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Thermal Structure of Clear Lake, Iowa

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Summer water temperatures in the shallow areas of Clear Lake were slightly higher and had a greater daily range than temperatures measured in the limnetic zone. The lake was not thermally stratified, although small differences sometimes were found between surface and bottom temperatures at the deepest point. Temperatures measured in the Clear Lake Water Treatment Plant were representative of those measured in the limnetic zone of the lake and provide a useful index of temperature conditions in the lake as a whole.

The average annual temperature curve is asymmetrical, with the highest temperature falling on August 5 and the lowest occurring 119 days later on November 30. The median and mean lake temperatures were 51° and 53.7°F. The median date of ice breakup was April 3 and the median date of freezing was November 27.

INDEX DESCRIPTORS: Lake Thermal Structure; Clear Lake, Iowa.

Previous knowledge of the thermal characteristics of Clear Lake is limited. Pearcy (1952) measured daily maximum and minimum water temperatures at one station during the summer of 1951 and recorded water temperatures intermittently at other stations. Other fisheries workers recorded water temperatures intermittently in conjunction with their research investigations (Small, 1959; Ridenhour, 1958; Buchholz, 1960), but no detailed studies of the thermal cycles have been made.

Clear Lake, located in north-central Iowa, has a surface area of 1,474 ha, a maximum depth of 6.0 m and an average depth of 3.7 m (Pearcy, 1952). It is 7.7 km long on its east-west axis, enabling prevailing westerly winds to mix the lake effectively. The circular west end of the lake is partly separated from the lake proper by a sand spit, which juts out from the southwestern shore of McIntosh Woods State Park (Figure 1). Ventura Marsh was previously connected to the lake by about 0.5 km of open water, but the marsh now is isolated from the lake by a road. Water flows from the marsh into the lake through a culvert. By midsummer the marsh is choked with higher aquatic plants. The marsh was considered to be a part of Clear Lake for this study.

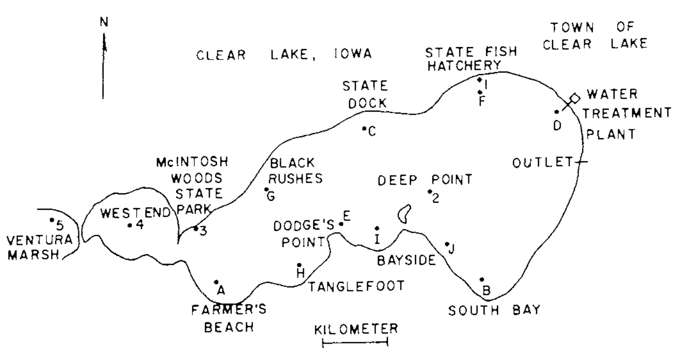

Figure 1. Map of Clear Lake showing location of temperature recording stations. Permanent stations are numbered and temporary stations are designated with letters.

Two kinds of data were utilized in this study. One consisted of field measurements of water temperatures at various locations in the lake during the summer of 1966, and the other was a 16-year series of daily water temperature readings recorded in the Clear Lake Water Treatment Plant. These records were considered potentially valuable because the treatment plant obtains its water supply directly from Clear Lake.

The objectives were to determine the variability in water temperatures within and between different habitats in the lake, to determine if the temperatures measured at the treatment plant were representative of those in the lake and to describe the annual temperature cycle in Clear Lake.

We are indebted to Mr. Vern Hines, Superintendent of the Clear Lake Water Treatment Plant, for making available the temperature data and other records collected by him or under his direction. We also wish to thank Mr. Robert Cooper, Superintendent of the Clear Lake Fish Hatchery, and Mr. Erwin Greattinger, Office of the Clear Lake Water Safety Patrol, for the use of their laboratory facilities and equipment. Suggestions and assistance during various phases of the study were given by Mr. Gary Atchison, Mr. Roger Mrachek and Mr. Thomas Huggins.

METHODS AND MATERIALS

From July 15 to September 23, 1966, five permanent recording stations and ten temporary recording stations were established to provide a representative picture of the lake's thermal structure (Figure 1). Ryan recording thermometers (Ryan Instruments, Inc., Seattle, Wash.) were used to monitor water temperature at each station.

Permanent Recording Stations

Station 1 was located in front of the State Fish Hatchery on the northeastern side of the lake in 80 cm of water. One recording thermometer was suspended 20 cm below the surface beneath the hatchery dock, 12 m from shore. This sta-

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tion represented an exposed, weed-free shoreline, which is characteristic of the eastern half of Clear Lake. A gently sloping sand and gravel bottom was characteristic of the site. Wave action varied with wind direction, and waves exceeding 76 cm were not uncommon. Weekly Secchi disc readings averaged 55.9 cm throughout the recording period.

Station 2 was located near the deepest point (5.9 m) in Clear Lake approximately 0.5 km northeast of the island. Waves were moderate to high at this limnetic-zone station. The average weekly Secchi disc reading was 61.0 cm.

A buoy system, composed of a large styrofoam float and a small underwater buoy, was used to suspend two recording thermometers at depths of 1.2 m and 5.2 m. The buoy was designed to maintain the thermometers at constant depth and to prevent damage by wave action. The entire underwater buoy complex was raised from the bottom when the thermometers were examined.

Station 3 was located on the southeastern shore of McIntosh Woods State Park in 80 cm of water about 150 m west of the boundary between the park and the Baptist Camp. A steel post was driven into the sand bottom 12 m from shore, and one recording thermometer was suspended 20 cm below the surface. After the first week a plywood sun shield was placed above the thermometer. The station represented a protected, weedy, shoreline habitat. Secchi disc readings averaged 58.4 cm at this station.

Station 4 was located in 2 m of water in the center of the large bay at the western end of Clear Lake. A buoy, similar to the one at station 2, was used to locate and suspend one recording thermometer about 1 m beneath the surface. The average Secchi disc reading was 40.7 cm.

Station 5 was within Ventura Marsh in 50 cm of water approximately 60 m from the northwestern edge of the road separating the marsh from the lake. A steel pipe supported one recording thermometer 30 cm beneath the surface, and a sun shield shaded the unit. The substrate at the site consisted of a thick layer of decaying organic material. Secchi disc readings were not taken because turbidity varied considerably in relation to daily wind conditions. The thermometer was removed on August 13, 1966.

Temporary Recording Stations

These stations were established to investigate habitats in Clear Lake not surveyed by the five permanent stations. Temperature recordings were made at 10 limnetic sites having an average depth of 3.4 m for approximately one-week intervals (Table 1). A buoy system, similar to the one previously described, was used to locate and support one recording thermometer about 1 m from the bottom. The average Secchi disc reading was 61.0 cm.

TABLE 1. LOCATIONS, WATER DEPTHS AND DATES OF COVERAGE FOR THE TEMPORARY RECORDING STATIONS.

Location (see Figure 1)	Depth (m)	Dates
(A) Farmer's Beach	2.4	7/15-7/22
(B) South Bay	3.7	7/23-7/27
(C) State Dock	3.4	7/27-7/30
(D) Water Treatment Plant	4.3	7/31-8/6
(E) Dodge's Point	3.7	8/7 -8/13
(F) Fish Hatchery	2.4	8/20-8/27
(G) Black Rushes	2.4	8/28-9/3
(H) Tanglefoot	4.0	9/3 -9/8
(I) Bayside	4.3	9/9 -9/15
(J) West Shore of East End	3.1	9/16-9/23

Ryan Recording Thermometers

The self-contained, waterproof Ryan recording thermometers function for eight days without attention. Each unit consisted of a metallic temperature-sensing coil connected to a stylus that recorded the temperature on a strip of pressure-sensitive graph paper. The exposed graph paper was stored on a spool driven by a clock-like timing device. The instrumentation was protected by a watertight steel cylinder. The assembled recorder weighed 1.87 kg and was 16.5 cm high and 8.3 cm in diameter. The thermometers were accurate within ±0.7°F.

Because the temperature-sensing element was not in direct contact with the water, it was recognized that there would be a lag in the response of the recorded temperature to a change in the water temperature. This lag was estimated in the laboratory by placing one of the instruments in a constant-temperature bath and allowing the recorder to come to equilibrium with the external temperature. It was then moved to another water bath of a different temperature for several hours before the temperature graph was removed. This procedure was repeated three times. When plotted against time, the differences between recorded and actual temperatures produced an exponential curve. A semilogarithmic plot of the data resulted in a straight line from which it was determined that the temperature differences were reduced by half every 26 min.

This result was used to estimate the potential errors due to the lag in the response of the recorder. In most instances the field records showed water temperatures followed a 24-hour cycle, with the high temperature occurring in the early evening, and the low in the late morning. We assumed that the diurnal curve could be approximated by a sine curve with a 24-hour period and applied the techniques outlined by Benedict (1969) to predict the potential errors. With a 26-min half-time, the amplitude of the recorded daily curve would be only 1.3 percent smaller than the amplitude of the external temperature curve, and the peaks and lows of the recorded curve would occur about 37 min later than they occurred outside of the instrument. Neither of these errors is considered significant in this study.

The average daily water temperature at each recording station was calculated by averaging the temperature at 0300 and every third hour afterward, including the reading at 2400. Graphs not including all eight of these points were not used. The incomplete graphs were obtained when the thermometers were taken to the laboratory each week, where accuracy was checked and new graph paper installed. Units were returned to the lake as quickly as possible, but weather conditions caused up to 48-hour delays in some instances.

Clear Lake Water Treatment Plant Records

The treatment plant is located on the northeastern end of the lake (Figure 1). Examination of the plant's structural plans suggested negligible temperature changes would result from pumping lake water into the plant where the temperature is recorded. Water is drawn from the 3-m stratum at a point where the maximum depth is 4 m. It is then pumped into the treatment plant via a 198-m intake pipe extending approximately 150 m into the lake. The water is pumped to the second floor of the plant where it is aerated. Flocculating and coagulating chemicals are added to the water as it is gravity fed into a large flocculator-settling tank on the first floor where the water temperature is recorded daily at about 1200 with a common dairy thermometer.

Twice during the summer of 1966, a Whitney underwater thermometer was used to record the water temperature near the intake pipe in the lake. On both occasions the lake water temperature was within 1°F of the temperature recorded in the treatment plant.

RESULTS

Diurnal Variations in Temperatures

Daily ranges or differences between the maximum and minimum temperatures on each day for 298 complete diurnal temperature curves at six recording stations were calculated and are summarized in Figure 2. Greatest daily temperature fluctuations were found at stations 1 and 3, which represent exposed and weedy shorelines, and at station 5, which represents a shallow marsh habitat. The water depth at all three of these stations is less than 1 m. The next greatest average daily temperature range was found at the West End station in 2 m of water, followed by the surface recorder at the deep station over 5.9 m of water. The smallest average daily temperature range was found near the bottom at the deepest station. In general, the shallower the water, the greater the range of the diurnal temperature curve.

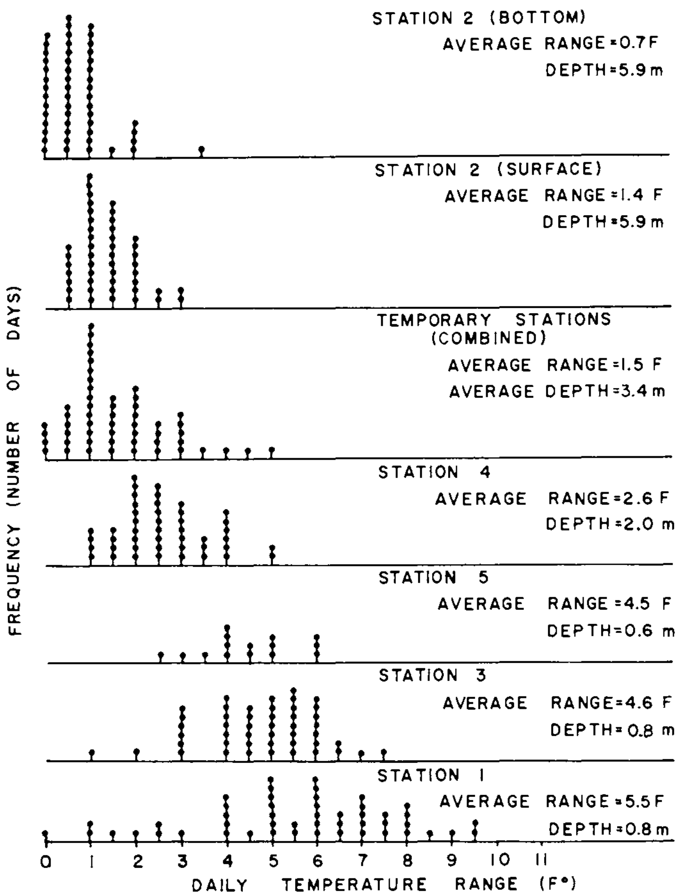

Figure 2. Frequency distributions of daily water temperature ranges recorded at various stations in Clear Lake from July 16 to September 22, 1966.

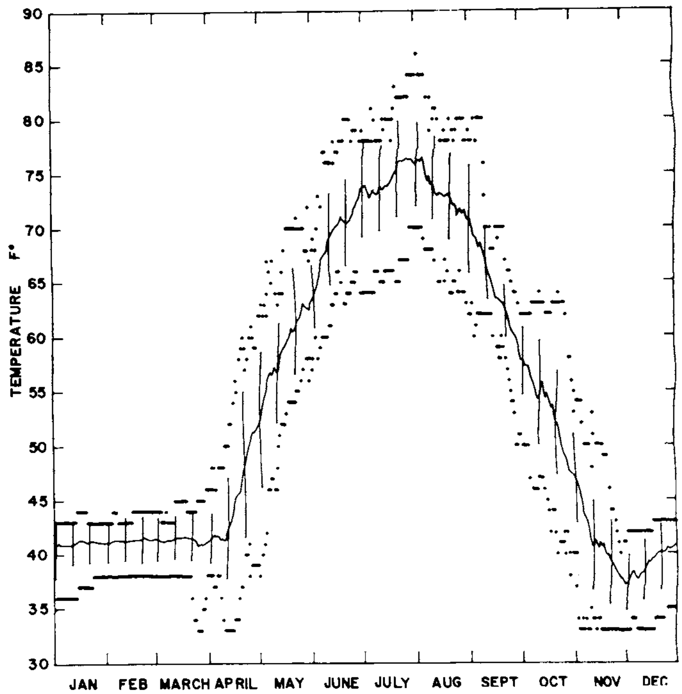

Figure 3. Average daily water temperatures recorded at the surface at station 2 as a function of the average daily temperatures recorded at the bottom at the same station.

Thermal Stratification

Data from the surface and bottom recorders at station 2 can be used to determine if Clear Lake undergoes thermal stratification. In general, the temperatures at the two depths followed one another (Figure 3), so that one can conclude that the deeper water is not isolated from the surface as is the case in classical thermal stratification. On the other hand, the average surface temperatures tended to be slightly higher than those at the bottom, indicating that the rate of mixing was not sufficient to keep the water column thermally homogeneous at all times, particularly at the higher end of the temperature scale. In general, we agree with the conclusion of Pearcy (1952) that Clear Lake does not thermally stratify.

Water Treatment Plant Temperatures

For each station the average daily water temperatures were compared with the temperatures recorded at the water treatment plant on the same days by using correlation analysis. Seven correlation coefficients (r) were highly significant at the 99 percent level of confidence. The three littoral stations (1, 3 and 5) had r values of 0.93, 0.91 and 0.85. Correlation coefficients for the three limnetic zone stations (2, 4 and the temporary stations combined) were 0.95, 0.97 and 0.96. The average daily water temperatures at the limnetic stations correlated slightly better with those at the treatment plant than did those at littoral stations.

TABLE 2. STATISTICAL TESTS OF THE DIFFERENCES BETWEEN THE DAILY WATER TEMPERATURES RECORDED AT THE WATER TREATMENT PLANT AND THE AVERAGE DAILY TEMPERATURES RECORDED AT EACH STATION.[1]

[1] The coefficients of correlation are for the relationship between the differences and the temperatures at the treatment plant; paired t-test is used to determine if the average differences in daily temperatures are significantly different from zero

Station	No. Pairs	r	Average Difference F	t
1	50	–0.251 n.s.	1.53	5.24 **
2 (Surface)	47	–0.260 n.s.	0.51	3.09 **
2 (Bottom)	52	–0.658 **	–0.90	
3	49	0.020 n.s.	1.84	6.81 **
4	45	0.046 n.s.	0.85	3.87 **
5	16	0.439 n.s.	0.80	1.59 n.s.
Temporary (Combined)	51	–0.220 n.s.	0.31	1.67 n.s.

n.s.–not significant at the 95 percent level.
**–significant at the 99 percent level.

To determine if the differences between the temperatures recorded at a given station and those recorded at the treatment plant were related to the absolute value of the water temperature, coefficients of correlation were calculated for these differences in relation to the temperatures recorded at the treatment plant on that day (Table 2). Except for the bottom temperature of station 2, the correlations were not significantly different from zero. It was then possible to calculate the average difference between temperatures measured at a given station and temperatures measured at the treatment plant. These differences are presented in Table 2 along with the results of paired t-tests used to determine if the differences were significantly different from zero.

On the average, the temperatures at the littoral stations 1 and 3 are 1.53°F and 1.84°F higher than those measured at the water treatment plant for the temperature ranges covered in this study (64° to 80°F). For the limnetic stations 2 (surface) and 4, the average daily temperatures were 0.51°F and 0.85°F higher than those at the treatment plant. The temperatures at the bottom of station 2 averaged 0.90°F below those at the treatment plant, although an unbiased test of this average could not be made because the differences were not independent of the absolute temperatures. The temperatures at station 5 in Ventura Marsh were not significantly different from those at the plant, although a small sample size made the test less sensitive than at the other stations. The water temperatures at the temporary stations were not significantly different from those at the water treatment plant.

The question whether the temperatures measured at the treatment plant are representative of the lake water temperatures is not easily answered, inasmuch as there is no single number that can be used to represent the lake water temperature on a given day. There are diurnal variations at each station, and there are differences in the water temperatures from one station to another. In general, the shallow stations have the greater range in daily temperatures and are somewhat warmer than those in the limnetic portion of the lake. The deepest portion of the lake has slightly lower temperatures than the surface waters. The temporary recording stations have water temperatures that come the closest to those measured at the water treatment plant. This is not surprising, because they are located near the boundary between the littoral and limnetic zones in about 3 m of water, which is similar to the location of the treatment plant intake.

From a practical standpoint, the temperatures measured at the plant are not greatly different from the average values found at the various stations, and correlations are very high. For most biological investigations, the plant temperatures can be considered as good estimates of the overall temperature of the lake and as a good index of the temperatures in the shallow areas along the shores. Although our study did not include the colder portions of the year, there is no reason to believe that the relationship would be significantly different at those times. Indeed, the decreasing amounts of solar radiation at those times might contribute to a more uniform thermal environment than found in the summer. It would be expected that, during the periods of ice cover, the usual inverse thermal stratification would lead to water temperatures at the plant that were somewhat higher than those found immediately below the ice.

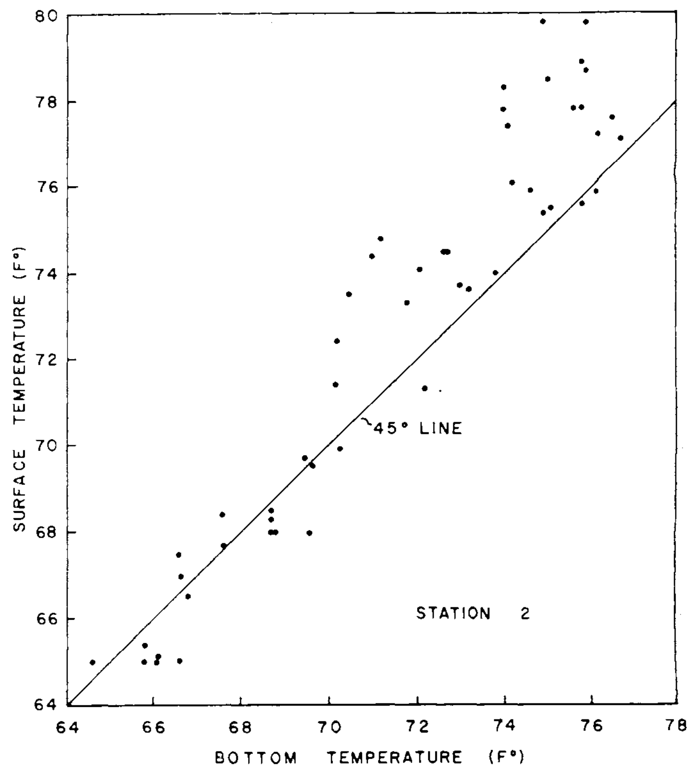

Figure 4. Average daily water temperatures recorded at the Clear Lake Water Treatment Plant for the years 1950 through 1965. The points represent the maximum and minimum temperatures recorded for each date, while the vertical lines represent one sample standard deviation above and below the mean calculated for the 1st, 11th and 21st days of each month.

Annual Temperature Cycle

The annual temperature cycle in Clear Lake has been summarized from the daily water temperatures measured at the water treatment plant for the 16-year period, 1950-1965. The average water temperature for each calendar day has been plotted in Figure 4 along with the maximum and minimum temperatures on those days. As an additional measure of the

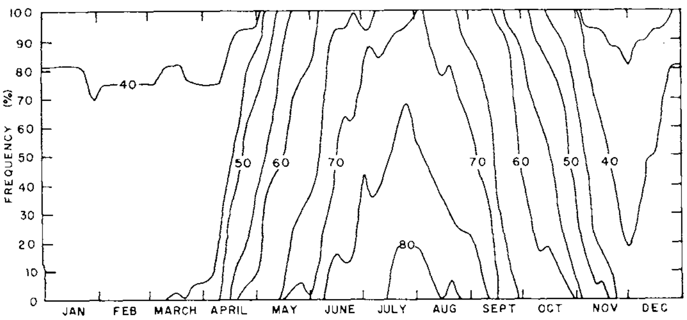

Figure 5. Cumulative frequency distributions of water temperatures recorded at the Clear Lake Water Treatment Plant on each day for the years 1950 through 1966.

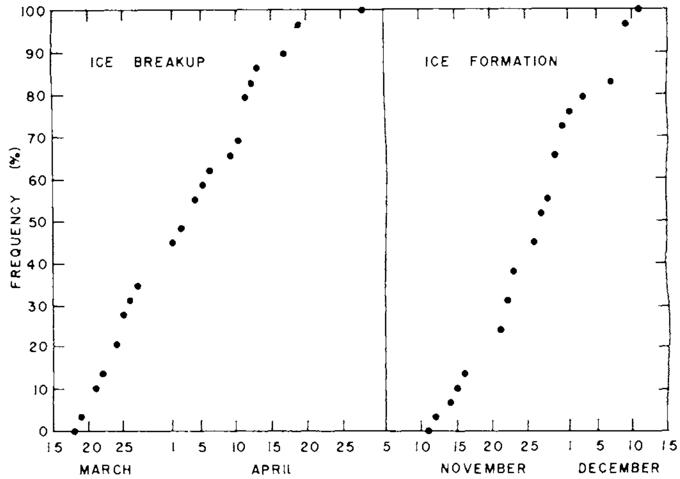

Figure 6. Cumulative frequency distributions of the dates of ice breakup and ice formation in Clear Lake for the years 1938 through 1966. For example, in 45 percent of the years covered, the ice broke up on or before April 1.

variability in temperatures, the sample standard deviation from the mean was calculated for the 1st, 11th and 21st day of each month and plotted as a vertical line extending one standard deviation above and below the respective means. The least variability was during the ice-covered period of December through March, and the greatest variability was during the warming period of April and May.

Another method of expressing variability is illustrated in Figure 5 where cumulative frequency distributions are drawn for each 5°F. These distributions were constructed from the 16-year record by determining, for specific days of the year, the number of days that indicated temperatures were equaled or exceeded and then expressing these as a percentage of the 16 years examined. The actual points were calculated for five-day intervals to smooth out the curves. As an example of how the curves can be used, a vertical line raised at the September 1 date will cross the 75°F line at 10 percent, the 70°F line at 45 percent, and the 65°F line at 88 percent. The greater the number of isotherms crossed by such vertical lines, the greater the variability in temperatures on that day. If some biological event, such as fish spawning, is known to be triggered by a specific temperature, these curves can be used to estimate the probability that the temperature will be reached by a specific date.

Data on freezing and thawing dates at Clear Lake have been treated similarly in Figure 6. The curves are based on the years 1938 through 1966 from data supplied by the Clear Lake Water Treatment Plant. They represent the day of ice breakup in the spring and the first day of ice cover in the fall. The median thaw date was April 3, with a 42-day range from March 17 to April 28 for the 29-year period covered. The median day of ice cover was November 27, with a 31-day range between November 12 and December 11. The ice-free period ranges from 217 to 261 days per year, with an average of 238 days. Neess and Bunge (1957) reported an average ice-free period of 153 days for Lake Mendota, Wisconsin.

We tested to see if there was any relationship between the date of ice-cover formation and the date of ice breakup in a given year. We wanted to see if a late date for ice breakup would lead to an early date of ice formation or vice versa. The freezing and thawing dates were expressed as the number of days since the first of the year, and a coefficient of correlation was calculated for the pairs of dates. It had a value of 0.184, which was not significant. A similar test was run between the date of ice cover and the date of thawing during the next spring. The correlation coefficient was 0.030, which also was not significant. We concluded that freezing and thawing dates were independent of each other.

With Figures 4, 5 and 6, the annual temperature cycle can be summarized. The ice leaves the lake about April 3 at a time when the water temperature as measured at the treatment plant is about 42°F. In many years, there is a drop in the recorded temperatures of about 5°F at this time, which probably reflects the breakdown of the inverse winter stratification. The average temperature for the month of April is 45.6°F. There is a continuing warming trend in May and June, with average temperatures of 59.0°F and 69.2°F, respectively. July, with an average temperature of 74.6°F, is the warmest month of the year, with the highest average daily temperatures occurring the last week of this month and extending into the first week of August. The highest temperature recorded in the 16 years of records was 86°F on August 2. August is slightly cooler, with an average temperature of 73.4°F. The cooling trend accelerates in September, October and November, with average temperatures of 64.5°F, 53.2°F and 40.9°F. Ice forms on the lake in half the years by November 27. The coolest temperatures are found in December, with an average of 39.3°F. Temperatures of 33°F were recorded 17 times in the first three weeks of December during the period of study. The water temperatures start to rise as soon as the ice cover is formed, presumably as the result of solar radiation penetrating the ice cover and establishing the winter stratification. The temperature rises slowly for the rest of the winter, with average temperatures of 41.0°F, 41.2°F and 41.3°F for the months of January, February and March.

The annual temperature curve is asymmetrical, with the highest average annual temperature of 76.5°F occurring on August 5, and the lowest average daily temperature of 37.1°F occurring on November 30. Thus the lake is warming over a period of 246 days and is cooling for only 119 days. On half the days, the temperatures are below 51°F, and the average daily temperature is 53.7°F.

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