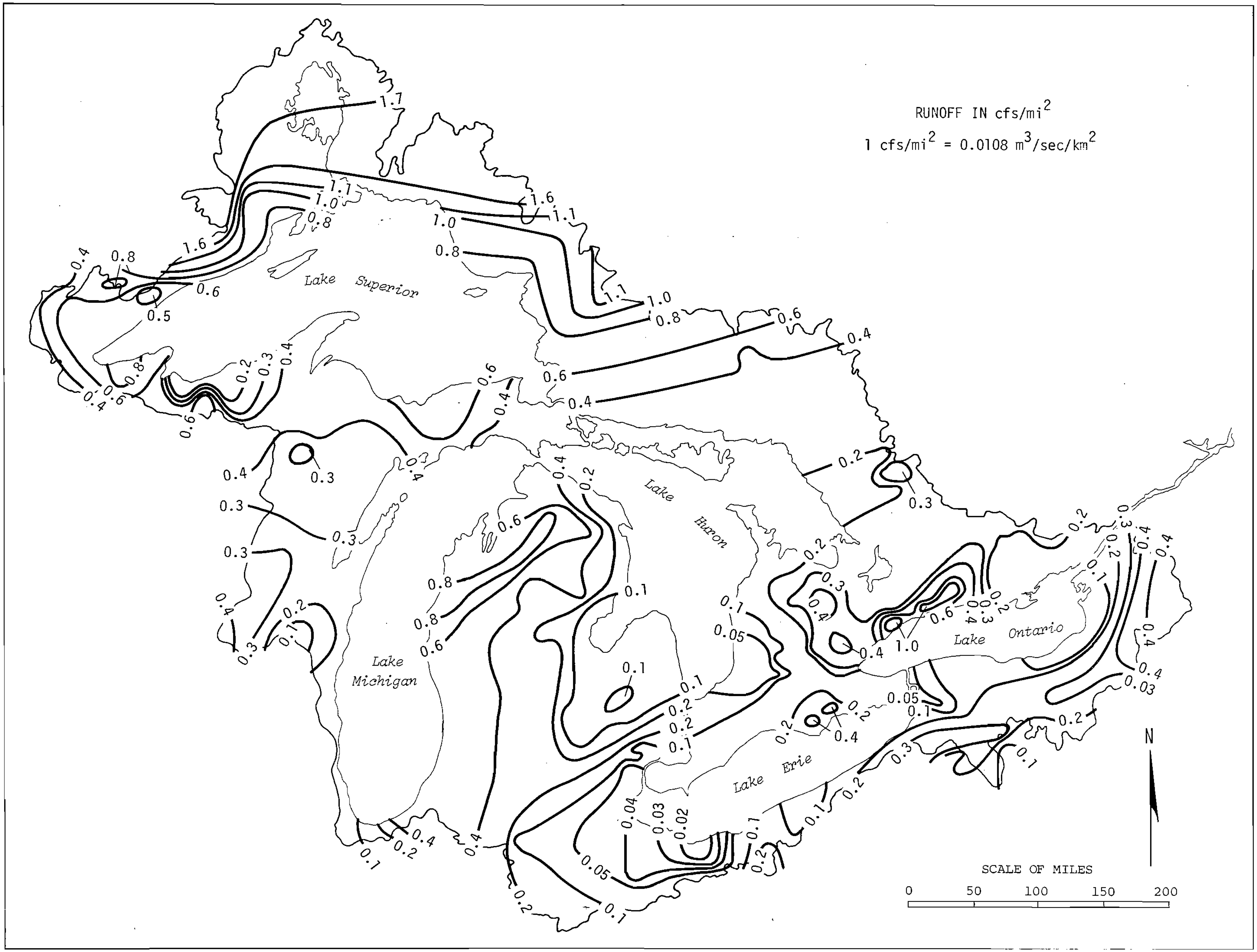

Figure 4. Runoff isopleths for July, 1964.

TABLE 22. Runoff into Lake Superior (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	0.82	0.75	1.47	1.70	1.46	1.52	0.89	0.67	0.77	1.07	1.25	0.96	1.11
1947	0.79	0.77	0.78	1.69	3.54	2.77	1.06	0.73	0.66	0.60	0.61	0.53	1.21
1948	0.53	0.51	0.65	2.87	2.11	0.89	0.66	0.65	0.58	0.50	0.73	0.76	0.95
1949	0.71	0.62	0.64	2.00	2.06	1.08	1.17	0.69	0.62	0.89	0.83	0.69	1.00
1950	0.81	0.74	0.78	1.59	4.26	1.93	1.51	1.14	0.81	0.84	1.03	0.97	1.37
1951	0.75	0.78	0.88	2.99	2.92	1.61	1.06	0.70	1.23	1.47	1.42	1.09	1.41
1952	0.85	0.79	0.82	2.48	1.60	1.30	1.42	1.06	0.69	0.63	0.66	0.71	1.08
1953	0.61	0.62	0.90	1.68	2.57	2.21	1.56	1.10	0.78	0.63	0.65	0.76	1.17
1954	0.79	0.81	0.85	2.57	3.37	1.93	1.03	0.75	0.67	0.91	0.85	0.71	1.27
1955	0.68	0.66	0.73	2.32	1.48	1.04	0.71	0.75	0.62	0.81	0.91	0.70	0.95
1956	0.70	0.64	0.59	1.69	2.29	1.39	1.12	0.71	0.70	0.61	0.72	0.67	0.99
1957	0.60	0.62	0.70	2.20	1.65	1.29	1.28	0.65	0.78	0.63	0.89	0.74	1.00
1958	0.72	0.67	0.63	1.50	1.05	1.06	1.23	0.73	0.94	0.86	1.03	0.86	0.94
1959	0.75	0.71	0.73	1.38	2.12	1.33	0.85	0.80	1.00	1.40	1.18	0.81	1.09
1960	0.74	0.68	0.65	2.38	3.17	1.30	0.71	0.61	0.68	0.62	0.90	0.74	1.10
1961	0.64	0.56	0.67	1.66	2.13	1.20	0.81	0.57	0.79	1.03	0.99	0.81	0.99
1962	0.70	0.67	0.64	1.22	2.04	1.02	0.66	0.62	0.74	0.68	0.68	0.64	0.86
1963	0.62	0.57	0.64	1.56	1.36	1.56	0.78	0.67	0.59	0.60	0.67	0.58	0.85
1964	0.60	0.59	0.61	1.88	2.87	1.55	1.19	0.95	1.00	1.15	1.30	1.02	1.23
1965	0.83	0.81	0.84	1.98	2.68	1.30	0.83	0.71	0.87	1.18	1.05	0.95	1.17
MEAN	0.71	0.68	0.76	1.97	2.34	1.46	1.03	0.76	0.78	0.86	0.92	0.79	1.09

[a] 1 $cfs/mi^2 = 0.0108\ m^3/sec/km^2$

TABLE 23. Runoff into Lake Michigan (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	1.11	0.77	1.83	0.90	0.70	0.80	0.61	0.43	0.44	0.42	0.62	0.59	0.77
1947	0.60	0.62	0.85	2.08	1.55	1.27	0.63	0.47	0.56	0.52	0.62	0.69	0.87
1948	0.57	0.66	1.60	1.29	1.24	0.58	0.50	0.40	0.37	0.39	0.57	0.57	0.73
1949	0.70	0.92	0.91	1.03	0.71	0.62	0.62	0.45	0.45	0.49	0.51	0.74	0.68
1950	1.04	0.83	1.39	2.06	1.35	0.86	0.70	0.56	0.57	0.53	0.58	0.75	0.93
1951	0.80	0.89	1.16	2.22	1.22	0.87	0.88	0.64	0.66	1.04	1.20	0.97	1.05
1952	1.32	1.07	1.29	2.20	0.97	0.81	0.87	0.68	0.50	0.45	0.56	0.70	0.95
1953	0.66	0.75	1.23	1.37	1.10	0.79	0.71	0.56	0.42	0.42	0.45	0.54	0.75
1954	0.48	0.71	0.85	1.34	1.05	1.05	0.66	0.48	0.55	1.34	0.83	0.77	0.84
1955	0.84	0.71	1.05	1.45	0.79	0.72	0.45	0.41	0.37	0.48	0.56	0.55	0.70
1956	0.48	0.54	0.90	1.38	1.55	0.68	0.69	0.62	0.50	0.43	0.49	0.53	0.73
1957	0.53	0.58	0.71	1.12	1.02	0.69	0.69	0.40	0.46	0.48	0.75	0.71	0.68
1958	0.62	0.56	0.80	0.89	0.56	0.48	0.61	0.40	0.48	0.46	0.59	0.46	0.58
1959	0.43	0.62	1.10	1.76	1.03	0.54	0.47	0.51	0.61	0.91	0.97	0.85	0.82
1960	1.11	0.86	0.81	2.11	2.34	1.11	0.73	0.67	0.69	0.61	0.90	0.65	1.05
1961	0.80	0.55	1.06	1.36	1.04	0.64	0.48	0.49	0.60	0.71	1.02	0.72	0.79
1962	0.63	0.63	1.28	1.69	1.22	0.67	0.49	0.43	0.50	0.55	0.54	0.50	0.76
1963	0.45	0.43	0.91	1.00	0.92	0.60	0.40	0.37	0.35	0.35	0.42	0.43	0.55
1964	0.47	0.43	0.54	0.87	0.97	0.48	0.41	0.40	0.49	0.47	0.52	0.53	0.55
1965	0.57	0.78	1.11	1.80	1.39	0.66	0.40	0.44	0.83	0.83	0.77	1.20	0.90
MEAN	0.71	0.70	1.07	1.50	1.14	0.75	0.60	0.49	0.52	0.59	0.67	0.67	0.78

[a] 1 cfs/mi^2 = 0.0108 m^3/sec/km^2

TABLE 24. Runoff into Lake Huron (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	1.28	0.95	2.64	1.37	1.02	0.84	0.45	0.35	0.33	0.32	0.72	0.88	0.93
1947	0.87	0.73	0.95	3.46	2.78	2.17	1.18	0.71	0.52	0.57	0.53	0.66	1.26
1948	0.54	0.60	2.09	2.55	1.73	1.07	0.71	0.62	0.48	0.45	0.80	0.90	1.05
1949	0.95	1.06	1.28	2.01	1.35	0.81	0.63	0.33	0.28	0.32	0.41	1.00	0.87
1950	1.49	0.94	1.56	2.54	1.92	0.83	0.54	0.38	0.41	0.39	0.70	1.11	1.07
1951	1.10	1.20	1.57	3.81	1.81	0.70	0.73	0.43	0.46	1.29	1.98	1.46	1.38
1952	1.60	1.19	1.44	2.91	1.20	0.73	0.60	0.64	0.50	0.42	0.62	1.13	1.08
1953	0.92	0.93	1.80	2.16	1.77	0.94	0.64	0.40	0.37	0.35	0.36	0.64	0.94
1954	0.57	1.18	1.63	2.55	1.63	1.33	0.62	0.31	0.45	2.00	1.32	1.06	1.22
1955	1.04	0.90	1.55	2.35	0.89	0.50	0.28	0.23	0.23	0.30	0.88	0.77	0.82
1956	0.53	0.47	1.08	1.95	2.10	1.00	0.72	0.50	0.62	0.68	0.69	0.90	0.94
1957	0.82	0.86	1.08	1.74	1.27	0.85	1.52	0.45	0.53	0.65	1.38	1.47	1.05
1958	1.02	0.82	1.09	1.14	0.58	0.37	0.42	0.26	0.29	0.40	0.63	0.66	0.64
1959	0.58	0.57	1.20	2.73	1.82	0.74	0.41	0.34	0.52	0.96	1.41	1.30	1.05
1960	1.23	0.90	0.94	3.46	3.18	1.40	1.04	0.60	0.44	0.56	0.88	0.74	1.28
1961	0.97	0.58	0.96	1.46	1.15	0.85	0.71	0.53	0.66	0.70	0.99	1.01	0.88
1962	0.72	0.70	1.43	1.57	1.60	0.59	0.31	0.26	0.27	0.41	0.48	0.50	0.74
1963	0.41	0.40	1.03	1.96	1.25	0.60	0.31	0.30	0.30	0.27	0.40	0.42	0.64
1964	0.51	0.56	0.77	1.77	1.13	0.44	0.30	0.28	0.47	0.61	0.58	0.79	0.68
1965	0.69	1.01	0.93	2.69	1.94	0.49	0.31	0.50	0.80	1.08	1.25	1.50	1.10
MEAN	0.89	0.83	1.35	2.31	1.61	0.86	0.62	0.42	0.45	0.64	0.85	0.95	0.98

[a] 1 cfs/mi^2 = 0.0108 m^3/sec/km^2

TABLE 25. Runoff into Lake St. Clair (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	1.21	0.80	2.36	0.32	0.48	0.69	0.11	0.11	0.08	0.11	0.21	0.37	0.57
1947	1.33	0.56	1.73	5.36	1.83	1.51	0.49	0.27	0.32	0.17	0.18	0.56	1.19
1948	0.21	0.79	3.80	1.14	1.70	0.31	0.22	0.14	0.10	0.17	0.48	0.37	0.79
1949	1.12	2.53	1.37	0.86	0.31	0.22	0.18	0.11	0.12	0.24	0.34	2.24	0.79
1950	2.99	1.70	3.56	3.05	0.53	0.31	0.30	0.21	0.23	0.27	0.81	2.17	1.34
1951	1.75	2.83	2.68	2.25	0.56	0.33	0.26	0.14	0.14	0.24	0.80	0.68	1.04
1952	2.67	1.34	2.30	2.02	0.76	0.24	0.18	0.18	0.15	0.12	0.20	0.36	0.88
1953	0.52	0.48	1.64	0.87	0.92	0.62	0.28	0.36	0.13	0.12	0.14	0.19	0.52
1954	0.27	2.51	2.46	2.02	0.39	0.24	0.14	0.11	0.12	1.38	0.66	1.07	0.94
1955	1.32	1.16	2.70	1.11	0.36	0.19	0.12	0.12	0.11	0.24	0.64	0.64	0.72
1956	0.33	0.84	2.86	1.84	3.31	0.54	0.40	0.71	0.48	0.28	0.34	0.79	1.06
1957	0.83	1.16	1.33	1.81	1.02	0.42	0.76	0.20	0.42	0.42	1.07	1.89	0.94
1958	0.54	0.47	1.18	0.67	0.28	0.29	0.24	0.15	0.18	0.18	0.27	0.24	0.39
1959	0.47	0.86	3.02	2.09	0.76	0.36	0.18	0.22	0.23	0.56	0.92	1.55	0.94
1960	1.19	1.21	1.19	3.44	1.15	1.15	0.22	0.19	0.12	0.15	0.20	0.14	0.86
1961	0.50	0.68	0.85	1.45	0.77	0.36	0.19	0.33	0.27	0.15	0.42	0.40	0.53
1962	0.36	0.38	2.47	0.79	0.35	0.33	0.12	0.14	0.14	0.17	0.61	0.48	0.53
1963	0.12	0.11	1.87	0.74	0.66	0.24	0.10	0.09	0.07	0.08	0.11	0.10	0.36
1964	0.27	0.29	0.75	0.96	0.56	0.19	0.13	0.31	0.20	0.11	0.11	0.42	0.36
1965	0.80	2.03	1.94	2.29	0.34	0.17	0.12	0.11	0.09	0.22	0.25	1.27	0.79
MEAN	0.94	1.14	2.10	1.75	0.85	0.43	0.24	0.21	0.19	0.27	0.44	0.80	0.78

[a] 1 $cfs/mi^2 = 0.0108\ m^3/sec/km^2$

TABLE 26. Runoff into Lake Erie (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	1.11	0.81	1.79	0.24	0.76	1.33	0.20	0.09	0.06	0.11	0.20	0.46	0.60
1947	1.56	0.74	1.47	3.43	2.21	2.20	0.38	0.22	0.31	0.16	0.31	0.61	1.13
1948	0.73	1.47	3.65	1.52	1.54	0.35	0.25	0.19	0.09	0.16	0.56	0.90	0.95
1949	2.26	2.04	1.29	1.08	0.77	0.35	0.21	0.13	0.14	0.20	0.16	1.02	0.80
1950	4.11	2.70	3.17	2.74	0.76	0.54	0.30	0.16	0.48	0.59	1.31	2.29	1.59
1951	2.18	2.80	2.63	2.19	1.10	0.58	0.50	0.15	0.12	0.19	0.84	1.32	1.21
1952	3.71	1.72	2.49	2.02	0.93	0.24	0.14	0.10	0.11	0.09	0.18	0.41	1.01
1953	0.77	0.63	1.59	0.83	1.26	0.44	0.18	0.16	0.09	0.08	0.11	0.24	0.53
1954	0.43	1.21	2.11	2.37	0.55	0.37	0.14	0.20	0.10	1.50	0.57	1.04	0.88
1955	1.31	1.32	3.00	1.32	0.31	0.20	0.17	0.14	0.07	0.33	1.03	0.62	0.82
1956	0.29	1.96	2.90	1.85	2.53	0.73	0.44	0.61	0.42	0.21	0.25	0.77	1.07
1957	1.04	1.19	0.97	3.40	0.95	0.76	0.75	0.16	0.25	0.31	0.66	1.95	1.03
1958	0.58	0.61	1.26	1.03	0.54	0.78	0.92	0.83	0.52	0.22	0.85	0.44	0.71
1959	1.91	2.96	2.36	2.17	1.16	0.37	0.22	0.16	0.16	0.57	1.00	1.56	1.21
1960	1.82	1.69	1.18	2.12	1.01	0.88	0.29	0.19	0.13	0.13	0.18	0.12	0.80
1961	0.39	1.07	1.85	3.21	0.96	0.52	0.23	0.29	0.22	0.16	0.43	0.47	0.81
1962	1.03	0.98	2.39	0.86	0.35	0.26	0.14	0.12	0.13	0.21	0.47	0.35	0.61
1963	0.28	0.21	2.89	1.00	0.39	0.28	0.15	0.14	0.09	0.09	0.17	0.21	0.49
1964	0.50	0.25	2.11	2.29	0.57	0.26	0.13	0.18	0.14	0.10	0.15	0.42	0.59
1965	1.05	1.68	2.12	1.98	0.53	0.24	0.12	0.11	0.13	0.36	0.51	1.15	0.83
MEAN	1.35	1.40	2.16	1.88	0.96	0.58	0.29	0.22	0.19	0.29	0.50	0.82	0.88

[a] $1\ cfs/mi^2 = 0.0108\ m^3/sec/km^2$

TABLE 27. Runoff into Lake Ontario (cfs/sq.mi[a] of surrounding land area)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	1.51	1.16	2.49	0.87	0.87	0.86	0.43	0.30	0.26	0.57	0.83	1.03	0.93
1947	1.62	1.55	1.84	4.03	2.92	2.56	1.02	0.65	0.42	0.31	0.50	0.72	1.51
1948	0.59	0.89	3.20	2.35	1.62	0.76	0.44	0.37	0.29	0.34	0.64	0.72	1.02
1949	1.52	1.64	1.65	1.91	0.75	0.33	0.21	0.22	0.32	0.38	0.47	1.15	0.87
1950	1.88	1.09	1.69	2.87	0.84	0.51	0.33	0.25	0.37	0.45	0.92	1.52	1.06
1951	1.92	2.05	2.86	4.06	1.35	0.57	0.77	0.35	0.42	0.46	1.06	1.26	1.42
1952	1.97	1.79	2.39	2.93	1.26	0.66	0.43	0.30	0.35	0.41	0.51	1.18	1.18
1953	1.06	1.20	2.06	1.60	1.90	0.66	0.36	0.43	0.39	0.34	0.39	0.87	0.94
1954	0.68	2.24	2.41	3.13	1.66	0.69	0.32	0.28	0.48	1.09	1.00	1.29	1.27
1955	1.34	0.91	3.30	2.85	0.71	0.47	0.28	0.31	0.25	1.17	1.56	1.10	1.19
1956	0.74	0.95	2.45	3.83	2.56	1.08	0.50	0.43	0.75	0.48	0.55	1.27	1.30
1957	1.36	1.30	1.76	1.82	1.20	0.64	0.72	0.37	0.41	0.34	0.62	1.39	0.99
1958	0.92	0.74	1.86	2.52	1.02	0.81	0.47	0.39	0.74	0.70	0.90	0.92	1.00
1959	1.35	1.44	2.37	4.02	1.19	0.44	0.41	0.29	0.29	0.74	1.22	2.14	1.32
1960	1.45	1.76	1.39	5.12	2.22	1.14	0.39	0.30	0.26	0.30	0.47	0.42	1.26
1961	0.67	0.92	1.99	2.51	1.53	1.03	0.56	0.37	0.37	0.30	0.53	0.88	0.97
1962	0.91	0.62	2.05	2.32	0.85	0.34	0.26	0.37	0.30	0.61	0.97	0.85	0.87
1963	0.55	0.51	2.05	2.82	1.33	0.47	0.25	0.35	0.29	0.25	0.45	0.87	0.85
1964	1.16	0.78	2.54	2.28	1.11	0.43	0.27	0.27	0.21	0.23	0.31	0.67	0.86
1965	0.76	1.82	1.46	2.53	0.98	0.33	0.25	0.26	0.32	0.67	1.34	1.66	1.02
MEAN	1.20	1.27	2.19	2.82	1.39	0.74	0.43	0.34	0.37	0.51	0.76	1.10	1.09

[a] 1 cfs/mi^2 = 0.0108 m^3/sec/km^2

GROUNDWATER

There is some discharge from groundwater into lakes along the shores and there may be seepage losses from the lakes to deep aquifers. However, these have usually been ignored or assumed to be very small or compensating.

Groundwater discharges into Lake Michigan from the general area east of the Mississippi-Great Lakes divide. The discharge is mainly by the base flow of streams that enter the lake and by bank seepage and underflow along the lake shore. Since an impermeable glacial till underlies much of the shore area, a value for bank seepage and underflow as low as 800 cfs (22.4 m^3/sec) for 3500 miles (5635 km) of shore may be reasonable under prevailing conditions (Bergstrom and Hanson, 1962).

Haefeli (1970) concluded that the configuration of the water table between Lake Simcoe and Lake Ontario corresponds generally with the topography. Piezometric, hydrogeochemical and mathematical analysis demonstrated the non-existence of major seepage from Lake Simcoe into the Lake Ontario basin. The groundwater divide conincides approximately with the basin boundary in the quanterary deposits as well as in the different underlying bedrock formations.

Hence, groundwater was considered to be negligible in this study.

NET BASIN SUPPLY

The precipitation, evaporation, runoff, and groundwater terms in Eq. 1 are usually combined into a single term which is called the net basin supply, NBS, to the lake. The water balance equation can then be written

$$\Delta S = NBS + I - O \pm D \qquad (4)$$

The value of the net basin supply term in Eq. 4 can be determined as the sum of the precipitation, evaporation, runoff, and groundwater contributions to the lake, or it can be determined as the residual after the value of the other terms in Eq. 4 have been determined.

Net Basin Supply as a Sum of Hydrologic Components

Since the groundwater contribution is assumed to be negligible, the net basin supply to each lake can be computed as

$$NBS = P - E + R \qquad (5)$$

The net basin supply values, which are obtained when the precipitation, evaporation, and runoff amounts are stated in units of cfs and substituted into Eq. 5, are listed in Tables 28 through 31. The net basin supply for Lake Michigan and Lake Huron is reported as though these lakes were a single lake. These lakes are considered as one lake because the boundary between them is difficult to establish and the flow from Lake Michigan to Lake Huron cannot be accurately determined. Therefore, the net basin supply values available for comparison are for the combined lakes.

TABLE 28. Net basin supply for Lake Superior (1000 cfs[a])

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	J-M[b]	5	-15	99	111	139	221	164	109	80	82	11	-39	81
	C-E[c]	2	17	77	118	113	147	123	78	73	79	45	-19	71
1947	J-M	-60	-23	8	147	227	310	188	111	60	33	7	-46	80
	C-E	-16	-2	33	149	234	223	141	95	59	25	-12	-35	75
1948	J-M	-47	-42	29	221	108	144	222	110	25	-6	59	-19	67
	C-E	-39	-17	65	176	147	91	101	91	22	5	30	2	56
1949	J-M	-24	-27	13	108	190	248	310	94	35	65	-17	-59	79
	C-E	-11	-7	28	124	158	175	162	68	42	54	2	-17	65
1950	J-M	-10	-1	22	112	294	254	264	156	70	65	18	-18	103
	C-E	2	11	61	201	266	248	179	126	98	88	44	-9	110
1951	J-M	-28	33	63	213	218	254	179	173	166	112	-20	-16	113
	C-E	-21	57	118	204	199	175	144	129	143	89	35	7	107
1952	J-M	-12	-14	40	183	155	258	308	198	59	-38	-1	0	95
	C-E	3	3	53	130	158	182	193	142	6	-52	-7	-14	67
1953	J-M	-24	9	50	122	235	285	266	149	43	6	14	-26	95
	C-E	-10	22	68	144	224	249	172	106	44	-5	-8	-6	84
1954	J-M	-26	34	11	205	242	242	152	101	94	39	-25	-28	87
	C-E	-23	3	51	202	261	178	110	55	45	29	-8	-38	72
1955	J-M	-26	-18	25	187	155	175	245	138	27	56	-26	-55	74
	C-E	-34	11	76	143	149	115	112	90	47	57	29	-9	66
1956	J-M	-22	-40	-25	84	158	214	210	143	51	5	-10	-38	61
	C-E	-18	-19	26	108	147	167	141	87	32	8	-2	-27	55
1957	J-M	-77	-16	16	148	114	196	186	44	77	-9	23	-44	55
	C-E	-26	19	57	135	154	157	123	65	36	17	7	-13	61
1958	J-M	-14	-61	28	95	79	157	237	135	70	24	-7	-46	59
	C-E	-9	8	29	68	105	152	137	114	82	36	18	-20	60
1959	J-M	-77	-63	22	87	245	204	218	260	150	76	-83	-22	86
	C-E	-20	-17	34	120	184	158	121	151	138	69	1	-22	77
1960	J-M	-44	-38	-25	225	254	173	201	138	79	17	-2	-87	75
	C-E	2	-14	25	195	233	155	98	75	44	24	11	-20	69
1961	J-M	-76	-4	35	110	151	158	191	107	137	35	-8	-48	66
	C-E	-19	14	60	134	148	111	77	66	67	43	22	-8	60
1962	J-M	-84	-25	15	89	219	142	162	161	90	22	-45	-73	57
	C-E	-26	-22	29	129	170	127	87	100	76	-9	-26	-22	52
1963	J-M	-100	-80	7	153	105	249	205	127	64	52	-48	-82	55
	C-E	-30	7	75	133	155	153	111	63	38	20	7	-33	58
1964	J-M	-42	-40	-9	188	290	203	210	157	139	61	14	-19	97
	C-E	-27	-2	29	178	228	162	130	118	98	52	30	10	84
1965	J-M	-68	-42	10	137	270	166	194	183	166	49	4	-8	89
	C-E	9	-4	47	141	190	161	138	114	113	90	60	38	92
MEAN	J-M	-43	-24	22	146	192	213	216	140	84	37	-7	-39	79
MEAN	C-E	-15	3	52	147	181	164	130	97	65	36	14	-13	72

[a] 1 cfs = 0.028 m^3/sec

[b] J-M denotes values computed by Jones and Meredith

[c] C-E denotes values reported by Corps of Engineers (U.S. Army Engineer Division, 1965c) except values for September, 1964, through December, 1965, which were computed as described in text.

TABLE 29. Net basin supply for Lake Michigan-Huron (1000 cfs[a])

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	J-M[b]	80	19	265	69	148	188	99	-18	-65	-86	-75	-38	49
	C-E[c]	104	141	210	172	157	194	87	-8	-36	-9	4	6	85
1947	J-M	13	-37	68	451	404	280	234	64	-23	-26	-35	-23	115
	C-E	45	67	170	350	370	314	160	61	43	-7	-11	-12	129
1948	J-M	-54	12	249	335	218	206	107	-30	-87	-90	104	-24	79
	C-E	-22	79	253	334	221	141	106	9	-89	-77	17	39	84
1949	J-M	33	79	110	199	139	249	180	23	-157	-16	-78	37	67
	C-E	61	132	159	225	181	180	116	-28	-64	-43	-53	53	76
1950	J-M	106	64	127	327	234	209	182	9	-23	18	-73	13	99
	C-E	149	134	215	310	238	201	161	84	26	-14	22	72	133
1951	J-M	40	77	167	491	240	197	261	127	8	184	75	65	161
	C-E	86	167	291	367	269	212	177	95	92	110	110	106	173
1952	J-M	107	56	150	381	229	226	337	101	-74	-228	44	47	115
	C-E	132	154	225	302	214	217	212	93	-72	-110	9	78	121
1953	J-M	64	104	217	251	302	245	199	42	-136	-69	-34	-25	97
	C-E	63	126	217	281	237	214	150	32	-42	-66	-43	-9	96
1954	J-M	-43	115	94	377	198	383	173	60	55	227	20	-24	136
	C-E	-4	106	216	283	295	253	137	54	131	156	82	60	147
1955	J-M	35	29	100	344	165	170	73	-42	-135	25	-80	-68	51
	C-E	40	109	177	233	208	111	68	-38	-59	4	-15	1	70
1956	J-M	-51	9	75	219	294	222	222	98	-59	-15	-83	-10	77
	C-E	-2	49	146	254	277	242	176	83	-15	-34	12	14	100
1957	J-M	-74	20	64	277	232	268	230	56	5	0	70	34	99
	C-E	-15	51	128	204	236	260	167	44	1	-6	43	91	100
1958	J-M	-1	-64	69	109	24	123	124	-47	3	-56	-61	-111	9
	C-E	85	50	68	102	104	123	119	64	0	-30	-45	-25	51
1959	J-M	-47	7	110	356	290	126	120	146	-38	87	38	103	109
	C-E	-4	64	216	300	248	162	98	89	84	74	68	102	125
1960	J-M	79	34	31	452	463	259	218	75	20	-15	25	-111	128
	C-E	157	76	125	378	427	286	196	99	11	-23	1	-5	144
1961	J-M	-55	26	130	187	111	205	189	14	76	-34	0	-30	68
	C-E	-39	85	156	190	182	157	134	102	74	43	18	10	93
1962	J-M	-26	5	112	166	263	178	127	22	-71	37	-86	-76	55
	C-E	17	87	181	245	216	161	91	69	25	-54	-59	-26	79
1963	J-M	-54	-84	122	229	238	175	153	40	-54	-60	-105	-127	40
	C-E	-1	48	165	253	190	147	118	55	-16	-13	-40	-50	71
1964	J-M	-24	-53	57	237	190	80	138	52	94	-65	-6	-51	55
	C-E	-18	35	63	191	217	132	97	52	12	-39	-49	20	59
1965	J-M	-48	85	79	327	285	127	87	114	233	-31	28	115	116
	C-E	77	107	171	310	236	164	105	86	82	99	70	93	133
MEAN	J-M	4	25	120	289	233	206	173	45	-21	-11	-15	-15	86
MEAN	C-E	46	93	178	264	236	193	134	55	9	-2	7	31	104

[a] 1 cfs = 0.028 m^3/sec

[b] J-M denotes values computed by Jones and Meredith

[c] C-E denotes values reported by Corps of Engineers (U.S. Army Engineer Division, 1965c) except values for September, 1964, through December, 1965, which were computed as described in text.

TABLE 30. Net basin supply for Lake Erie (1000 cfs[a])

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	J-M[b]	7	4	80	5	31	43	4	-31	-35	-25	-23	0	5
	C-E[c]	-1	56	80	4	60	65	-1	-50	-3	-37	-7	-2	13
1947	J-M	61	-6	46	134	79	62	20	18	-22	-10	-34	11	30
	C-E	40	7	63	138	105	78	7	4	-30	1	-57	62	35
1948	J-M	6	35	114	78	49	26	11	-16	-34	-38	9	10	21
	C-E	-21	54	105	67	78	32	-5	-1	-39	-22	10	14	22
1949	J-M	74	62	44	44	21	-0	9	-21	-30	-17	-27	23	15
	C-E	30	82	70	28	43	18	6	-42	-16	-20	-2	35	19
1950	J-M	134	71	86	100	19	3	24	-12	3	-1	11	41	40
	C-E	151	43	132	117	21	33	15	-7	-21	-6	15	53	46
1951	J-M	63	79	97	89	34	18	10	-30	-30	-13	-6	36	29
	C-E	54	74	94	86	50	29	1	-24	-44	-12	-3	53	30
1952	J-M	105	50	78	87	23	-10	-6	-6	-19	-80	-12	12	18
	C-E	103	68	74	81	48	11	-21	-20	-27	-91	12	14	21
1953	J-M	39	16	64	40	54	8	1	-18	-42	-38	-22	-11	8
	C-E	27	30	55	45	63	10	-3	-21	-43	-48	-10	-18	7
1954	J-M	16	57	74	122	-9	7	-17	-23	-34	65	-9	17	22
	C-E	20	75	92	112	3	17	-22	-11	-37	50	4	17	26
1955	J-M	26	41	91	84	1	-13	8	17	-33	6	-6	2	19
	C-E	35	34	92	68	16	-7	-12	-8	-34	-13	-4	15	15
1956	J-M	8	58	87	83	76	24	26	36	-29	-24	-41	26	28
	C-E	1	65	109	87	93	29	20	16	-38	-15	-48	38	30
1957	J-M	20	41	33	146	27	39	37	-27	-6	-34	-10	47	26
	C-E	28	63	24	123	48	40	28	-29	-14	-34	-7	49	26
1958	J-M	4	-9	35	57	-2	16	38	2	2	-35	-6	-15	7
	C-E	16	9	-10	43	2	43	43	-4	-7	-26	-26	18	8
1959	J-M	55	71	67	93	53	-10	7	-5	-15	8	0	47	31
	C-E	75	90	87	82	59	10	0	-12	-24	-13	-11	71	34
1960	J-M	54	39	17	100	49	22	2	-4	-29	-55	-27	-26	12
	C-E	46	45	40	70	61	51	8	0	-39	-72	-15	-28	14
1961	J-M	-13	45	65	132	11	24	23	13	-4	-34	-16	-10	19
	C-E	8	36	75	135	37	35	24	0	-19	-47	-5	-25	21
1962	J-M	19	19	59	33	4	10	1	-3	-33	-19	-11	-0	6
	C-E	41	36	62	17	11	17	-20	-15	-30	-32	5	-6	7
1963	J-M	-15	-17	93	47	-4	-2	3	-25	-48	-36	-23	-18	-4
	C-E	-19	3	101	68	12	1	-13	-27	-48	-24	-19	-41	-1
1964	J-M	18	-2	81	107	14	-5	-0	5	-46	-43	-34	-3	8
	C-E	23	0	91	81	16	8	-8	-2	-43	-37	-29	22	10
1965	J-M	38	43	61	69	28	6	1	1	-7	-25	-7	36	20
	C-E	14	84	67	47	33	-3	-7	-12	-32	-30	-18	40	15
MEAN	J-M	36	35	69	82	28	13	10	-6	-24	-22	-15	11	18
MEAN	C-E	34	48	75	75	43	26	2	-13	-29	-26	-11	19	20

[a] 1 cfs = 0.028 m^3/sec

[b] J-M denotes values computed by Jones and Meredith

[c] C-E denotes values reported by Corps of Engineers (U.S. Army Engineer Division, 1965c) except values for September, 1964, through December, 1965, which were computed as described in text.

TABLE 31. Net basin supply for Lake Ontario (1000 cfs[a])

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
1946	J-M[b]	22	19	75	26	41	35	5	1	-4	12	11	15	22
	C-E[c]	32	40	80	25	49	38	12	0	6	23	17	22	29
1947	J-M	47	21	64	130	108	109	61	14	3	12	-1	12	48
	C-E	66	41	74	144	109	112	59	10	-5	-5	7	10	52
1948	J-M	-1	25	102	88	64	35	17	4	-11	6	34	12	31
	C-E	15	42	112	87	71	41	21	2	-13	2	25	3	34
1949	J-M	40	52	42	69	21	6	-11	-27	-9	9	7	35	19
	C-E	54	59	52	73	33	20	8	-15	3	1	-2	39	27
1950	J-M	63	27	43	87	36	31	27	22	-12	19	19	31	33
	C-E	82	42	68	114	37	36	24	16	-7	17	35	47	43
1951	J-M	46	61	97	150	45	37	34	3	0	8	21	40	45
	C-E	53	69	103	142	48	45	44	1	4	0	27	40	48
1952	J-M	51	48	70	102	48	18	11	-4	-4	-22	21	28	30
	C-E	63	48	78	101	67	27	14	0	-1	-21	9	27	34
1953	J-M	26	20	67	51	82	26	1	-1	-3	-3	1	13	23
	C-E	33	29	80	51	93	30	17	4	-3	-13	-1	18	28
1954	J-M	9	73	66	114	44	35	-9	7	-1	39	34	40	37
	C-E	16	80	77	111	60	42	3	5	12	33	33	26	41
1955	J-M	21	26	104	109	35	47	-0	13	-21	64	17	12	36
	C-E	35	27	106	101	37	19	7	17	-11	68	17	6	36
1956	J-M	9	31	70	131	89	37	9	8	2	3	2	32	35
	C-E	21	29	77	128	104	36	23	21	0	-2	-3	28	39
1957	J-M	25	39	49	79	48	44	27	-13	12	-10	7	46	29
	C-E	29	37	57	64	45	46	22	-15	7	-22	10	34	26
1958	J-M	13	14	53	89	30	32	29	15	28	14	8	5	27
	C-E	12	20	53	76	38	36	17	3	22	-2	16	12	25
1959	J-M	31	32	65	133	40	19	18	1	-16	22	28	71	37
	C-E	31	43	73	130	56	26	25	-1	-12	13	21	68	39
1960	J-M	34	56	28	174	95	46	9	4	-14	0	15	-8	36
	C-E	37	61	34	157	87	52	10	1	-21	-11	-6	-14	32
1961	J-M	-3	35	65	102	62	63	33	19	4	4	17	17	35
	C-E	-6	38	67	85	61	51	22	1	-9	-17	4	8	25
1962	J-M	13	18	57	87	47	19	-8	1	-4	11	15	13	22
	C-E	16	26	56	84	39	18	8	16	3	10	18	9	25
1963	J-M	-3	-2	63	97	53	14	13	20	-15	-9	33	10	23
	C-E	1	5	64	95	61	18	13	18	-13	-11	20	14	24
1964	J-M	19	6	77	84	43	18	14	11	-21	-13	-3	13	21
	C-E	22	15	79	83	51	24	17	7	-19	-15	4	17	24
1965	J-M	8	53	41	87	37	22	12	17	19	5	40	40	31
	C-E	17	55	49	79	36	26	10	17	4	18	42	40	32
MEAN	J-M	24	33	65	100	53	35	15	6	-3	9	16	24	31
MEAN	C-E	31	40	72	96	59	37	19	5	-3	3	15	23	33

[a] 1 cfs = 0.028 m^3/sec

[b] J-M denotes values computed by Jones and Meredith

[c] C-E denotes values reported by Corps of Engineers (U.S. Army Engineer Division, 1965c) except values for September, 1964, through December, 1965, which were computed as described in text.

Net Basin Supply as a Residual

Equation 4 can be rewritten such that

$$NBS = \Delta S - I + O \mp D \qquad (6)$$

The value of the change in storage term is calculated from the area of the lake and the measured change in the level of the lake over the period of time. The value of the inflow, outflow, and diversion terms are determined from stream gaging records and flow rating curves. The Corps of Engineers (U.S. Army Engineer Division, 1965c) used Eq. 6 to determine the net basin supply values for the period January, 1900, through August, 1964, for all of the lakes. The values for January, 1946, through August, 1964, are listed in Tables 28 through 31.

The end-of-period stages used by the Corps of Engineers (U.S. Army Engineering Division, 1965c) to compute the amount of change in storage for each month for Lakes Superior and Michigan-Huron were derived by averaging the monthly mean lake stages for two consecutive months. The daily mean water level at a lake level gage is obtained by averaging the 24 instantaneous hourly readings of the day. The monthly mean water level is the average of the daily means for the month (U.S. Army Engineer Division, 1965b).

A different method was used to determined the end-of-period stages for Lakes Erie and Ontario. The mean of the Cleveland gage for two days prior and two days following the end of the month was used for the end-of-period level for Lake Erie (U.S. Army Engineer Division, 1965c). The end-of-period level for Lake Ontario was determined by super imposition of the daily mean stages recorded at four gages on the lake (U.S. Army Engineer Division, 1965c).

We then used Eq. 6 to calculate the net basin supply values for September, 1964, through December, 1965. These values are also listed in Tables 28 through 31. The inflow, outflow, diversion, and stage data were supplied by the Lake Survey Center (personal communication, 1971). The end-of-period levels used to compute the amount of change in storage for each month were computed as the average of the monthly mean water level for two consecutive months at the gage at Point Iroquois, Michigan, for Lake Superior and at the gage at Harbor Beach, Michigan, for Lakes Michigan-Huron. The end-of-period levels for Lake Erie were determined by the same procedure as used by the Corps of Engineers. The procedure is described above. The mean of the Oswego, New York, gage reading for two days prior and two days following the end of the month was used as the end-of-period level to compute the amount of change in storage for each month for Lake Ontario.

DISCUSSION OF RESULTS

The average net basin supply values computed for this study are compared in Fig. 5 with the average of the net basin supply amounts reported by the Corps of Engineers for the period 1946 through 1965. The 20 year mean net basin supply computed in this study for Lake Superior is approximately 9 percent greater than the average of the values reported by the Corps of Engineers. The 20 year mean net basin supply values computed in this study for Lakes Michigan-Huron, Erie, and Ontario are respectively approximately 17, 10, and 6 percent less than the average of the values reported by the Corps of Engineers. The 20 year total net basin supply for all lakes is only about 6½ percent less than that reported by the Corps of Engineers.

There is a closer agreement between the monthly net basin supply values computed in this study and those reported by the Corps of Engineers for Lakes Erie and Ontario than there is for Lakes Superior and Michigan-Huron. We believe that part of the difference between the monthly values computed in this study and the values reported by the Corps of Engineers for Lakes Superior and Michigan-Huron is due to the method of determining the end-of-period levels for computing the monthly amount of change in storage in the lake. The end-of-period levels for Lakes Superior and Michigan-Huron were determined by averaging the mean water levels for two consecutive months. In contrast the end-of-period levels for Lakes Ontario and Erie were determined from data for only one or four days near the end of the month. The best agreement is for Lake Ontario for which data from several gages for the last day of the month are used to determine the end-of-period level.

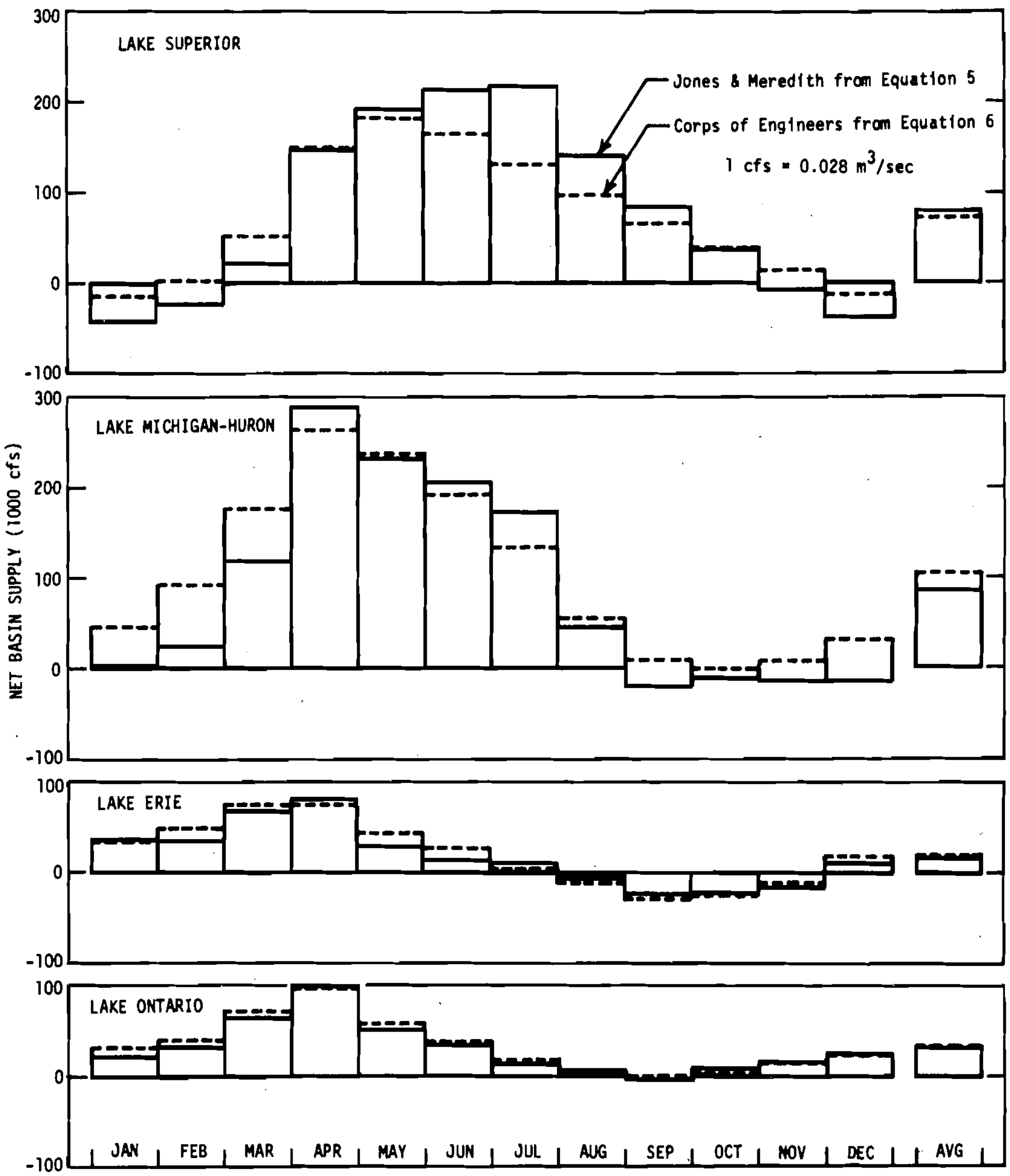

Figure 5. Average net basin supply for 1946 through 1965.

Waters of the Great Lakes are utilized along the lake shores and in the land drainage area for many purposes. Any consumptive use in the land drainage area would have the effect of reducing the amount of water which would occur as surface runoff into the lake. The consumptive use of water in the Ohio portion of land area tributary to Lake Erie has been estimated to be about 2 percent of the surface runoff for this area (U.S. Army Engineer Division, 1965b). This amounts to only about 220 cfs (6.2 m^3/sec) which would have an insignificant effect on the net basin supply values which are computed in units of 1000 cfs (28 m^3/sec).

One factor which has not been considered is the effect of thermal expansion of water on the lake levels. Derecki (1964) estimated that there would be an expansion or contraction of about 1 cm of depth on a lake for a 6°C increase or decrease in the water temperature. Monthly temperature changes of this magnitude occur on each lake during the late spring or early summer and fall of each year. The consideration of thermal expansion would change the values of the ΔS term in Eq. 6 and would have the effect of reducing the net basin supply values reported by the Corps of Engineers for the months when the temperature is increasing and increasing the net basin supply values when the temperature is decreasing. The change in the net basin supply values due to 1 cm change in lake level is 11,000 cfs (308 m^3/sec), 16,000 cfs (448 m^3/sec), 3,500 cfs (98 m^3/sec), and 2,650 cfs (74 m^3/sec) respectively for Lakes Superior, Michigan-Huron, Erie, and Ontario. These changes are significant and would have the effect of bringing the monthly net basin supply values computed for this study and those reported by the Corps of Engineers into closer agreement for Lakes Erie and Ontario. However, it would increase the discrepancy between the monthly values for Lakes Superior and Michigan-Huron. The yearly average would not change, though, because the net temperature change on a yearly basis is insignificant.

SUMMARY AND CONCLUSIONS

The amount of precipitation, evaporation, and runoff into the lake from the surrounding land areas has been determined for each of the Great Lakes for each month of calendar years 1946 through 1965. Even though Lake St. Clair is not usually considered as one of the Great Lakes, the amounts of precipitation on it and the runoff into it for each month of 1946 through 1965 are also presented.

The net basin supply values computed for this study are relatively close to the values reported by the Corps of Engineers. The monthly precipitation, evaporation, and runoff values provide us with a rather complete set of data with which to begin to develop hydrologic models of the lakes.

The groundwater contribution to the net basin supply values was assumed to be insignificant. Not much is known about the groundwater contribution to the lakes and this subject should receive further study.

The effect of thermal expansion on lake levels might also be further studied to determine if the net basin supplies reported by the Corps of Engineers should be changed to account for this phenomenon. Finally and probably most important we feel that the amount of changes in lake volumes should all be computed using a consistent method for determining the end-of-period lake levels. If the effects of thermal expansion and a consistent method for determining the end-of-period lake levels are used to determine the amount of change in storage in the lake, the monthly net basin supply values as computed in this study might be adjusted to those determined from Eq. 6 by adjusting the monthly evaporation values since these are felt to be the least reliable of the computed values.

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