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NOTE

ESTIMATES OF LAKE ST. CLAIR EVAPORATION[1]

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ABSTRACT. Monthly evaporation from Lake St. Clair was determined for individual years of a 26-year period, 1950-75, by the mass transfer method applied to available land-based data adjusted to overwater conditions. Because of extensive ice cover on the lake, the overwater mass transfer results were adjusted for the effect of ice cover during winter. The ice-cover adjustment reduced the average annual evaporation by 100 mm to 750 mm. The mass transfer method is the only technique that permits operational evaporation estimates from this lake with presently available data and it is also the approach most amenable to future improvements.

INTRODUCTION

Evaporation from Lake St. Clair is needed for a variety of Great Lakes hydrology studies, particularly those dealing with the water balance of the St. Clair River-Lake St. Clair-Detroit River system. A typical example is the recent international (United States-Canada) coordination of monthly St. Clair and Detroit River flows by the River Flow Subcommittee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data (Derecki 1978a). Comparison and coordination of these flows requires independently determined long-term monthly values of overwater precipitation, drainage basin runoff, lake evaporation, and lake storage. Summation of these variables constitutes the hydrologic balance between the two rivers and permits transfers of the river flows (Quinn 1976). This note summarizes the results of a study conducted to determine long-term monthly evaporation from Lake St. Clair for the 1950-75 period (Derecki 1978b).

METHOD

When availability of data is considered, the only technique that permits operational evaporation estimates from Lake St. Clair is the mass transfer method. Other feasible approaches, such as water or energy budgets, cannot be used on this lake because of lake characteristics or data limitations. Water budget computations are meaningless because of extremely large inflow-outflow volumes in relation to the size of the lake, which make evaporation roughly equivalent to 1 percent of the inflow or outflow and require accuracy beyond practical limits. Data requirements for the energy budget method are even more stringent and preclude computation of long-term monthly evaporation by individual years.

Lake evaporation determined by the mass transfer method is a function of the overwater wind speed and the vapor pressure difference between the saturated air at the water surface and the air above. Lake St. Clair evaporation was computed by the modified Lake Hefner equation (U.S. Geological Survey 1954), which for metric units and climatological data standardized at the 8-m level becomes

$$E = 0.097\,(e_s - e_a)\,U_a$$

where evaporation (E) is in millimeters per day, saturated vapor pressure (e_s) and air vapor pressure (e_a) are in millibars, and the wind speed (U_a) is in

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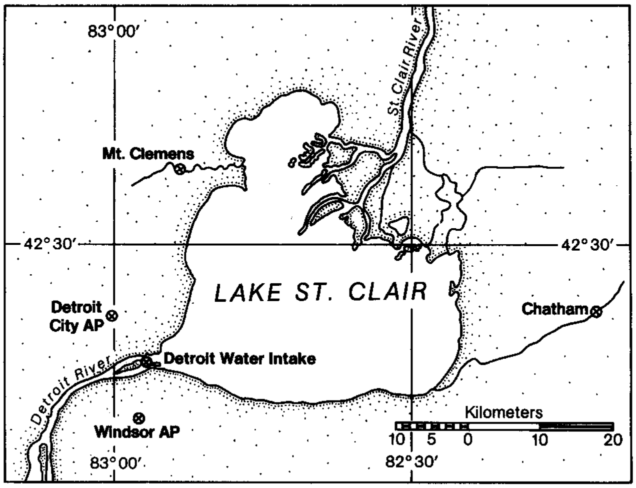

FIG. 1. Lake St. Clair and location of data stations.

meters per second. Equation modification involves adjustment of basic data to overwater conditions, since all long-term data are restricted to land stations (Figure 1).

The Lake Hefner mass transfer equation was tested on Lake Mead (U.S. Geological Survey 1958) and adopted for use on the Great Lakes by Richards (1964), who modified the basic equation by incorporating monthly lake/land wind and humidity ratios. This approach was used in subsequent studies to compute long-term Great Lakes evaporation for monthly periods (Richards and Irbe 1969, Derecki 1976). In the present study the constant monthly ratios are replaced by variable adjustments to reflect changes in monthly weather conditions from year to year. The land to lake adjustments for wind and humidity (air and dew point temperaturues) are based on air stability and overwater fetch criteria applicable to Lake St. Clair. These adjustments were obtained from the results presented by Phillips and Irbe (1978), which were determined from the International Field Year on the Great Lakes (IFYGL) observations conducted on Lake Ontario during 1972-73.

Determination of saturation vapor pressure and air stability, defined as air-water temperature difference ($T_a - T_w$), requires water surface temperatures. The only sources of long-term water temperature records on Lake St. Clair are the municipal water intakes. These subsurface records were adjusted to represent lake surface conditions by using water surface data from shipboard observations. The water surface temperature adjustments were derived from water temperature surveys conducted by the Great Lakes Environmental Research Laboratory (GLERL), NOAA, during the 1974 open-water season. Lake surface temperatures during winter were estimated from ice-cover observations and air temperatures.

Because of extensive ice cover on Lake St. Clair, winter evaporation computed by the mass transfer method for open-water conditions may be considerably overestimated. The ice-cover reduction of evaporation is included by considering both open-water and ice-covered areas of the lake during winter. Partial suppression of evaporation by ice cover was evaluated by considering the ice cover effects on air stability (wind and dew point temperature) and vapor pressure. Monthly lake ice cover was determined from ice surveys conducted regularly since the winter of 1961 by the Lake Survey Center (presently GLERL), NOAA, and Ice Forecast Central in Canada. Estimates of ice cover prior to 1961 were obtained from monthly ice cover-air temperature relationships derived from the available data (Derecki 1978b).

The mass transfer coefficient represents the Lake Hefner calibrated constant, and its use for Lake St. Clair may be questionable. In subsequent IFYGL evaporation studies, Quinn and den Hartog (1979) found considerably lower values for Lake Ontario. Their 3-m level mass transfer coefficient (M) from the regression is 0.107 (Figure 2), compared to the Lake Hefner value of 0.124. However, as pointed out in their study, the trend of the data points is clearly curvilinear and the use of coefficient M will produce underestimates during high evaporation periods and overestimates during low evaporation periods. Since low evaporation (including condensation) is clustered around zero. its over-

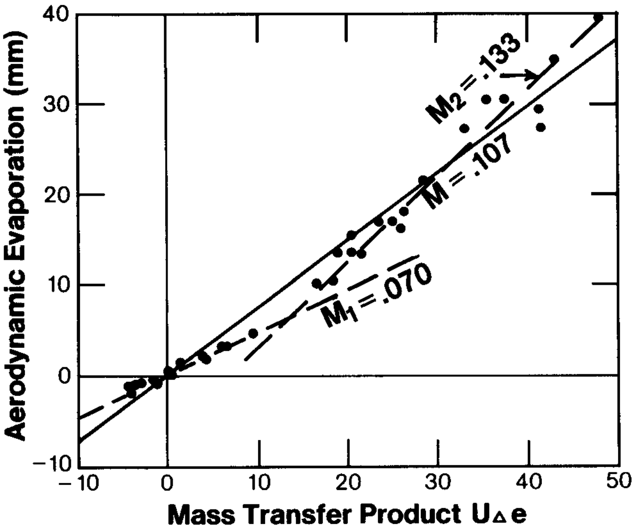

FIG. 2. Mass transfer coefficients derived from Lake Ontario IFYGL results.

estimation will have little effect on the net total, but underestimation during high evaporation periods is significant, with a resulting reduction of net evaporation values. Approximating the curve with two straight lines (dashed) eliminates the bias, with resulting constants of 0.070 and 0.133 for the low and high evaporation portions of the curve (M_1 and M_2), respectively. The weighted average of these two values for the indicated range gives a weighted coefficient of about 0.120, which is much closer to the Lake Hefner constant of 0.124. For the 8-m level computations, used in the present study, this Lake Hefner constant is equivalent to 0.097. Data and calculation details are given in the evaporation report (Derecki 1978b).

RESULTS

The mass transfer evaporation computed by the Lake Hefner equation modified for lake surface conditions is given in Table 1. Adjustment of the wind speed and vapor pressure difference to the standard height of 8 m produced a net computed increase in evaporation of 10 percent. The average annual evaporation from Lake St. Clair for the 1950-75 period is 748 mm, with annual extremes of 533 mm in 1956 and 967 mm in 1958. Seasonal distribution of the mass transfer evaporation estimates, indicating average, maximum, and minimum monthly values, is shown in Figure 3. The average monthly evaporation varies from 17 mm in February to 134 mm in September. The individual monthly extremes range from 8 mm of condensation to 193 mm of evaporation. The low evaporation trough for Lake St. Clair extends throughout winter and early spring, in contrast to that for the Great Lakes, where it normally occurs in spring. Extension of low evaporation through winter is caused by extensive ice cover. Even without the ice, the low and high evaporation periods from Lake St. Clair would tend to occur sooner because of limited heat storage capacity in this shallow lake.

The reduction of Lake St. Clair evaporation due to ice cover is significant throughout winter (Derecki 1978b). The average reduction is approximately 40 mm in January and February and 10 mm in March and December, with an annual total of

TABLE 1. Lake St. Clair mass transfer evaporation, mm.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1950	17.3	14.0	26.5	17.9	36.5	40.0	59.6	93.9	88.8	67.7	111.9	33.1	607.1
1951	17.6	9.6	15.4	7.8	32.6	34.6	44.3	83.7	133.1	77.6	90.2	39.2	585.8
1952	15.1	15.5	14.2	12.7	55.4	57.5	77.4	86.9	133.6	172.0	71.0	37.9	749.2
1953	19.7	30.9	9.5	29.9	16.1	33.7	68.7	121.8	176.9	108.1	94.0	65.6	774.8
1954	26.7	16.5	33.6	-1.6	79.0	8.0	86.1	123.7	133.5	106.1	71.9	42.0	725.5
1955	26.8	10.2	24.2	5.3	57.0	43.1	48.0	95.1	135.3	95.5	97.9	39.4	677.8
1956	15.6	11.1	18.0	21.1	26.8	17.2	40.7	73.4	130.0	69.5	84.3	24.7	532.5
1957	23.6	11.3	21.9	-0.8	53.5	35.5	48.6	121.8	104.9	121.7	91.6	39.5	673.1
1958	36.8	22.9	18.4	18.1	131.1	75.7	49.8	142.3	145.5	149.9	133.4	43.5	967.4
1959	11.8	15.8	27.9	26.2	37.9	89.4	104.6	91.1	161.5	129.0	98.9	26.7	820.8
1960	21.3	19.9	13.9	-6.3	28.9	39.3	76.0	70.8	116.8	112.3	77.4	65.4	635.6
1961	20.4	12.0	17.5	21.3	85.7	62.0	57.3	83.9	103.5	114.9	117.5	63.9	759.8
1962	28.1	6.4	24.7	37.0	47.6	52.2	77.4	88.5	152.7	103.4	69.9	51.1	739.0
1963	6.0	8.2	2.6	45.7	89.6	61.8	105.1	171.8	149.8	126.9	97.7	51.6	916.9
1964	24.9	18.6	6.8	9.7	85.1	73.2	90.3	113.2	130.3	101.7	81.5	32.7	768.1
1965	25.2	17.7	17.9	6.4	17.2	64.7	92.8	95.6	91.1	131.8	95.7	41.8	697.9
1966	37.0	11.2	19.2	27.4	94.7	54.8	96.9	107.6	141.5	126.7	63.5	51.7	832.2
1967	25.7	12.4	10.7	20.9	82.8	31.7	53.4	128.4	135.3	78.1	90.0	35.2	704.7
1968	17.3	20.5	8.1	36.9	49.9	26.9	57.3	101.7	101.4	125.2	81.0	54.3	680.5
1969	24.6	26.7	50.7	15.1	55.4	42.0	45.5	99.8	156.0	145.0	72.7	42.8	776.5
1970	7.7	14.9	25.2	8.9	29.9	54.5	38.3	146.3	140.7	84.0	107.6	62.2	720.1
1971	25.3	14.1	26.4	43.0	103.7	28.8	137.5	162.7	105.9	81.7	127.4	51.9	908.5
1972	48.0	26.1	38.4	30.8	40.9	63.5	41.4	85.3	132.7	132.4	76.9	37.2	753.5
1973	42.6	22.8	-7.7	33.1	50.2	15.9	66.5	108.7	192.8	120.4	96.4	68.0	809.8
1974	32.3	20.1	24.7	19.7	59.5	49.2	97.9	111.1	166.2	121.7	95.6	41.5	839.4
1975	43.4	32.0	39.5	46.6	37.0	31.9	100.3	94.8	130.8	115.1	58.2	69.6	799.0
Mean	24.7	17.0	20.3	20.5	57.1	45.7	71.6	107.8	134.2	112.2	90.5	46.6	748.3

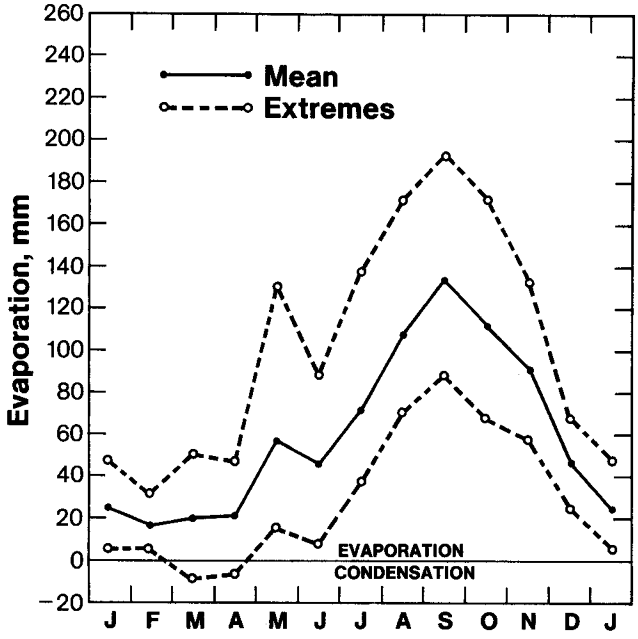

FIG. 3. Lake St. Clair mass transfer evaporation, 1950-75.

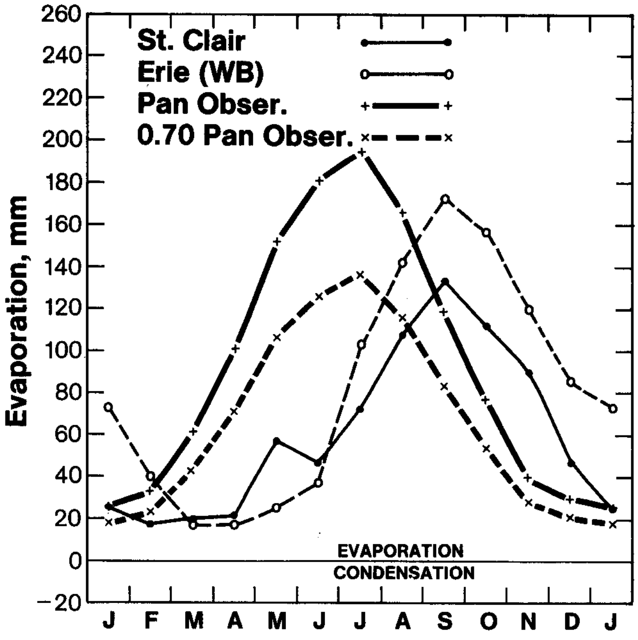

FIG. 4. Comparison of Lake St. Clair evaporation with Lake Erie and pan observations, 1950-75.

about 100 mm. Evaporation reduction due to April ice cover may be important during individual years, but has no significant effect on average long-term values.

Reduction of evaporation due to ice cover is equivalent to the increase in evaporation derived from overwater adjustments of lake perimeter data. Without wind and humidity adjustments, the lake perimeter evaporation estimates result in gross underestimation of overlake evaporation during the entire high evaporation season (about 30 mm per month) and produce an annual total about 100 mm too low.

Because long-term montly Lake St. Clair evaporation could not be verified by other methods (water or energy budgets), an indirect approach was used to provide relative evaluation of the mass transfer results. The indirect evaluation of Lake St. Clair evaporation based on comparison with adjacent lakes and pan evaporation data is shown in Figure 4. Because of climatic and physical similarities, Lake Erie was chosen. Lake Erie evaporation was determined by the water budget method (Derecki 1976) and should reflect actual surface conditions during winter. The ice cover on Lake Erie is also extensive, and the available mass transfer estimates do not include ice-cover reduction of evaporation. Both magnitude and seasonal distribution of evaporation on the two lakes appear reasonable. Lake Erie values are higher during most of the year, reflecting greater overwater fetch and heat storage effects during summer and winter respectively.

The pan evaporation data are for southeast lower Michigan, with some estimates based on extrapolation of partial records during winter. As expected, annual pan evaporation is much higher than lake evaporation. Reduction of pan evaporation by a pan coefficient, such as the traditional 0.70 value employed, produces annual evaporation of reasonable magnitude, which could be used as a rough indication of lake evaporation. However, the seasonal distribution of pan evaporation is completely different because of heat storage effects.

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