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SECOND RECORD OF OSCILLATIONS IN LAKE LEVEL, WITH RECORD OF LAKE TEMPERATURE AND OF METEOROLOGY, SECURED AT THE MACBRIDE LAKESIDE LABORATORY, LAKE OKOBOJI, IOWA, JULY, 1916.

JOHN L. TILTON.

In the "Proceedings of the Iowa Academy of Science" for 1916 may be found a somewhat similar title for a paper in which data obtained in July, 1915, were discussed. It is the purpose of the present paper to present the records of a second year. These records were obtained in part for personal information, and in part for reference by students at the laboratory. It is believed that the records (and also those of last year) are sufficiently accurate for use by those studying the limnology of the lake and possibly by those who may work on the heat budget. The computations of volume, given in the last paper, are here omitted. Unfortunately it was not convenient to obtain records the fifteenth of August, nor near that date, the time preferred for such records.

Since from data previously obtained it was evident tidal effects and changes in level due to changes in barometric pressure were not appreciable near the laboratory, all discussion of such data is omitted from the present paper. Only a part of the record of meteorology is here given, and that part is largely presented by diagrams. Wind direction and general velocity were noted, and data used in connection with oscillations in lake level, but they are not given separately in this report.

APPARATUS.

To ascertain the temperature at different levels in the lake a Leeds and Northrup "Electrical Resistance Thermometer" was at first used (see records of lake temperatures for June 28 and July 18) with excellent results; but on July 25 the lead cable sprang a leak, preventing further determinations by means of that instrument. Recourse was then had to a minimum thermometer held in a horizontal position, as extemporized the previous year. To determine whether the pressure of water in the

lake affected the minimum thermometer the thermometer was later placed in a water gauge and subjected to various pressures of air up to fifty pounds per square inch. Under the conditions of the experiment the effect on the thermometer varied from the tenth of a degree for fifty pounds to a degree for fifty pounds, with an average rise of thirty-five hundredths of a degree for the five best determinations. This would give a correction of forty-three hundredths of a degree to be subtracted from the reading of fifty-six degrees Fahrenheit obtained for the deepest place in the lake, 135 feet, as recorded a year ago. In the present records of lake temperature this correction is not included. (It applies only to those of the twenty-sixth of July.)

The maximum and minimum temperatures on the porch were obtained by the use of the ordinary maximum and minimum thermometers such as are used by the Weather Bureau. The minimum thermometer is subject to an additive correction of half a degree, which is here included in the data used. The maximum thermometer requires no correction.

To record fluctuations in the level of the lake the same apparatus was used as last year, consisting of a cylindrical float in a larger cylinder pierced with a few nail holes. On the upper end of the float was a pen that traced a line on a revolving cylinder.

GENERAL CONDITIONS.

For study of the effect of wind pressure upon the general movement of water in the lake the opportunity for observation in July, 1916, was not as good as in July, 1915, when the wind was more variable and at times stronger than in 1916. The data on temperature are in some respects better than those obtained in 1915. Records were obtained in three different places with a view to comparing temperatures obtained north and south of the center of oscillation.

The inflow from Spirit Lake seemed by inspection to be about equal to the outflow from Lower Gar Lake, as last year; but the lake was four inches higher this year than last.

FLUCTUATIONS IN LAKE LEVEL AT THE LABORATORY.

The graph, not here reproduced, reveals a uniform fall in the surface due to evaporation, interrupted by occasional precipitation, the two about compensating each other the first and third

weeks of the session (June 26-July 2 and July 10-16). Four rainfalls caused marked elevations in the surface of the lake. One occurred in the night of June 28-29, when a heavy rain raised the surface 1.75 inches. On July 2 the surface was raised .4 inch, on July 19 it was raised .5 inch and on July 24, .6 inch. In each case the graph shows the presence of large storm waves.

Slight fluctuations that seem due to oscillations in the level of the lake at the point of observation are noted in the graph for June 30 and for July 2, each amounting to .06 inch, when waves were small, each oscillation varying through a period of ten hours. On July 19 there was a rise in the level of the lake of about .06 inch for about six hours at the point of observation, and then a return to the former level without a corresponding depression. This was accompanied by high waves, when a strong wind shifted from southeast to northwest. In a similar manner on the night of July 23-24 there was an oscillation when there were large waves preceding a thunderstorm. The wind had been in the southwest the day preceding the storm. Of changes in direction during the storm there is no record.

During the night of July 23-24 the wind gauge recorded an average velocity of 9.1 miles per hour. This was the only instance during the time that the wind gauge was used that there was any relation to be detected between wind velocity and the oscillations in the lake. During that time the wind was almost constantly from the southwest. Generally when the wind gauge near the laboratory (and about sixty feet above the lake) recorded a velocity of about four miles per hour the wind out in the center of the lake was strong enough to raise large waves on which white caps were nearly ready to appear.

CIRCULATION IN THE LAKE, AND THE TEMPERATURE.

Changes in the circulation of water at the end of the pier were noticeable, and these followed the direction and velocity of the wind. They were of two types: When the wind blew strongly toward the laboratory from the lake not only were floating objects tossed up on the beach but the warm water at the surface was pushed in and down, so that often when the wind was prolonged the water at the bottom was at the same temperature as that at the surface at the end of the pier where the water was

seven feet deep. When the wind blew in the opposite direction, away from the pier, there was an upward and outward movement resulting in a lower temperature at the bottom at the end of the pier. During the latter part of June and the early part of July the water from beneath the surface mingling with that at the surface (combined with effects due to radiation, evaporation and contact with air of different temperature) caused a drop in the surface temperature of one and even two degrees, and on one occasion (June 21), assisted by the low temperature

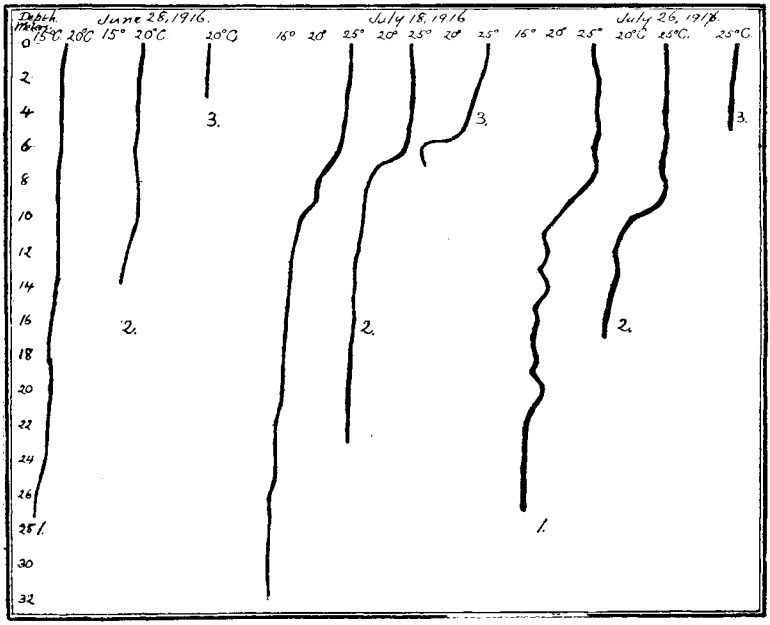

FIG. 1a. Graph of the temperature records for the different depths in Lake Okoboji. 1, at the center of oscillation of the lake, southeast of "The Inn"; 2, west of Hayward's Bay and near the middle of the lake; 3, about half way between the end of the spit and the laboratory pier in Miller's Bay.

of a cool day, caused a lower temperature at the evening observation than at the morning observation, the temperature at the surface and at the bottom being the same (62.5° Fahr.), the latter without the immediate influence of evaporation and of the temperature of the air. On quiet sunny days the temperature of the surface water rose even as much as six degrees (July 29).

Circulation that was pronouncedly horizontal was commonly noticeable at the end of the laboratory pier. Sometimes it was seen in the slow movement of a thin surface film even an eighth of an inch in depth moved by gentle winds. Often when the wind was strong there was a general movement of the water as seen at the pier. Up to the last two days of the observations this drift seemed to follow the direction of the wind when the wind was northwest, southwest, south and even southeast. Apparently the drift to the north when the wind was southeast was due to a double eddy within the bay, a second eddy forming west of the spit opposite the laboratory. On the last two days (July 26 and 27) it was noticed that even with a southwest wind the circulation at the pier was toward the south, as if the effect of the strong southeast wind of July 25 still persisted.

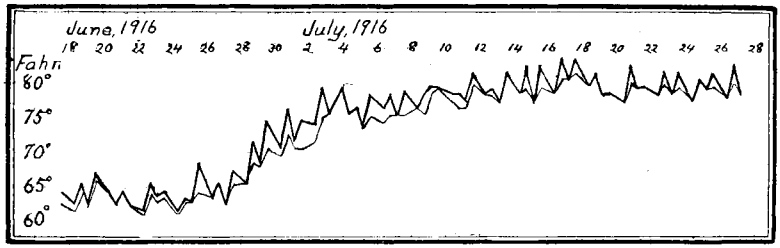

FIG. 1b. The heavy upper line gives the temperature of the surface water at the end of the laboratory pier during the session of 1916, June 18-July 26. The light lower line gives the temperature at the bottom (depth seven feet) at the end of the laboratory pier. In places the two lines coincide.

Apparently the weeds were interfering with the circulation in the bay at the times of the last two observations of temperature (July 18 and 26), since the temperature at the bottom amid the weeds was higher than the temperature of the water above the weeds.

In the last temperature observations taken out in the lake (July 25-26) after a strong southeast wind for two days, a stratum of water warmer than the water above it and also warmer than the water below it, was found at a depth of about eight meters (26 feet). When this was first noticed it was thought to be due to an error of observation, but the difference was detected in readings taken a mile and a half apart and on two successive days. It seems evident that this circulation involved horizontal sheets of considerable extent. The other variations seen in the curves for

July 26 seem also to mark the presence of water with different temperatures, but not of the extent of that mentioned above.

The graph gives a thickness of only five to seven meters for the epilimnion July 18, and a thickness of only two meters and of one meter for the thermocline. The graph for July 26 gives a thickness of seven and a half meters for the epilimnion and of three and a half for the thermocline. Doubtless these increased in the next three weeks.

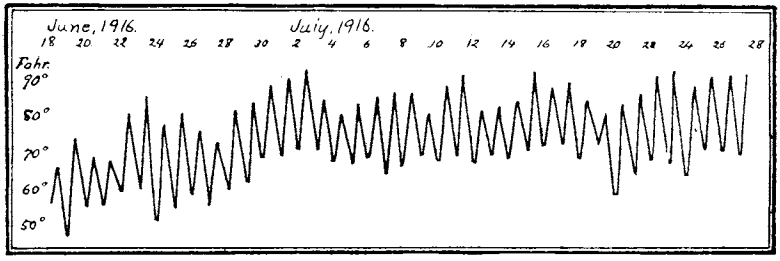

FIG. 1c. Graph of maximum and minimum temperature on the porch of the cottage at the Lakeside Laboratory during the session of 1916, June 18-July 26.

SURFACE TEMPERATURE.

The temperature of the surface at the pier rose steadily almost daily from 62.5° Fahr. on June 18 to 78.5° Fahr. on July 10, and then varied between 78.5° and 83.5°; so that for bathing the water was generally above 78.5° Fahr.

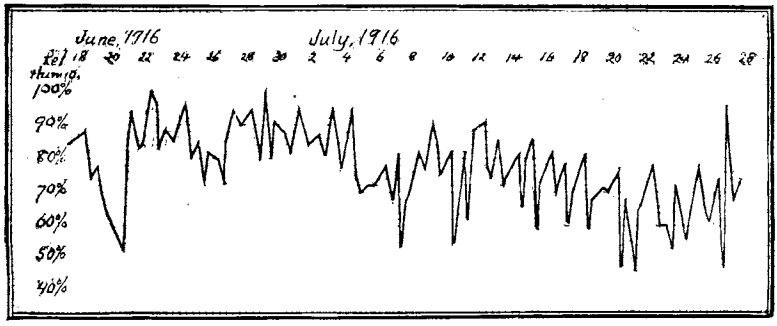

FIG. 1d. Graph of the relative humidity on the porch of the cottage at the Lakeside Laboratory, June 18-July 26, 1916, from observations at 7 a. m., 12 m. and 7 p. m.

METEOROLOGY.

The maximum temperature of the air on the cottage porch ranged from 64° Fahr. (June 21) to 93.4° Fahr. (July 23), at which time it was ten degrees below the temperature reported

from cities away from the lake. The average maximum temperature from June 18 to July 27 was 83.8° Fahr. The relative humidity at noonday from June 17 to July 27, inclusive, averaged 67 per cent. From morning, noon and evening determinations it averaged 84.6 per cent for the same time. The general direction of the wind was southwest, and the sky averaged clear to partly cloudy.

LAKE TEMPERATURE, JUNE 28, 1916.

Meters	Feet	1		2		3	
		F.°	C.°	F.°	C.°	F.°	C.°
0	0	66.0	18.9	68.0	20.0	67.2	19.6
1.5	5	64.5	18.1	65.8	18.8	66.3	19.1
3.0	10	64.5	18.1	65.5	18.7	66.2	19.0
4.6	15	64.5	18.1	65.5	18.7		
6.1	20	64.5	18.1	64.0	17.8		
7.6	25	64.0	17.8	64.8	18.2		
9.1	30	64.0	17.8	65.0	18.3		
10.7	35	64.0	17.8	64.6	18.1		
12.2	40	64.0	17.8	63.1	17.3		
13.7	45	63.3	17.4	64.0	17.8		
15.2	50	62.6	17.0	61.7	16.5		
16.8	55	61.6	16.4				
18.3	60	61.8	16.6				
19.8	65	61.9	16.6				
21.3	70	61.0	16.1				
22.9	75	61.0	16.1				
24.4	80	60.4	15.8				
25.9	85	58.4	14.7				
27.4	90	57.3	14.1				

1. Taken near the center of oscillation of the lake, southeast of "The Inn".

2. Taken near the middle of the lake off Hayward's Bay.

3. Taken half way between the spit and the laboratory pier, Miller's Bay. At the end of the laboratory pier on June 28th the temperature at the surface was 20.6° C. and the temperature at the bottom 19.5° C.

In the two following tables the numbers at the heads of the columns refer to the same locations.

LAKE TEMPERATURES, JULY 18, 1916.

Meters	Feet	1		2		3	
		F.°	C.°	F.°	C.°	F.°	C.°
0	0	77.4	25.3	75.6	24.2	78.3	25.7
1	3.3	77.4	25.3	75.6	24.2	77.2	25.1
2	6.6	77.0	25.0	75.6	24.2	75.6	24.2
3	9.8	76.5	24.7	75.6	24.2	74.3	23.5
4	13.1	76.1	24.5	75.2	24.0	73.2	22.9
5	16.4	75.2	24.0	74.5	23.6	71.2	21.8
6	19.7	74.7	23.7	74.1	23.4	59.9	15.5
7	23.0	71.4	21.9	64.9	18.3	60.8	16.0
8	26.3	68.4	20.2	63.9	17.7		
9	29.5	68.4	20.2	63.3	17.4		
10	32.8	64.0	17.8	62.8	17.1		
11	36.1	63.3	17.4	61.9	16.6		
12	39.4	62.2	16.8	61.0	16.1		
13	42.7	61.5	16.4	60.6	15.9		
14	45.9	61.0	16.1	60.6	15.9		
15	49.2	60.8	16.0	60.3	15.7		
16	52.5	60.6	15.9	60.1	15.6		
17	55.8	60.3	15.7	59.4	15.2		
18	59.1	59.9	15.5	59.2	15.1		
19	62.3	59.5	15.3	58.9	14.9		
20	65.6	59.0	15.0	58.8	14.9		
21	68.9	58.6	14.8	58.6	14.8		
22	72.2	57.6	14.2	58.8	14.9		
23	75.5	57.6	14.2	58.8	14.9		
24	78.7	57.7	14.3				
25	82.0	57.2	14.0				
26	85.3	55.9	13.3				
27	88.6	55.9	13.3				
28	91.9	55.8	13.2				
29	95.1	55.4	13.0				
30	98.4	55.4	13.0				
31	101.7	55.9	13.3				
32	105.0	55.6	13.1				

LAKE TEMPERATURES, JULY 26, 1916.

Meters	Feet	1		2		3	
		F.°	C.°	F.°	C.°	F.°	C.°
0	0	79.0	26.1	80.0	26.7	80.1	26.7
1	3.3	79.0	26.1	80.0	26.7	79.3	26.3
2	6.6	80.0	26.7	79.5	26.4	78.9	26.1
3	9.8	79.5	26.4	79.5	26.4	78.6	25.9
4	13.1	79.3	26.3	79.2	26.2	78.1	25.6
5	16.4	79.5	26.4	79.4	26.3	*	*
6	19.7	78.8	26.0	79.3	26.3		
7	23.0	79.5	26.4	78.7	25.9		
8	26.3	77.5	25.3	79.5	26.4		
9	29.5	72.5	22.5	78.5	25.8		
10	32.8	69.1	20.6	71.2	21.8		
11	36.1	65.7	18.7	68.3	20.2		
12	39.4	66.8	19.3	64.6	18.1		
13	42.7	64.5	18.1	65.4	19.1		
14	45.9	67.5	19.7	65.1	18.4		
15	49.2	63.5	17.5	64.5	18.1		
16	52.5	63.5	17.5	63.5	17.5		
17	55.8	63.0	17.2	63.5	17.5		
18	59.1	63.7	17.6				
19	62.3	62.5	16.8				
20	65.6	65.5	18.6				
21	68.9	62.7	17.1				
22	72.2	61.0	16.1				
23	75.5	60.5	15.8				
24	78.7	60.3	15.7				
25	82.0	60.3	15.7				
26	85.3	59.8	15.4				
27	88.6	60.0	15.6				

*Total depth 4.5 meters (14.8 ft.), temperature 78.5° F. (25.8° C.)

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