THERMAL STRATIFICATION IN SOME EASTERN OKLAHOMA WATERS[1]

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Research programs initiated by Birge (1,2,3) and his associates in Wisconsin produced some basic assumptions on temperature conditions and heat budgets in natural waters. Welch and others have for many years investigated the thermal characteristics of Michigan lakes. Weibe (22,23,24), Dendy (6) and their co-workers at TVA have published considerable information on temperature and its relation to fishing in their waters. Chandler and Weeks (4) and Doan (7) on Lake Erie, Shapovalov (17) in California and many others have worked on the role of temperature in fisheries.

Papers by Irwin (11) and Thompson (18) on Grand Lake, and Leake (12) on Crystal Lake are the only Oklahoma records of thermal stratification. Texas information seems to be limited to papers by Harris and Silvey (10) and Cheatum, Longnecker, and Metler (5). The writer was unable to find recorded thermal data from Arkansas, Kansas, or Missouri. Some work, published from Colorado (14,15,16), deals with higher altitude lakes.

A series of continued physical, chemical, and biological investigations was initiated on the waters of Eastern Oklahoma during the summer of 1950. The studies were designed to compare limnological characteristics of Oklahoma waters with recorded data on other waters. The thermal data, collected in the first summer, are presented at this time.

The waters described in this study are located in Muskogee, Sequoyah, and Cherokee Counties in the central part of Eastern Oklahoma. Weekly examinations were made of the waters of the Illinois, Grand, and Arkansas rivers, Manard Bayou, and a small unnamed tributary of the Arkansas River.

Thirteen ponds of various sizes between 0.1 acre and 15 acres, with depths between 1 meter and 4½ meters were examined in Muskogee County. Some ponds were being used for stock water and some for minnow culture. The 15 acre pond alone produced any considerable amount of wave action since the other ponds were either situated in areas protected by trees and hills, or were too small to be subject to effective wave action. This work consists mainly of weekly records for Pray Pond, a reservoir with 5.35 surface acres, a maximum depth of about 4½ meters and a volume of about 15 acre feet. The other ponds were each analyzed once during the summer.

Greenleaf Lake, a larger impoundment examined, has 920 surface acres and a volume of approximately 14,720 acre feet (13). It drains an area of about 52,000 acres of which 80% is timber, 10% is pasture, and 10% is cultivated land. The maximum depth is about 15 meters at spillway level and this depth may be found at several places in the old creek bed. The lake is more than 4½ miles in maximum length and about one-half mile at its greatest width. Its banks are precipitous with very little shallow water; therefore, it has no extensive beds of aquatic vegetation, even though it is clear and has been in existence since 1936. Greenleaf Lake temperatures were checked three or four times weekly and on many occasions data were collected at two or more places in the lake.

Temperature data were secured with a Whitney direct reading thermometer of the electrical resistance type. All readings were taken by meter depths, and all values were expressed on the centigrade scale. Thermoclines were recog-

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nized as being present when the temperature decrease was 1° C. or more per meter of depth, according to Birge's rule (19).

STREAMS. The Arkansas River was sampled at Webbers Falls, Oklahoma, under the bridge on Highway 64. The Illinois River station was located a short distance below Tenkiller Dam (under construction). Grand River was sampled at the east end of the bridge, west of Fort Gibson, near the confluence of Grand and Arkansas Rivers. The Manard Bayou station was located at the bridge on Highway 10 south of Muskogee, as was the station on a smaller tributary creek farther south.

The stream surface temperatures recorded during this study varied between 24.8° and 33.1° C. (Average 27.1°). The summer of 1950 was unusually cool and moist so that these temperatures are actually cooler than those listed for the upper Mississippi River between Minnesota and Missouri in July and August of 1921 (27-29° C. average given by Galtsoff, (9).) Stream temperatures found in this study were lower at the surface and at the bottom than at comparable depths in impoundments throughout the period of observation. Thermoclines were present in Manard Bayou on three occasions with 2.1° C. decline in the first meter on July 3 while on June 26 and July 20 temperature decreases in the first meter were 1.2° and 1.3° C. respectively. Temperature drops of slightly more than 1° C. were found in the first meter of the Arkansas River on June 19 and June 26. In both of these streams the water level was low and current at a minimum at the stations examined. A reduction of current has long been recognized as necessary for this stratification (9). It is interesting to note that the Arkansas River was turbid (380 ppm. on June 19, and 87 ppm. on June 26) while Manard Bayou was clear (less than 25 ppm. of turbidity and with 1½ meters Secchi disc visibility) when measured on each occasion. No thermocline was found in the other streams with a more rapid current at the stations tested.

PONDS. Welch (19) stated that pond waters tend in general to follow the temperature of the atmosphere. This statement has been accepted for natural ponds with the many reservations and exceptions listed in his discussion. Since 1935 all parts of the United States, and the southwestern states in particular, have been building many small impoundments usually called farm ponds. Data on ponds have been taken from the natural ponds of the north and applied to these small impoundments. Although stocking of farm ponds has received much interest, some basic things, as temperature, have been almost completely ignored in the literature.

Thirteen ponds were examined during this study, and although only one (Pray Pond) was visited regularly, all of them exhibited thermal phenomena similar to that listed for Pray Pond (Table I). All were thermally stratified so that surface temperatures were inadequate to describe them as distinct ecological situations. Pond bottom temperatures did not increase to any considerable extent during June and July. All ponds showed thermoclines from surface to bottom when examined except the 15 acre pond where the

TABLE I

Temperature Data from Pray Pond

DATES OF SAMPLING

DEPTH IN METERS	JUNE				JULY						
	16	17	24	29	6	13	14	18	24	25	27
0	33.3	31.4	29.2	27.9	30.5	28.1	27.5	27.6	31.3	27.8	30.8
1	28.8	28.9	28.0	27.9	27.3	28.0	26.4	25.8	27.9	27.6	27.1
2	20.8	21.6	27.5	25.4	23.8	23.9	24.1	25.0	24.4	25.1	24.7
3	18.5	17.6	18.2	18.1	18.6	18.6	19.6	19.4	19.2	20.4	20.1
4		16.0		15.9	15.9	15.9	16.3	16.1	16.7	17.5	16.7
4.5		15.3		15.5	15.6	15.6	15.6	16.1	16.2	16.4	16.0

temperature was uniform at 0, 1, and 2 meters. Data collected by Dr. J. K. G. Silvey (personal correspondence, 1950) in North Texas during the period 1939-1949 were examined and agree with the above statements. All ponds falling within the size limits given and with depths of greater than three meters were thermally stratified. Silvey found decreases of 6.8°C. in the second meter and 6.9°C. in the third meter of a three meter pond of 3.57 acres in June, 1949. Although Eggleton (8), stated that "records of more than 7 degrees centigrade drop per meter of depth are very rare," the writer found such decreases on five different days in two of the ponds and once in Greenleaf Lake. Silvey found an 8.2° C. decline in one of his ponds and a 7.0° C. decline in another in June of 1949.

All records of more than 7° C. fall per meter were secured in June. These results are perhaps best compared with the work on Bog lakes in northern Michigan in the early summer where those with comparable depth show similar thermal conditions in the absence of wind action (20,21).

Not only decline in temperature per meter but also total vertical fall in temperature of the ponds is comparable to the bog lake data. In Oklahoma ponds such a drop in temperature was commonly as much as 12° C. and one examination revealed a decline of 16.1° C. within 4½ meters. Silvey has data on two ponds showing 13° C. decline in two meters. Welch (20,21) found surface to bottom declines of as much as 15° C. to be common to several bog lakes in Northern Michigan.

GREENLEAF LAKE. Greenleaf Lake temperatures were checked at four primary stations (Fig. 1). Station number 1 was visited at least once weekly. Stations number 2, 3, and 4 were examined on occasions during the eight weeks period.

Thermal stratification was discovered at the first visit to Greenleaf Lake on June 12. Welch (19) states that thermocline formation often begins with a wide thermocline (4-18 meters in Douglas Lake), or may be evidenced as 2 or 3 thermoclines with the total temperature decline about the same in either instance. Greenleaf Lake exhibited three thermoclines on June 12. Thermoclines did not exceed two in number on later visits, although two thermoclines were present on many later occasions. At least one thermocline was evident throughout the observation period.

The initial thermocline limits approach each other during the summer in Northern waters with the top of the thermocline being lowered and the bottom being raised slightly (19). In Greenleaf Lake both the upper and lower limits of the persistent thermocline were below those of earlier dates. (Table II). Secondary thermoclines appeared on many occasions but the limits of the persistent thermocline gradually fell from between 0 and 7 meters on June 17 to between 7 and 9 meters in late July. Finally in late July a heavy rain refilled the reservoir that had been drawn down for repairs to the spillway and on August 1 the thermocline was between 9 and 11 meters.

A drop of 9.8° C. in one meter between 6 and 7 meters was found on June 18 by the writer and Dr. W. H. Irwin near the leeward end of the part of the lake with the greatest fetch (station 4). Further upwind approximately the same decline in temperature was accomplished in a thermocline between 4 and 7 meters (station 3). At station 1 near the upwind end of the lake the thermocline was found to exist between 2 and 7 meters. The wind was blowing up the lake at about 15 miles per hour on this day after a few days of relative calm. Gauges have not been established, but it seems reasonable to assume that warm epilimnion water was being displaced to produce a seiche on this date. Temperature data for station 1 in Greenleaf Lake are given in Table III.

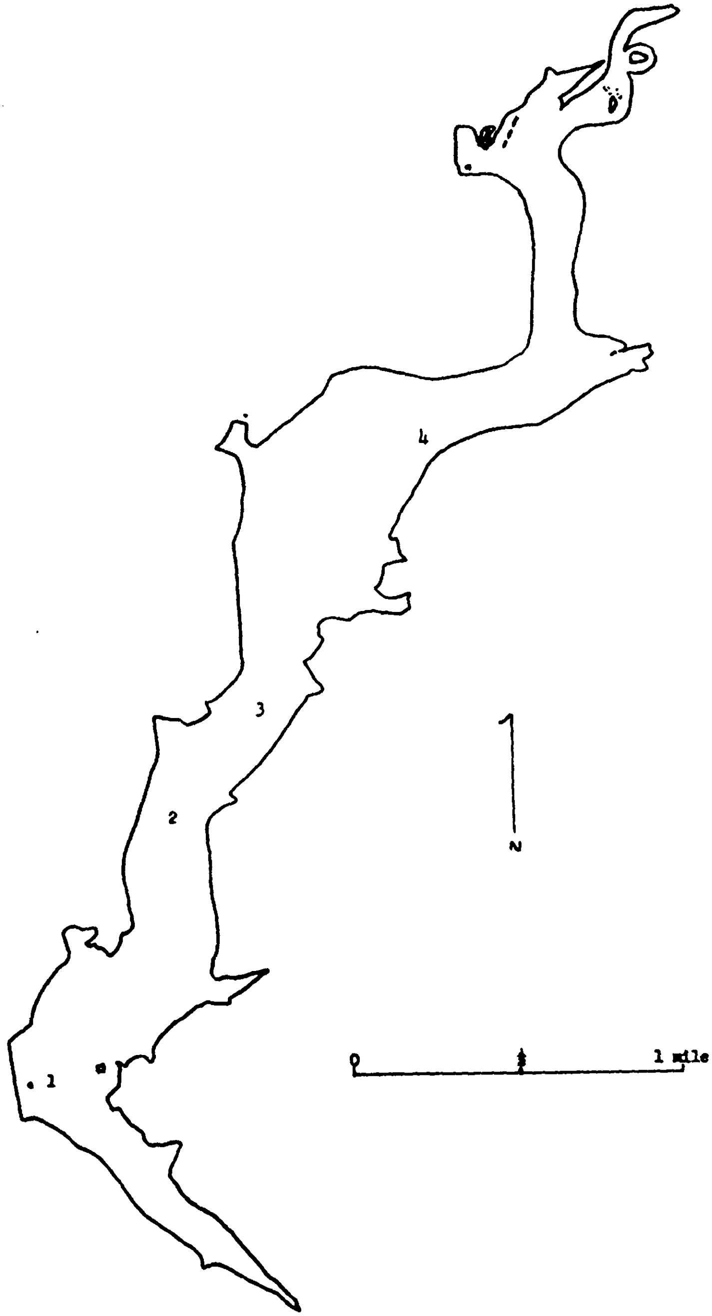

FIGURE 1

TABLE II

Thermocline Limits and Fall in Temperature Within the Thermocline at Greenleaf Lake

DATE (1950)	THERMOCLINE STATION 1		THERMOCLINE STATION 2		THERMOCLINE STATION 3		THERMOCLINE STATION 4	
	LIMITS	FALL IN TEMPERATURE	LIMITS	FALL IN TEMPERATURE	LIMITS	FALL IN TEMPERATURE	LIMITS	FALL IN TEMPERATURE
June 12	5-7	3.5°						
June 13			3-6	6.5°				
June 16					4-5	5.8°		
June 17	0-7	12.4°	2-7	10:3°				
June 18	2-7	8.6°			4-7	9.6°	6-7	9.8°
June 20	3-7	9.0°						
June 24			5-7	7.4°				
June 25	4-7	7.1°						
June 27	5-8	8.3°	4-8	8.5°				
June 30	5-8	7.3°						
July 4	5-8	7.0°						
July 8	4-8	7.3°						
July 10	5-8	6.3°						
July 11	5-8	6.3°	5-8	6.3°				
July 12	5-8	6.3°						
July 14	5-8	6.2°						
July 18	6-8	5.9°	6-9	6.2°	6-8	3.8°		
July 19	6-9	6.0°						
July 25	7-9	5.1°						
July 27	7-9	4.8°	7-9	5.1°	7-9	5.3°	7-9	4.9°
Aug. 1	9-11	2.5°						

TABLE III

Temperature Data from Greenleaf Lake
Station 1

DEPTH IN METERS	DATES OF SAMPLING: JUNE							JULY										AUG.
	12	17	18	20	25	27	30	4	8	10	11	12	14	18	19	25	27	1
0	27.0	30.9	27.9	30.2	27.2	28.3	27.6	27.2	27.5	26.0	25.9	26.5	28.1	25.9	26.1	27.8	27.7	26.4
1	25.4	28.9	27.5	28.6	27.0	28.2	27.4	27.0	27.5	26.1	25.8	26.2	28.0	25.8	26.0	27.8	27.1	26.2
2	24.2	27.7	26.9	28.2	26.9	27.5	27.3	26.9	27.3	26.1	25.8	26.0	27.6	25.8	25.9	17.6	27.0	26.1
3	23.6	26.2	25.8	26.8	26.7	27.4	27.3	26.8	27.0	26.1	25.8	25.9	26.6	25.7	15.7	16.8	26.9	25.8
4	22.2	23.1	23.5	24.8	26.4	27.2	27.2	26.7	26.7	26.1	25.7	25.7	26.4	25.7	25.5	26.2	26.6	25.3
5	21.8	21.4	21.5	22.4	23.7	27.0	26.7	26.3	25.5	25.9	25.6	25.6	25.6	25.7	25.3	25.7	25.5	23.8
6	19.5	19.5	19.5	20.6	20.9	23.8	23.6	24.0	24.1	24.3	24.6	24.6	23.8	25.4	25.0	25.1	25.2	23.0
7	18.3	18.5	18.3	19.2	19.3	19.7	20.5	20.5	21.3	21.3	21.3	21.4	22.2	23.5	23.9	24.3	24.3	22.5
8	17.7	18.0	18.0	18.4	18.6	18.7	19.4	19.3	19.4	19.6	19.3	19.3	19.4	19.5	20.1	21.3	21.6	22.3
9	17.5	17.8	17.7	17.9		18.3	18.9	19.0	18.9	19.2	18.8	18.7	18.9	18.9	19.0	19.2	19.5	22.0
10		17.6	17.5			18.1	18.3	18.7	18.6	19.0	18.6	18.5	18.7	18.7	18.7	18.8	18.9	21.0
11								18.5	18.4	18.6	18.4	18.4	18.5	18.4	18.4	18.6	18.6	19.5
12								18.1	18.1		18.2	18.0	18.1	18.1	18.0	18.3	18.1	18.7
13								17.6	17.5			17.5	17.9	17.6	17.6	17.9	17.6	18.4
14									17.4			17.3		17.4	17.3	17.5	17.4	18.0
15																		17.7

No density current (22) is recognizable by a study of the Greenleaf Lake temperature data. However, after the heavy rains late in July a layer of turbid water was found (10-13 meters) between upper and lower clear waters, and chemical conditions (to be described in a later paper) also indicated that a density current was present.

Summary

1. Eastern Oklahoma waters were thermally stratified in the summer of 1950.
2. Although the Arkansas River was turbid and Manard Bayou clear they became similarly stratified during early summer.
3. Surface to bottom stratification was found in 12 of the 13 ponds examined.
4. Temperature declines of 7° - 9.8 degree C. per meter were encountered in waters of the area.
5. A seiche was probably present on one occasion in Greenleaf Lake.
6. Three thermoclines were present on June 12 and two on several occasions in Greenleaf Lake.
7. The persistent thermocline in Greenleaf lake appeared at increased depths as the summer progressed.
8. Bottom temperatures of all impoundments increased very little during the summer.
9. A density current was evidenced by turbid water in the lower middle portion of Greenleaf Lake but exhibited no special thermal features.

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