

## GREAT LAKES BEGINNING-OF-MONTH WATER LEVELS AND MONTHLY RATES OF CHANGE OF STORAGE<sup>1</sup>

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**ABSTRACT.** Time series of beginning-of-month water levels and rates of change of lake storage were determined for each of the Great Lakes and Lake St. Clair for 1941-1975 period. The Thiessen polygon procedure was used to compute the beginning-of-month levels because it provides more representative over-all lake levels than straight averaging and requires minimum subjectivity. The effect of crustal movement on the rate of change of lake storage was investigated and found to be negligible. A gage density analysis showed good agreement between various size gage networks with the maximum deviation between networks decreasing with increasing gage density. Thiessen polygon weighting factors are presented for the current gage networks to enable future extension of the time series.

### INTRODUCTION

The need for improved hydrologic data for Great Lakes water resource and scientific studies is increasing as the value of the water resources increases. This study presents a procedure to better quantify beginning-of-month water levels and rates of change in storage of each of the Great Lakes and Lake St. Clair based upon the Thiessen polygon technique. Beginning-of-month levels are necessary to compute the change in storage term of the lakes' hydrologic cycle and are also used for the calibration, verification, and application of Great Lakes water quantity and regulation models.

Previous studies such as the International Great Lakes Level Board (1973) study used straight averaging with some subjective adjustment and only a limited number of the available gages to compute lake levels and changes in storage. In this study the Thiessen polygon procedure was selected as it provides a better representative lake level than straight averaging and requires minimum subjectivity. Since 1950 the number of available water level gages has increased from 25 to 50. The initial study period was comprised of the years 1950-1970 as they contained a sufficient number of water level gages to analyze the effect of the gage density on the begin-

ning-of-month level computations. This period is also significant because it includes the high lake levels of 1952, as well as the record lows of 1964. The recommended procedure is used to develop a data base for the 1941-1975 time period as it is of the greatest current interest to researchers, engineers, and managers in the Great Lakes community.

### METHODOLOGY

The beginning-of-month water levels were computed by the use of a water level gage network on the periphery of the lake. Ideally, the beginning-of-month level should represent the instantaneous level at the beginning of the month. Practically, however, representative instantaneous true water levels are difficult, if not impossible, to measure because of the effect of short-term fluctuations in wind speed and direction and changes in atmospheric pressure over very small time periods. These fluctuations could cause considerable error in computing a true instantaneous level for the lake. This error is lessened by specifying that the beginning-of-month level for each gage shall be equal to the average of the daily mean water levels of the first day of the month and the last day of the preceding month.

The computations procedure set forth by Quinn (1971) consists of applying areally weighted factors

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to water levels for each gage in the network. The weighting factors were computed from Thiessen polygon networks drawn from the various water level gage networks. This is expressed mathematically as

$$L_0 = W_1 L_1 + W_2 L_2 + W_3 L_3 + \dots + W_n L_n$$

for

$$W_1 + W_2 + W_3 + \dots + W_n = 1.0$$

where

$L_0$  is the weighted beginning-of-month water level

$L_1-L_n$  are the beginning-of-month levels at the various gage locations

$W_1-W_n$  are the Thiessen polygon weighting factors for gage locations, 1 to n

n is the number of water level gages in the network.

The basic data consisted of daily mean water levels for the first and last days of the months for each water level gage in operation. These levels were computed from the gages by use of sampling rates that varied from hourly observations in the

current period to some tri-daily observations in the early portion of the study. Gage response times, which are usually less than 1 minute, are sufficient to filter out effects of wind and ship generated waves and to determine longer period lake level variations. The water level gage locations used in the study are shown in Figure 1. Occasional missing gage data were interpolated from existing gages.

The monthly rates of storage changes were computed by multiplying the differences between two consecutive beginning-of-month levels by the area of the lake given in Table 1 and dividing by the number of seconds in the month.

TABLE 1. Lake areas.

Lake	Area, km <sup>2</sup>
Lake Superior	82,100
Lake Michigan	57,700
Lake Huron	59,500
Lake St. Clair	1,110
Lake Erie	25,700
Lake Ontario	19,000

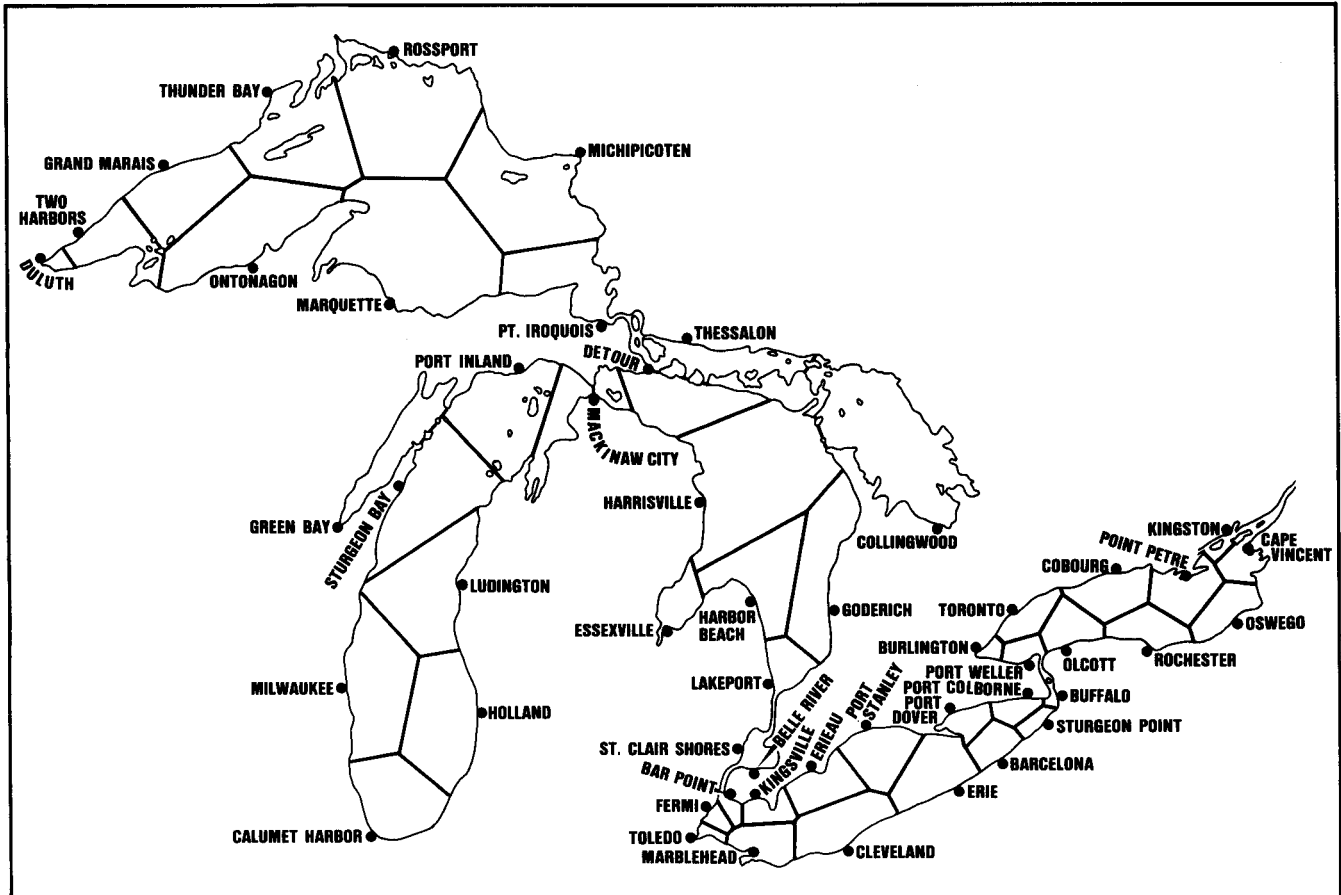


FIG. 1. Gage locations and Thiessen polygon networks.



TABLE 3. Lake Superior beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APP	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	183.00	182.92	182.85	182.78	182.94	183.02	183.12	183.16	183.18	183.30	183.33	183.24
1942	183.16	183.08	183.01	183.02	183.06	183.21	183.23	183.26	183.29	183.26	183.29	183.28
1943	183.19	183.14	183.19	183.08	183.11	183.26	183.45	183.44	183.43	183.34	183.26	183.17
1944	183.04	182.96	182.89	182.87	182.91	183.07	183.27	183.37	183.41	183.39	183.26	183.19
1945	183.10	183.04	183.01	183.08	183.18	183.19	183.24	183.28	183.33	183.32	183.25	183.18
1946	183.11	183.06	183.01	183.04	183.07	183.13	183.22	183.25	183.25	183.27	183.30	183.24
1947	183.16	183.06	183.00	182.93	183.04	183.19	183.39	183.38	183.37	183.34	183.25	183.16
1948	183.04	182.96	182.87	182.86	183.03	183.05	183.08	183.13	183.18	183.13	183.06	183.06
1949	182.99	182.95	182.90	182.84	182.91	183.03	183.14	183.26	183.24	183.21	183.23	183.16
1950	183.08	183.05	182.99	182.97	183.05	183.33	183.44	183.49	183.49	183.45	183.42	183.37
1951	183.26	183.17	183.17	183.18	183.29	183.37	183.44	183.44	183.47	183.48	183.46	183.36
1952	183.30	183.24	183.15	183.11	183.21	183.22	183.33	183.47	183.50	183.39	183.22	183.12
1953	183.04	182.97	182.93	182.92	182.99	183.15	183.27	183.33	183.35	183.26	183.15	183.06
1954	182.98	182.91	182.87	182.82	182.95	183.13	183.26	183.25	183.19	183.14	183.08	183.02
1955	182.92	182.84	182.78	182.78	182.91	182.97	183.01	183.06	183.10	183.11	183.13	183.08
1956	182.99	182.92	182.83	182.75	182.79	182.93	183.00	183.10	183.12	183.09	183.02	182.96
1957	182.90	182.75	182.75	182.74	182.86	182.94	183.05	183.11	183.10	183.10	183.03	183.02
1958	182.94	182.87	182.81	182.76	182.81	182.83	182.94	183.03	183.08	183.10	183.06	183.04
1959	182.95	182.87	182.83	182.79	182.83	183.00	183.07	183.10	183.23	183.29	183.25	183.13
1960	183.03	182.97	182.89	182.83	183.00	183.18	183.20	183.20	183.18	183.12	183.05	183.04
1961	182.91	182.83	182.81	182.81	182.86	182.96	183.01	183.03	183.02	183.05	183.04	182.99
1962	182.92	182.83	182.80	182.77	182.81	182.96	183.00	183.03	183.09	183.09	183.03	182.94
1963	182.86	182.79	182.74	182.78	182.85	182.90	183.04	183.05	183.08	183.07	183.03	182.96
1964	182.87	182.83	182.74	182.68	182.82	183.00	183.11	183.12	183.16	183.21	183.11	183.04
1965	182.96	182.86	182.80	182.78	182.85	183.00	183.04	183.05	183.06	183.09	183.07	183.05
1966	183.00	182.93	182.87	182.90	182.95	183.06	183.11	183.12	183.17	183.10	183.08	183.02
1967	182.97	182.92	182.86	182.85	182.99	183.03	183.13	183.13	183.15	183.08	183.08	183.01
1968	182.93	182.85	182.77	182.79	182.93	183.01	183.20	183.35	183.37	183.41	183.40	183.26
1969	183.20	183.19	183.12	183.04	183.14	183.19	183.22	183.21	183.21	183.12	183.09	183.03
1970	182.94	182.90	182.83	182.79	182.89	183.08	183.16	183.26	183.22	183.23	183.28	183.26
1971	183.17	183.08	183.08	183.08	183.14	183.27	183.33	183.33	183.31	183.28	183.27	183.22
1972	183.12	183.06	183.03	183.04	183.10	183.21	183.21	183.27	183.36	183.35	183.24	183.17
1973	183.08	183.02	182.96	183.02	183.08	183.23	183.33	183.39	183.45	183.37	183.33	183.25
1974	183.16	183.10	183.04	182.97	183.08	183.18	183.29	183.36	183.42	183.41	183.38	183.35
1975	183.26	183.22	183.17	183.11	183.12	183.20	183.29	183.32	183.27	183.25	183.20	183.23

TABLE 4. Lake Michigan beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	175.88	175.85	175.83	175.83	175.93	175.99	175.96	175.93	175.83	175.83	175.96	175.96
1942	175.95	175.94	175.90	176.00	176.12	176.28	176.29	176.31	176.23	176.18	176.09	176.07
1943	176.04	176.00	176.03	176.16	176.25	176.47	176.62	176.68	176.69	176.63	176.57	176.47
1944	176.35	176.32	176.33	176.31	176.41	176.45	176.50	176.49	176.42	176.45	176.34	176.29
1945	176.13	176.07	176.10	176.19	176.24	176.45	176.52	176.58	176.49	176.49	176.35	176.42
1946	176.39	176.34	176.36	176.56	176.49	176.56	176.57	176.53	176.38	176.32	176.18	176.15
1947	176.07	176.15	176.02	176.06	176.30	176.43	176.55	176.59	176.59	176.52	176.55	176.28
1948	176.41	176.22	176.27	176.38	176.44	176.50	176.50	176.42	176.42	176.30	176.14	176.05
1949	175.95	175.86	175.95	176.07	176.09	176.12	176.17	176.13	176.04	175.92	175.79	175.69
1950	175.76	175.75	175.74	175.88	176.04	176.09	176.14	176.28	176.26	176.22	176.18	176.03
1951	176.09	176.13	176.20	176.26	176.55	176.60	176.63	176.72	176.82	176.70	176.69	176.72
1952	176.71	176.73	176.74	176.79	176.95	177.01	177.06	177.02	177.08	176.93	176.74	176.70
1953	176.66	176.55	176.61	176.70	176.85	176.88	176.89	176.90	176.84	176.77	176.67	176.56
1954	176.39	176.36	176.40	176.42	176.62	176.67	176.75	176.77	176.71	176.71	176.78	176.70
1955	176.66	176.60	176.58	176.56	176.66	176.69	176.68	176.63	176.47	176.34	176.29	176.15
1956	176.10	176.08	176.09	176.13	176.23	176.33	176.38	176.41	176.40	176.28	176.22	176.08
1957	175.99	175.95	175.97	175.98	176.05	176.13	176.15	176.21	176.16	176.04	176.02	175.93
1958	176.00	175.94	175.98	175.92	175.88	175.94	175.92	175.95	175.82	175.71	175.71	175.54
1959	175.57	175.50	175.54	175.63	175.80	175.95	175.94	175.89	175.97	175.90	175.87	175.88
1960	175.95	175.94	175.95	175.98	176.16	176.38	176.49	176.52	176.54	176.48	176.44	176.29
1961	176.23	176.13	176.10	176.14	176.20	176.22	176.28	176.31	176.20	176.21	176.05	176.08
1962	175.94	175.95	175.97	176.03	176.13	176.15	176.19	176.13	176.09	176.00	175.92	175.81
1963	175.71	175.64	175.64	175.74	175.80	175.85	175.86	175.84	175.79	175.74	175.64	175.53
1964	175.41	175.42	175.32	175.38	175.54	175.57	175.56	175.59	175.55	175.55	175.47	175.44
1965	175.39	175.38	175.48	175.51	175.67	175.81	175.82	175.84	175.83	175.92	175.82	175.81
1966	175.86	175.81	175.88	176.00	176.06	176.08	176.11	176.04	176.03	175.87	175.78	175.80
1967	175.86	175.87	175.84	175.92	176.15	176.19	176.30	176.30	176.26	176.18	176.13	176.12
1968	176.05	176.09	176.08	176.07	176.17	176.25	176.35	176.33	176.41	176.34	176.36	176.26
1969	176.21	176.28	176.29	176.23	176.45	176.59	176.71	176.77	176.70	176.58	176.57	176.43
1970	176.47	176.35	176.34	176.34	176.46	176.55	176.57	176.62	176.52	176.56	176.53	176.48
1971	176.46	176.38	176.38	176.55	176.64	176.74	176.77	176.75	176.77	176.70	176.59	176.57
1972	176.55	176.47	176.49	176.47	176.65	176.72	176.77	176.80	176.90	176.85	176.84	176.72
1973	176.79	176.87	176.76	176.93	177.02	177.07	177.12	177.13	177.08	177.01	176.90	176.80
1974	176.76	176.72	176.77	176.83	176.94	177.04	177.10	177.07	176.97	176.89	176.81	176.84
1975	176.65	176.70	176.64	176.70	176.86	176.91	176.99	176.93	176.99	176.80	176.67	176.59

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TABLE 5. Lake Huron beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	175.87	175.87	175.86	175.80	175.93	175.95	175.96	175.96	175.89	175.87	175.85	175.93
1942	175.88	175.91	175.92	176.03	176.07	176.19	176.33	176.31	176.22	176.20	176.17	176.08
1943	176.04	176.66	176.11	176.17	176.30	176.42	176.65	176.70	176.69	176.61	176.49	176.52
1944	176.40	176.40	176.34	176.38	176.36	176.43	176.53	176.50	176.42	176.40	176.30	176.30
1945	176.19	176.19	176.13	176.18	176.30	176.39	176.56	176.53	176.49	176.44	176.42	176.40
1946	176.36	176.35	176.34	176.40	176.45	176.47	176.56	176.52	176.46	176.39	176.30	176.17
1947	176.10	176.02	176.07	176.04	176.25	176.45	176.56	176.63	176.57	176.55	176.45	176.45
1948	176.23	176.21	176.19	176.30	176.46	176.51	176.55	176.56	176.41	176.27	176.19	176.13
1949	176.11	176.06	176.03	175.96	176.05	176.09	176.16	176.19	176.09	175.97	175.90	175.82
1950	175.71	175.77	175.83	175.81	176.00	176.08	176.20	176.22	176.23	176.21	176.14	176.21
1951	176.11	176.13	176.14	176.24	176.46	176.57	176.65	176.75	176.67	176.67	176.77	176.74
1952	176.69	176.77	176.74	176.75	176.92	176.98	176.99	177.10	177.03	176.96	176.77	176.76
1953	176.68	176.69	176.62	176.65	176.67	176.78	176.89	176.90	176.88	176.74	176.66	176.55
1954	176.52	176.42	176.43	176.45	176.56	176.60	176.76	176.76	176.73	176.70	176.79	176.77
1955	176.63	176.58	176.54	176.56	176.68	176.70	176.68	176.63	176.60	176.38	176.26	176.25
1956	176.15	176.10	176.09	176.11	176.21	176.37	176.36	176.40	176.39	176.31	176.17	176.12
1957	176.11	176.11	176.05	175.95	176.04	176.10	176.22	176.23	176.11	176.10	175.99	176.01
1958	175.95	175.96	175.88	175.91	175.98	175.89	175.92	175.93	175.92	175.89	175.76	175.71
1959	175.51	175.56	175.54	175.59	175.79	175.87	175.88	175.93	175.93	175.89	175.92	175.93
1960	175.91	175.93	175.95	175.93	176.10	176.37	176.49	176.56	176.54	176.47	176.27	176.40
1961	176.20	176.13	176.10	176.12	176.19	176.19	176.24	176.24	176.22	176.20	176.22	176.06
1962	176.03	175.98	175.99	176.01	176.05	176.16	176.16	176.15	176.08	175.99	175.91	175.78
1963	175.71	175.62	175.63	175.66	175.76	175.81	175.81	175.83	175.80	175.71	175.64	175.60
1964	175.45	175.38	175.37	175.35	175.40	175.52	175.55	175.55	175.56	175.51	175.42	175.41
1965	175.38	175.40	175.36	175.43	175.64	175.73	175.79	175.76	175.78	175.85	175.91	175.90
1966	175.94	175.93	175.88	175.95	176.04	176.05	176.06	176.03	175.98	175.94	175.82	175.87
1967	175.85	175.84	175.88	175.86	176.03	176.12	176.27	176.27	176.23	176.14	176.09	176.05
1968	176.12	176.01	176.08	176.09	176.20	176.22	176.30	176.35	176.33	176.42	176.26	176.28
1969	176.31	176.28	176.22	176.28	176.37	176.47	176.67	176.74	176.69	176.56	176.46	176.52
1970	176.33	176.36	176.32	176.30	176.38	176.47	176.54	176.60	176.56	176.56	176.48	176.40
1971	176.40	176.41	176.49	176.42	176.60	176.66	176.73	176.74	176.68	176.61	176.59	176.49
1972	176.55	176.46	176.40	176.46	176.56	176.68	176.73	176.79	176.85	176.86	176.74	176.78
1973	176.71	176.63	176.69	176.78	176.84	177.03	177.08	177.03	177.04	176.90	176.91	176.82
1974	176.75	176.80	176.73	176.75	176.91	176.98	177.07	177.08	177.02	176.89	176.76	176.65
1975	176.68	176.63	176.66	176.68	176.72	176.87	176.92	176.91	176.82	176.81	176.65	176.63

TABLE 6. Lake St. Clair beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	174.62	174.05	174.10	174.35	174.48	174.54	174.54	174.53	174.43	174.37	174.37	174.35
1942	174.39	174.21	173.76	174.52	174.34	174.81	174.83	174.86	174.79	174.74	174.64	174.67
1943	174.90	174.32	174.59	174.75	174.89	175.12	175.19	175.25	175.17	175.19	175.03	174.91
1944	174.66	174.59	174.48	174.75	174.94	175.01	175.06	174.99	174.89	174.91	174.77	174.62
1945	174.74	174.27	174.54	174.77	174.86	175.06	175.13	175.13	175.02	175.11	174.97	174.91
1946	174.99	174.35	174.41	174.98	174.92	175.03	175.11	175.08	174.94	174.84	174.79	174.63
1947	174.66	174.60	174.42	174.74	174.97	175.13	175.20	175.21	175.19	175.09	175.02	174.81
1948	174.92	174.71	174.86	175.04	175.04	175.13	175.13	175.07	174.60	174.86	174.71	174.64
1949	175.13	175.03	174.97	174.99	174.75	174.78	174.81	174.77	174.64	174.57	174.45	174.33
1950	174.44	174.63	174.39	174.74	174.92	174.84	174.85	174.86	174.84	174.78	174.71	174.70
1951	174.69	174.60	174.85	175.00	175.15	175.17	175.21	175.22	175.19	175.10	175.08	175.06
1952	175.28	175.06	175.25	175.28	175.41	175.44	175.52	175.47	175.44	175.32	175.10	175.04
1953	175.04	175.05	175.01	175.13	175.22	175.28	175.32	175.31	175.28	175.14	175.06	174.93
1954	174.82	174.41	174.86	175.05	175.20	175.15	175.22	175.20	175.16	175.10	175.18	175.09
1955	175.17	174.98	175.14	175.18	175.24	175.23	175.22	175.17	175.08	174.93	174.83	174.70
1956	174.72	173.93	174.23	174.68	175.00	175.00	175.03	175.06	175.06	174.92	174.79	174.62
1957	174.62	174.32	174.63	174.65	174.84	174.85	174.87	174.92	174.82	174.75	174.64	174.52
1958	174.64	173.99	174.26	174.32	174.50	174.55	174.58	174.63	174.55	174.49	174.42	174.26
1959	174.19	174.05	174.14	174.53	174.62	174.69	174.66	174.61	174.61	174.53	174.46	174.43
1960	174.58	174.23	174.59	174.75	174.78	174.94	175.05	175.06	175.04	174.98	174.80	174.64
1961	174.66	174.46	174.73	174.76	175.00	174.93	174.95	174.96	174.88	174.79	174.65	174.61
1962	174.67	174.17	174.36	174.70	174.69	174.70	174.75	174.70	174.66	174.61	174.50	174.46
1963	174.57	174.21	174.19	174.55	174.57	174.52	174.52	174.49	174.43	174.34	174.27	174.21
1964	174.21	173.87	173.84	174.21	174.35	174.37	174.32	174.31	174.31	174.22	174.10	174.04
1965	174.07	173.80	173.95	174.32	174.42	174.47	174.50	174.44	174.45	174.42	174.38	174.25
1966	174.49	174.36	174.35	174.58	174.72	174.71	174.74	174.68	174.64	174.50	174.38	174.43
1967	174.58	174.60	174.52	174.67	174.75	174.84	174.96	174.89	174.85	174.74	174.71	174.74
1968	174.82	174.77	174.74	174.86	174.83	174.99	175.07	175.00	174.93	174.89	174.78	174.85
1969	174.85	174.99	174.90	174.93	175.10	175.21	175.27	175.35	175.25	175.13	175.00	174.88
1970	174.62	174.77	174.75	174.94	174.99	175.08	175.13	175.15	175.09	175.07	174.98	174.95
1971	175.01	174.68	174.98	175.07	175.12	175.20	175.23	175.20	175.24	175.13	175.04	174.98
1972	175.02	175.05	174.93	175.07	175.16	175.28	175.33	175.35	175.34	175.31	175.30	175.27
1973	175.34	175.41	175.33	175.57	175.53	175.58	175.68	175.61	175.53	175.45	175.29	175.29
1974	175.37	175.42	175.37	175.46	175.52	175.58	175.59	175.53	175.47	175.34	175.21	175.28
1975	175.21	175.31	175.34	175.34	175.38	175.41	175.48	175.41	175.48	175.35	175.19	175.04

TABLE 7. Lake Erie beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	173.67	173.62	173.49	173.49	173.57	173.62	173.66	173.63	173.54	173.41	173.39	173.35
1942	173.37	173.32	173.33	173.59	173.77	173.88	173.92	173.95	173.86	173.77	173.74	173.76
1943	173.81	173.76	173.75	173.87	174.04	174.36	174.36	174.38	174.24	174.10	174.03	173.96
1944	173.85	173.70	173.71	173.82	174.10	174.20	174.20	174.06	173.98	173.91	173.78	173.75
1945	173.72	173.61	173.63	173.92	174.03	174.18	174.31	174.26	174.14	174.15	174.11	174.03
1946	173.95	173.92	173.81	173.98	173.98	174.10	174.24	174.16	174.01	173.90	173.82	173.74
1947	173.68	173.72	173.62	173.75	174.19	174.38	174.45	174.36	174.31	174.13	174.05	173.92
1948	173.90	173.82	173.87	174.14	174.24	174.35	174.35	174.25	174.13	173.98	173.84	173.80
1949	173.75	173.85	173.92	173.90	173.96	174.00	173.98	173.92	173.80	173.67	173.58	173.50
1950	173.53	173.84	173.88	174.03	174.19	174.13	174.08	174.04	173.94	173.86	173.81	173.85
1951	173.88	173.91	174.03	174.23	174.33	174.36	174.36	174.29	174.17	174.04	173.98	174.00
1952	174.07	174.31	174.35	174.48	174.58	174.60	174.53	174.44	174.37	174.25	174.03	173.98
1953	174.01	174.10	174.07	174.18	174.22	174.35	174.38	174.32	174.25	174.09	173.98	173.94
1954	173.87	173.81	173.90	174.08	174.32	174.27	174.27	174.20	174.13	174.03	174.17	174.14
1955	174.13	174.14	174.17	174.35	174.43	174.36	174.30	174.22	174.16	174.01	173.94	173.85
1956	173.78	173.58	173.58	173.82	173.99	174.22	174.21	174.17	174.18	174.00	173.88	173.72
1957	173.75	173.67	173.70	173.75	174.03	174.06	174.12	174.09	173.93	173.85	173.72	173.66
1958	173.77	173.61	173.51	173.57	173.63	173.64	173.74	173.78	173.74	173.69	173.54	173.47
1959	173.38	173.43	173.53	173.68	173.87	173.92	173.86	173.79	173.72	173.59	173.59	173.56
1960	173.68	173.74	173.75	173.79	173.97	174.07	174.16	174.14	174.10	173.98	173.83	173.76
1961	173.64	173.59	173.71	173.89	174.20	174.18	174.17	174.13	174.07	173.93	173.77	173.71
1962	173.64	173.61	173.60	173.78	173.83	173.83	173.86	173.82	173.77	173.69	173.62	173.62
1963	173.55	173.45	173.39	173.64	173.73	173.74	173.70	173.65	173.57	173.48	173.41	173.35
1964	173.27	173.28	173.28	173.46	173.65	173.63	173.60	173.53	173.50	173.38	173.25	173.18
1965	173.24	173.28	173.37	173.53	173.67	173.69	173.67	173.61	173.57	173.53	173.47	173.46
1966	173.56	173.54	173.60	173.72	173.85	173.88	173.89	173.84	173.78	173.64	173.48	173.58
1967	173.72	173.71	173.67	173.80	173.95	174.01	174.04	174.02	173.94	173.86	173.80	173.81
1968	173.92	173.95	173.96	174.05	174.07	174.16	174.21	174.14	174.07	173.98	173.85	173.89
1969	173.97	174.00	174.03	174.05	174.29	174.42	174.43	174.52	174.36	174.21	174.03	174.04
1970	174.02	173.86	173.86	173.99	174.15	174.20	174.22	174.24	174.13	174.07	174.03	174.00
1971	174.03	173.94	174.06	174.18	174.22	174.28	174.29	174.23	174.18	174.14	174.06	173.97
1972	174.04	174.02	174.02	174.20	174.37	174.42	174.47	174.44	174.39	174.40	174.30	174.40
1973	174.49	174.50	174.44	174.72	174.74	174.74	174.81	174.71	174.60	174.43	174.35	174.29
1974	174.33	174.44	174.48	174.65	174.69	174.74	174.71	174.61	174.51	174.37	174.23	174.26
1975	174.30	174.36	174.46	174.52	174.52	174.53	174.57	174.46	174.53	174.42	174.30	174.23

TABLE 8. Lake Ontario beginning-of-month levels in meters.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1941	74.33	74.35	74.36	74.40	74.50	74.43	74.35	74.31	74.18	74.05	74.01	74.00
1942	74.01	73.98	73.98	74.32	74.51	74.63	74.62	74.59	74.48	74.42	74.35	74.38
1943	74.44	74.53	74.64	74.88	74.99	75.39	75.43	75.34	75.22	75.03	74.93	74.86
1944	74.71	74.61	74.57	74.62	74.84	74.95	75.31	74.94	74.77	74.66	74.49	74.41
1945	74.38	74.39	74.44	74.81	74.96	75.18	75.20	75.17	75.01	75.00	75.05	75.08
1946	75.02	74.97	74.96	75.06	74.97	74.99	74.98	74.89	74.76	74.66	74.61	74.54
1947	74.52	74.65	74.61	74.73	75.02	75.27	75.51	75.52	75.35	75.13	74.94	74.80
1948	74.73	74.69	74.77	75.07	75.22	75.33	75.30	75.18	75.01	74.80	74.66	74.63
1949	74.54	74.63	74.78	74.82	74.93	74.88	74.77	74.65	74.49	74.39	74.27	74.19
1950	74.26	74.49	74.60	74.79	75.01	75.02	74.99	74.91	74.81	74.64	74.58	74.62
1951	74.67	74.78	74.94	75.15	75.47	75.46	75.42	75.36	75.15	74.98	74.84	74.83
1952	74.88	75.02	75.14	75.32	75.55	75.65	75.55	75.41	75.24	75.10	74.88	74.82
1953	74.81	74.81	74.81	74.99	75.05	75.21	75.15	75.03	74.90	74.76	74.61	74.51
1954	74.52	74.48	74.66	74.82	75.11	75.16	75.12	74.95	74.83	74.72	74.76	74.81
1955	74.85	74.85	74.85	75.17	75.38	75.34	75.20	75.01	74.94	74.75	74.86	74.80
1956	74.69	74.57	74.51	74.64	74.95	75.17	75.09	74.97	74.91	74.76	74.60	74.47
1957	74.43	74.41	74.43	74.47	74.61	74.69	74.73	74.71	74.53	74.46	74.28	74.21
1958	74.29	74.28	74.26	74.35	74.45	74.44	74.43	74.37	74.27	74.24	74.12	74.08
1959	74.00	74.10	74.21	74.43	74.72	74.72	74.59	74.46	74.30	74.11	74.07	74.08
1960	74.25	74.33	74.49	74.48	74.89	75.02	74.94	74.77	74.57	74.40	74.35	74.34
1961	74.23	74.12	74.16	74.38	74.69	74.85	74.85	74.75	74.62	74.45	74.29	74.23
1962	74.21	74.16	74.13	74.29	74.61	74.77	74.78	74.72	74.67	74.56	74.50	74.45
1963	74.41	74.26	74.12	74.33	74.65	74.89	74.91	74.84	74.76	74.54	74.30	74.24
1964	74.13	73.95	73.77	73.97	74.28	74.49	74.54	74.49	74.40	74.18	73.95	73.77
1965	73.69	73.67	73.81	73.97	74.26	74.45	74.55	74.52	74.47	74.40	74.37	74.42
1966	74.43	74.38	74.40	74.58	74.60	74.70	74.79	74.70	74.64	74.51	74.35	74.35
1967	74.44	74.48	74.40	74.44	74.72	74.90	74.99	75.00	74.90	74.80	74.74	74.69
1968	74.57	74.53	74.51	74.69	74.73	74.82	74.94	74.89	74.75	74.60	74.42	74.44
1969	74.47	74.54	74.51	74.53	74.79	74.97	75.01	74.88	74.66	74.42	74.29	74.29
1970	74.30	74.24	74.28	74.37	74.67	74.78	74.82	74.84	74.68	74.54	74.47	74.42
1971	74.44	74.41	74.47	74.60	74.83	74.84	74.83	74.73	74.65	74.51	74.38	74.26
1972	74.34	74.43	74.49	74.66	74.94	75.10	75.17	75.17	75.01	74.76	74.54	74.59
1973	74.82	74.99	75.03	75.33	75.55	75.59	75.49	75.24	75.01	74.72	74.58	74.48
1974	74.60	74.83	74.90	74.99	75.25	75.46	75.40	75.24	74.96	74.69	74.41	74.37
1975	74.38	74.49	74.66	74.79	74.90	74.92	74.91	74.76	74.65	74.60	74.50	74.42

TABLE 9. Effect of network size on beginning-of-month levels for Lake Michigan.

Period	No. of observations	Networks compared	Mean Dev* (cm)	Std. Dev* (cm)	Max. Dev* (cm)
1946-1972	324	3 gage vs 4 gage	0	1	5
1950-1972	275	4 gage vs 5 gage	0	1	3
1955-1972	216	5 gage vs 6 gage	0	0	1
1960-1972	312	6 gage vs 7 gage	0	1	2
1965-1972	288	7 gage vs 8 gage	0	0	1

al data observations were added to the 1960-1972 period to make it statistically compatible with the other periods. These additional observations consisted of mid-month and one-third-month levels obtained by the same procedure as the beginning-of-month levels. The results of the analysis of Lake Michigan are presented as an example in Table 9. The table shows good agreement between the networks with the maximum deviation between networks decreasing with increasing density, as is expected. Similar results were found for the other lakes.

### Changes-in-Storage

A time series of monthly changes in storage was generated for each lake by the equation

$$\Delta S_t = \frac{(L_{o,t+1} - L_{o,t})^A}{86,400 \times D}$$

where

$\Delta S_t$  is the change in storage for month t in m<sup>3</sup>/sec

$L_{o,t}$  is the beginning-of-month lake level for month t in m

$L_{o,t+1}$  is the beginning-of-month lake level for month (t+1) in m

A is the lake area in m<sup>2</sup>

D is the number of days in month t

86,400 is the number of seconds per day

The resulting monthly rates of change of storage for each lake are available from the publications listed in the preceding section. During the years when the gage density changed, the monthly rates of change in storage may not agree exactly with the recommended beginning-of-month levels. This is because the change in storage was computed from temporally uniform gage densities.

### CONCLUSIONS

This study presents a time series of beginning-of-month levels and rates of change in storage of sufficient quality for both scientific and operational studies. Thiessen polygon weighting factors are presented for the current gage networks to enable future extension of the time series.

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