EVAPORATION STUDY

AT

SHARP STATION POND

NEAR

BATON ROUGE, LOUISIANA

TECHNICAL REPORT NUMBER 4

prepared by

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1969

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TECHNICAL REPORT NO. 4

EVAPORATION STUDY AT SHARP STATION POND NEAR BATON ROUGE, LOUISIANA

by

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PUBLISHED BY

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1969

STATE OF LOUISIANA

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EVAPORATION STUDY AT SHARP STATION POND NEAR BATON ROUGE, LOUISIANA

By Fred N. Lee

ABSTRACT

The mass-transfer coefficient, N, for the evaporation equation,

$$E=Nu\Delta e,$$

was defined for a 2 1/2 acre pond near Baton Rouge. A value of N=0.00041 was determined by regression analysis of data collected over a 5-year period from 1962 to 1967. This value compares favorably with that determined at two other sites in a humid region, one in North Carolina and one in Florida; however, it is somewhat greater than would be expected for similar size ponds in a more arid climate.

The report also defines a seasonal variation of the combined effect of inseepage, outseepage, and evapotranspiration for the pond. The base loss resulting from the combined effect of these factors is 0.0048 foot per day. An adjustment varying from as much as +0.003 foot per day in the summer to -0.005 foot per day in the winter must be applied to the base loss to account for seasonal variations and define total water loss.

INTRODUCTION

One problem that confronts the engineer or hydrologist concerned with water management is the loss of water by evaporation from rivers and lakes. This problem is amplified in areas of the country where the potential evaporation exceeds the precipitation for the greater part of the year. A need for defining the relation between evaporation and the causative factors, such as wind and temperature, has arisen from this problem. The U.S. Geological Survey recognized this need and has made investigations of various methods of determining evaporation. The mass-transfer method has proven successful. Most of the work utilizing this method has been performed in arid parts of the country. Few data are available for humid areas.

Mass-transfer data were collected by the U.S. Geological Survey at a small pond near Baton Rouge from 1962 to 1967. The purpose of this project was to define the mass-transfer coefficient for this site and to compare it with other sites. Such knowledge will provide a better understanding of evaporation processes and will be useful in estimating evaporation at similar sites in humid regions. Data are now being collected at a site in north Louisiana to provide additional information.

CLIMATE

The general climatic classification for this area is humid and subtropical. Warm temperatures prevail from May through September with mild temperatures existing the remaining part of the year. Some freezing weather does occur but only a few days each year can be expected. The average temperature for the area is about 68° F with maximum temperatures occurring in July and minimum temperatures in December. The average maximum is about 78° F and the average minimum is about 57° F.

The average annual precipitation is about 56 inches. The highest average monthly rainfall occurs in July and the lowest average in October. Intense rainfalls of short duration, associated with advection or convection type thunderstorms, occur from late spring to early fall. Rainfalls of a less intense and more uniform nature occur along frontal lines during the late fall to early spring months.

The prevailing wind direction is from the southeast. Wind movement occurs throughout the year with a slight maximum in the spring. During the late summer and early fall months, freak wind conditions occur when hurricanes move into the area from the Gulf of Mexico. High winds are associated with these low pressure systems and sometime exceed 100 miles per hour.

DESCRIPTION OF THE POND

The pond, with an approximate surface area of 2 1/2 acres, is located on the north side of the engineering depot at Sharp Station near Baton Rouge. It is approximately rectangular in shape, lying in an east-west direction, and with an earth-fill dam along the north side. Dirt was dredged from the pond area to get material for this dam. This dredging left a trench about 16 feet deep along the entire length of the north side. The other three sides were dredged at a later date to give more storage capacity to the pond. Depths in the pond range from 3 feet in the center to 16 feet along the sides.

A 24-inch outflow pipe is located at the northeast corner of the pond. The invert of the pipe was at an elevation of 1.88 feet gage datum when the evaporation station was established. The pipe was raised in November 1966 to increase the storage capacity of the pond. The elevation of the invert was then determined to be 3.37 feet, gage datum.

The cover in the vicinity of the pond consists of thick woods grass that grows up to the edges of the pond, several willow trees along the north edge, thick woods of various type trees and underbrush about 100 feet north of the pond, and a patch of oak trees about 50 feet south of the west edge. The pond itself has various types of water lillies growing around its edges. This growth of lillies extends out into the pond 5 to 10 feet. Various types of water grass grow underneath the surface of the water and, in periods of low water, extend 2 to 3 inches above the surface. See figure 1 for a sketch of the general layout in the vicinity of the pond.

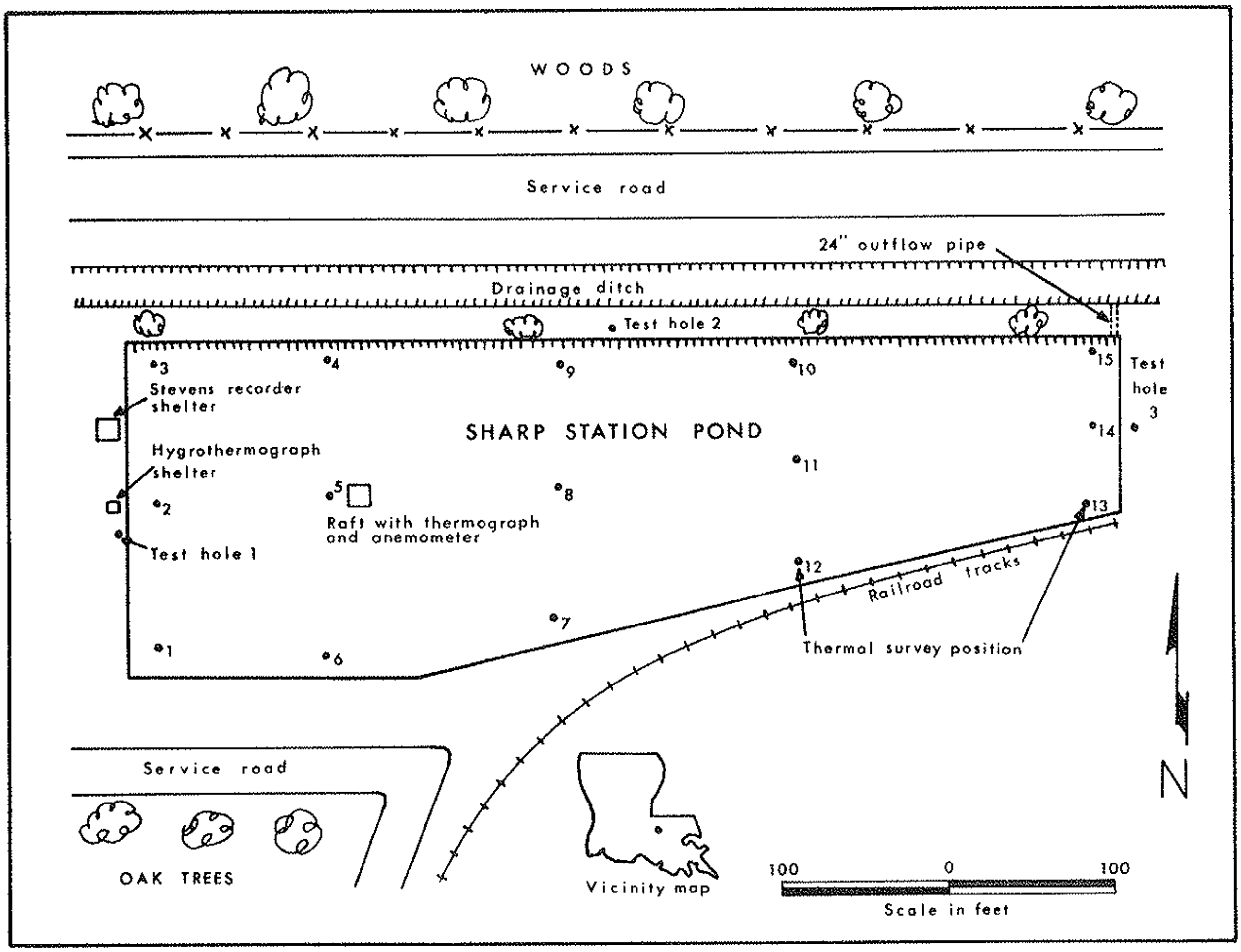

Figure 1.--Location sketch of pond area.

Soil samples were taken at three points around the pond in 1963 to determine the soil type underlying the pond (fig. 1). The description of these samples are as follows:

<u>Hole No. 1</u>

Moderately firm gray clay from surface to a total depth of 17 1/2 feet, mottled by iron-oxide stains below 2 1/2 feet.

<u>Hole No. 2</u>

Moderately firm gray clay with iron oxide-staining to a total depth of 16 feet and with some calcium carbonate inclusions from 6 to 10 feet.

<u>Hole No. 3</u>

Moderately firm gray clay mottled with iron stains from the surface to a total depth of 9 feet.

THERMAL SURVEY

A thermal survey was made on October 26, 1964, to determine if the water surface temperatures over the deep water around the edges of the pond were different from the temperatures over the shallow water in the center. It was thought that the water in the center of the pond might have a higher temperature because of the shallow depth.

A day was selected when the skies were clear and there was very little wind movement. Water surface temperatures were taken at 15 different locations on the pond over a time period from 9 a.m. to 3 p.m. Table 1 gives these values. The values in this table indicate there was no great variation in temperature at the different locations. Figure 1 gives approximate location of each thermal survey position.

Table 1.--Thermal survey

Station	Time	Water temp. °F	Time	Water temp. °F	Time	Water temp. °F	Time	Water temp. °F	Time	Water temp. °F
Raft	0922	68	1019	68	1157	71	1315	71	1429	72
1	0932	68	1030	69	1202	71	1319	72	1432	72
2	0935	68	1032	69	1205	71	1322	72	1434	72
3	0938	68	1035	69	1208	71	1326	72	1437	72
4	0940	68	1038	69	1211	70	1329	71	1439	72
5	0943	68	1041	69	1215	71	1332	71	1442	72
6	0946	68	1045	69	1219	71	1334	72	1444	72
7	0949	68	1048	69	1222	71	1337	72	1446	72
8	0951	68	1051	69	1226	71	1339	71	1448	71
9	0954	68	1054	69	1230	71	1342	72	1450	72
10	0957	68	1056	69	1233	71	1344	71	1452	71
11	1000	68	1058	69	1236	70	1346	71	1454	71
12	1003	68	1100	69	1240	70	1348	72	1455	72
13	1006	68	1104	69	1242	70	1350	72	1458	71
14	1009	68	1106	69	1245	70	1352	71	1500	71
15	1012	68	1110	70	1247	71	1355	70	1502	71
Raft			1115	70	1250	71	--	71	1506	72

INSTRUMENTATION

Instruments set up at the pond were as follows:

1. Stevens duplex recorder (gage height ratio 10:12; time scale 2.4 inches per day) to record pond stage and rainfall.

2. Hygrothermograph to record air temperature, in degrees Fahrenheit, and relative humidity, in percent.

3. Thermograph to record water-surface temperature, in degrees Fahrenheit. The temperature bulb was incorrectly positioned between December 1962 and September 1964; however, the data used for the regression analysis from this period of record agree reasonably well with the data collected after September 1964.

4. Anemometer to record total wind movement, in miles, with an accessory adapter that records 10-mile increments of wind movement on the edge of the thermograph chart.

All instruments operated properly with only a few days of lost record. Figure 1 shows the location of the various instruments.

ANALYSIS OF DATA

The mass transfer equation is

$$E = Nu\Delta e,$$

where E is the evaporation, in feet per day,
N is a coefficient of proportionality defined by the slope of the line drawn through the plotted points, Δh versus $u\Delta e$,
u is the wind speed, in miles per hour,
and Δe is the difference between the saturation vapor pressure at the temperature of the water surface and the vapor pressure of the air, in millibars.

The methods of computing these items are given in the following paragraphs.

Computation of Daily Fall in Gage Height (Δh)

The average daily fall in gage height, Δh, is the total fall in gage height divided by the number of days in the period selected for record computation. To compute Δh, periods of record were selected when there was no surface outflow or inflow and no rainfall. Changes in pond stage, representing all water losses, were determined directly from the gage-height chart to the nearest 0.001 foot. Figure 2 shows pond stage for the period of record and periods used to compute Δh.

Computation of Wind Speed (u)

The average wind speed, u, was computed for the same periods of record used in the Δh computations. An accessory pen recording on the outer edge of the circular thermograph chart made a "pip", or short radial line, to mark the passage of each 10 miles of wind movement. The average wind speed, u, in miles per hour, was computed by counting these marks, multiplying by 10, and dividing by the number of hours in the period.

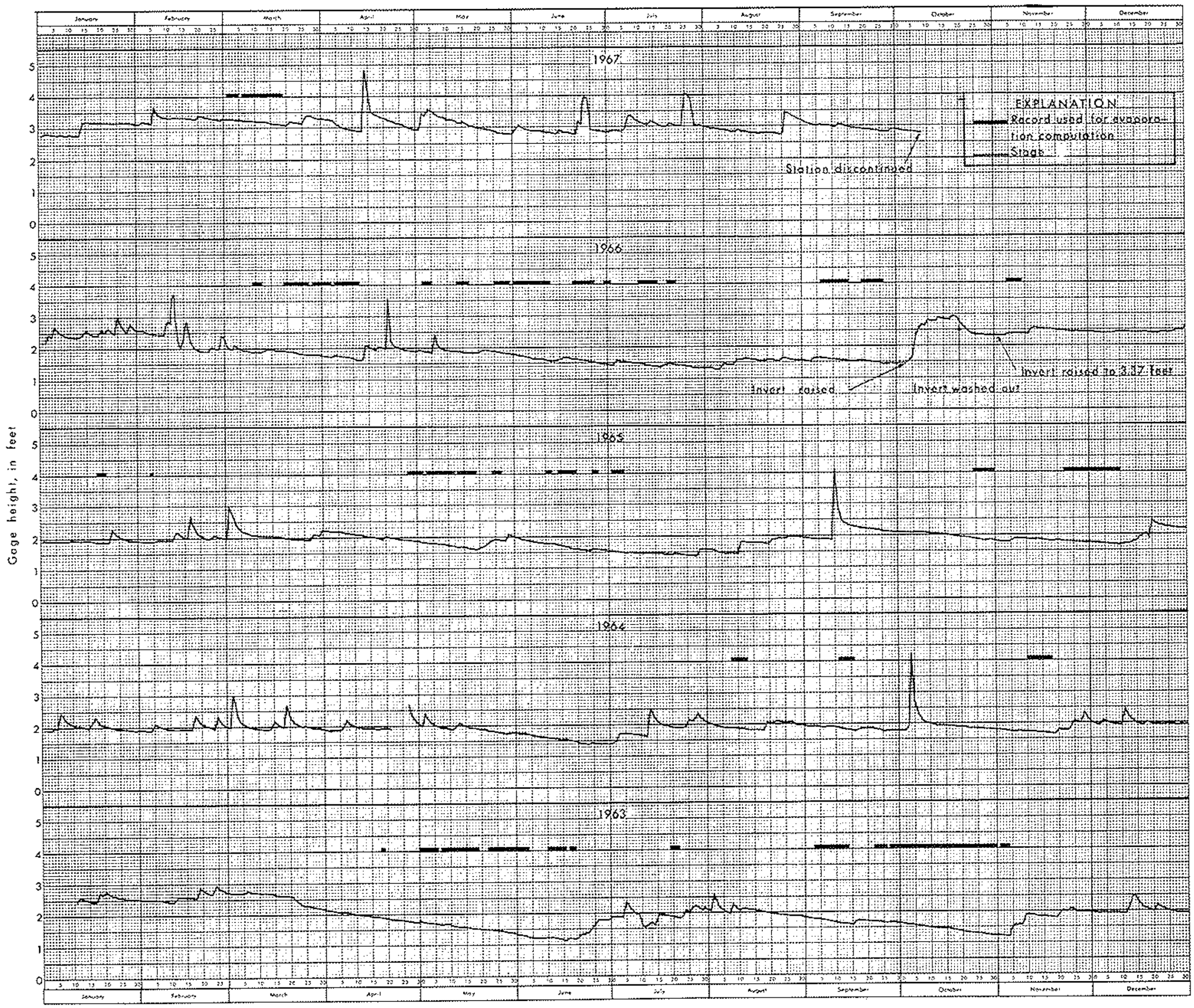

Figure 2.--Pond stage and periods of record used

Computation of Vapor Pressure Difference (Δe)

To compute the vapor pressure difference, Δe, the following items are needed:

1. The saturation vapor pressure, e_s, in millibars, corresponding to the average air temperature for the period selected. The average air temperature for the period is computed by adding the daily average temperatures and dividing by the number of days involved. Daily average temperatures were obtained graphically from a continuous recording.

2. The vapor pressure, e_o, in millibars, corresponding to the average water-surface temperature for the period selected. The average water-surface temperature for the period is computed by adding the daily average water-surface temperatures, and dividing by the number of days involved. Daily average water-surface temperatures were taken from a continuous recording.

3. The average relative humidity, in percent. This value is obtained by summing the daily average values and dividing by the number of days involved. The daily average is obtained from a continuous recording. The vapor pressure difference, Δe, is then computed as follows:

   (a) Multiply e_s by the average relative humidity divided by 100. This gives the value e_a, which is the vapor pressure of the air.

   (b) The value Δe is equal to $(e_o - e_a)$.

Regression Analysis

The main purpose of this study is to define the mass-transfer coefficient, N, for the general evaporation equation,

$$E = Nu\Delta e,$$

and to compare this value with N values for other sites. The term, "N", is a coefficient of proportionality and can be defined by the slope of the best-fitting line drawn through the plotted points, Δh versus $u\Delta e$. (fig. 3) This line was positioned by using the least squares method explained by Waugh (1952). The slope, N, of the line is 0.00041. The general evaporation equation then becomes,

$$E = 0.00041u\Delta e.$$

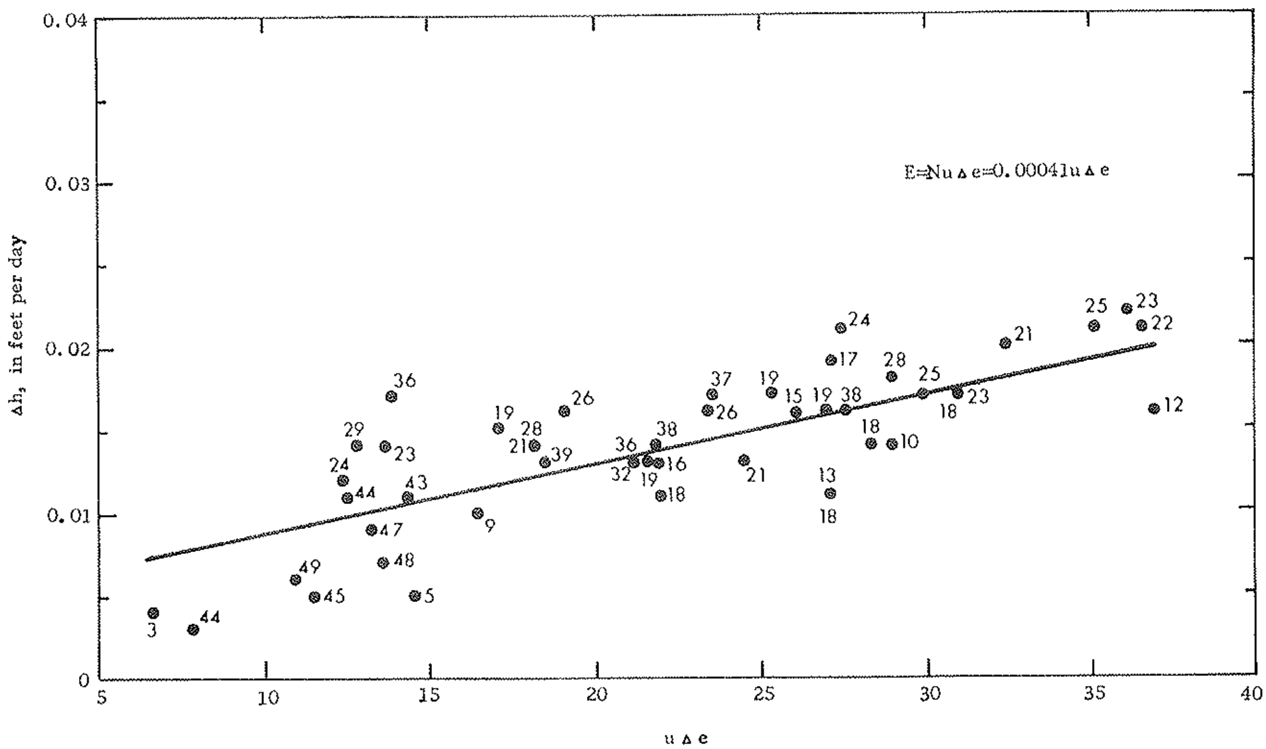

Figure 3.--Relationship curve, Δh versus $u\Delta e$

A total of 48 points (table 2) were used in the regression analysis. Of the 48, one point, (3/9/66), was considerably out of line and was discarded in the analysis. All other data collected during the 5 years of operation were used except for the days of outflow, inflow, rainfall, or missing record. These data represent all seasons of the year.

The points plotted in figure 3 (numbers indicate week of the year) scatter considerably about the best-fitting line. This scatter is partly caused by variations of inseepage, outseepage, and evapotranspiration during the different seasons of the year, and possibly to variation of seepage with stage. A plot was made of stage versus deviation of the plotted points from the curve in figure 3. This plot was made to see if the seepage varies with stage; however, no trend could be detected. This indicates that stage has little or no affect on seepage at this pond, at least not for the limited range in stage experienced. Deviations, Y, of the points were plotted against week of the year as shown in figure 4. This curve represents an adjustment which partially accounts for the seasonal variations of inseepage, outseepage, and evapotranspiration. Table 3 gives values taken from this curve corresponding to each week of the year.

Table 2.--Data for computation of mass-transfer coefficient "N"

From		To		Gage height data				Vapor pressure			Avg. u (mph)	uΔe	Week no.
Date	Hour	Date	Hour	Beg. (ft)	End. (ft.)	Diff. (ft.)	Δh (ft/day)	Avg. e_o (mb)	Avg. e_s (mb)	Δe (mb)			
1963													
4/18	2400	4/29	2400	1.876	1.728	0.148	0.013	30.3	23.0	7.3	3.0	21.9	16
4/30	2400	5/6	2400	1.770	1.669	.101	.017	28.8	16.9	11.9	2.6	30.9	18
5/7	2400	5/19	2400	1.700	1.499	.201	.017	34.5	22.4	12.1	2.1	25.4	19
5/22	2400	5/31	2400	1.492	1.315	.177	.020	35.6	21.5	14.1	2.3	32.4	21
5/31	2400	6/4	2400	1.315	1.230	.085	.021	33.9	21.7	12.2	3.0	36.6	22
6/10	2400	6/16	2400	1.247	1.114	.133	.022	40.9	28.4	12.5	2.9	36.2	23
6/17	2400	6/19	2400	1.200	1.176	.024	.012	33.9	28.2	5.7	2.2	12.5	24
7/19	2400	7/22	2400	1.872	1.810	.062	.021	44.3	31.3	13.0	2.7	35.1	25
9/3	2400	9/14	2400	1.784	1.595	.189	.017	38.8	28.9	9.9	1.4	13.9	36
9/22	2400	9/26	2400	1.684	1.620	.064	.016	27.2	18.0	9.2	3.0	27.6	38
9/27	2400	10/31	2400	1.642	1.207	.435	.013	27.3	16.4	10.9	1.7	18.5	39
11/1	2400	11/4	2400	1.216	1.184	.032	.011	17.1	11.1	6.0	2.1	12.6	44
1964													
8/8	2400	8/13	2400	1.878	1.813	.065	.013	41.7	30.6	11.1	1.9	21.1	32
9/11	2400	9/16	2400	1.874	1.790	.084	.017	31.6	20.3	11.3	2.1	23.7	37
11/10	2400	11/18	2400	1.706	1.664	.042	.005	26.6	21.5	5.1	2.3	11.7	45
1965													
1/18	2400	1/21	2400	1.878	1.866	.012	.004	13.6	11.5	2.1	3.2	6.7	3
2/4	2400	2/5	2400	1.875	1.870	.005	.005	12.3	9.7	2.6	5.6	14.6	5
4/27	2400	5/2	2400	1.918	1.824	.094	.019	30.2	14.2	16.0	1.7	27.2	17
5/3	2400	5/9	2400	1.830	1.744	.086	.014	33.0	23.2	9.8	2.9	28.4	18
5/9	2400	5/12	2400	1.744	1.699	.045	.015	35.7	25.0	10.7	1.6	17.1	19
5/13	2400	5/19	2400	1.690	1.594	.096	.016	35.6	26.0	9.6	2.8	26.9	19
5/24	2400	5/27	2400	1.914	1.874	.040	.013	37.4	29.5	7.9	3.1	24.5	21
6/10	2400	6/12	2400	1.783	1.756	.027	.014	39.8	28.4	11.4	1.2	13.7	23
6/14	2400	6/20	2400	1.728	1.603	.125	.021	41.5	27.8	13.7	2.0	27.4	24
6/25	2400	6/27	2400	1.604	1.577	.027	.014	40.4	29.0	11.4	1.6	18.2	26
7/1	2400	7/5	2400	1.532	1.468	.064	.016	44.6	29.9	14.7	1.6	23.4	26
10/24	2400	10/31	2400	1.879	1.800	.079	.011	20.7	10.4	10.3	1.4	14.4	43
12/6	2400	12/10	2400	1.689	1.663	.026	.006	15.0	10.0	5.0	2.2	11.0	49
11/22	1245	11/29	1335	1.790	1.730	.060	.009	22.6	16.8	5.8	2.3	13.3	47
11/29	1335	12/6	1055	1.742	1.693	.049	.007	15.9	9.4	6.5	2.1	13.6	48
1966													
3/9	2400	3/12	2400	1.879	1.864	.015	.005	16.3	4.7	11.6	6.0	69.6	10
3/19	2400	3/27	2400	1.883	1.793	.090	.011	23.2	13.5	9.7	2.8	27.2	12
3/28	2400	4/3	2400	1.782	1.714	.068	.011	22.3	13.6	8.7	3.1	27.0	13
4/4	2400	4/10	2400	1.755	1.658	.097	.016	24.5	12.2	12.3	3.0	36.9	14
4/10	2400	4/12	2400	1.658	1.627	.031	.016	26.4	20.7	5.7	4.6	26.2	15
5/2	2400	5/5	2400	1.879	1.846	.033	.011	27.1	21.3	5.8	3.8	22.0	18
5/13	2400	5/17	2400	1.868	1.815	.053	.013	36.8	27.4	9.4	2.3	21.6	19
5/25	2400	5/29	2400	1.856	1.800	.056	.014	36.2	23.2	13.0	1.4	18.2	21
5/31	2400	6/12	2400	1.771	1.562	.209	.017	37.0	24.1	12.9	2.4	31.0	22
6/19	2400	6/26	2400	1.628	1.508	.120	.017	37.5	23.3	14.2	2.1	29.8	25
6/29	2400	7/1	2400	1.468	1.436	.032	.016	39.8	25.1	14.7	1.3	19.1	26
7/10	2400	7/16	2400	1.470	1.359	.111	.018	45.0	29.8	15.2	1.9	28.9	28
7/19	2400	7/22	2400	1.466	1.424	.042	.014	42.9	31.2	11.7	1.1	12.9	29
9/6	2400	9/15	2400	1.629	1.508	.121	.013	35.3	26.8	8.5	2.5	21.2	36
9/19	2400	9/26	2400	1.538	1.441	.097	.014	31.7	20.2	11.5	1.9	21.8	38
11/4	2400	11/9	2400	2.386	2.369	.017	.003	19.8	16.9	2.9	2.7	7.8	44
1967													
3/1	2400	3/5	2400	3.268	3.229	.039	.010	21.7	16.2	5.5	3.0	16.5	9
3/6	2400	3/19	2400	3.240	3.056	.184	.014	26.8	15.2	11.6	2.5	29.0	10

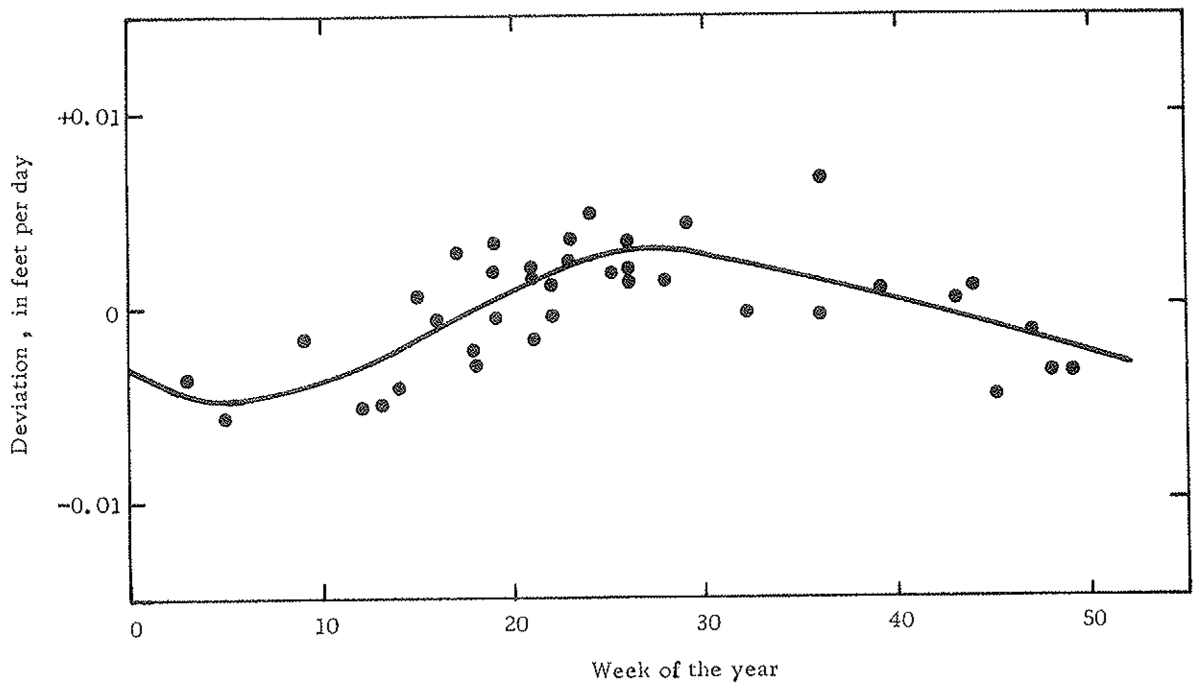

Figure 4.--Gains due to inseepage and losses due to outseepage and evapotranspiration.

Table 3.--Gains due to inseepage and losses due to outseepage and evapotranspiration.

Week of year	Y(ft. per day)	Week of year	Y(ft. per day)	Week of year	Y(ft. per day)	Week of year	Y(ft. per day)
1	-0.003	14	-0.002	27	+0.003	40	0
2	-.004	15	-.002	28	+.003	41	0
3	-.004	16	-.001	29	+.002	42	-.001
4	-.005	17	-.001	30	+.002	43	-.001
5	-.005	18	0	31	+.002	44	-.001
6	-.005	19	0	32	+.002	45	-.001
7	-.005	20	+.001	33	+.002	46	-.002
8	-.004	21	+.001	34	+.001	47	-.002
9	-.004	22	+.002	35	+.001	48	-.002
10	-.004	23	+.002	36	+.001	49	-.002
11	-.003	24	+.002	37	+.001	50	-.003
12	-.003	25	+.003	38	0	51	-.003
13	-.002	26	+.003	39	0	52	-.003

Total losses from the pond (other than direct outflow) can be computed if the effects of inseepage, outseepage and evapotranspiration are taken into account. The net effect of these factors results in a base loss of 0.0048 feet per day, as determined from the intercept of the curve in figure 3. The general equation for total losses, L, in feet per day, at the pond would then be,

$$L=0.00041u\Delta e+0.0048+Y,$$

with the value of Y depending on the week of the year.

Comparison of Results to Other Studies

Studies made by Harbeck (1962) show that the "N" coefficient for a 2 1/2 acre pond should be 0.00027. The coefficient, (0.00041), computed for the Sharp Station pond, is much greater than this. This difference can be attributed to the direction of the prevailing wind, boundary conditions affecting wind structure, shapes of the respective ponds, and other physical characteristics. It should be emphasized that each pond or lake is different and may not conform to any of the past results and that the results of Harbeck (1962) and those shown below can only be used as a guide when no other information is available. The tabulation below gives coefficients computed at two other study sites in humid regions as compared to Sharp Station.

Name of study site	Area, in acres	Coefficient, N
Lake Michie, North Carolina (Turner, 1966)	480	0.00030
Lake Helene near Polk City, Fla	54	.000358 1/
Sharp Station, near Baton Rouge	2 1/2	.00041

The above coefficients indicate that as the size of the pond decreases, the coefficient, N, increases. This is reasonable, and it follows what other investigations have shown even though the values may be different.

CONCLUSIONS

This report analyzes all the factors involved in the mass-transfer equation, $E=Nu\Delta e$. All can be measured except the coefficient, N. Regressions were made to define this term and comparisons made to other like studies. It was found that the coefficient, N, of 0.00041 is

[1] Coefficient computed from preliminary data subject to revision.

somewhat higher than was found in other studies, but presumably this can be attributed to the direction of the prevailing wind, boundary conditions affecting wind structure, the shapes of the respective ponds, and other physical characteristics.

A seasonal variation of the combined effect of inseepage, outseepage, and evapotranspiration was also defined for the pond. The base loss resulting from the combined effect of these factors is 0.0048 feet per day. An adjustment varying from as much as +0.003 foot per day in the summer to -0.005 foot per day in the winter must be applied to the base loss to account for seasonal variations and define total water loss.

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