Temperature Relations in Shallow Turbid Ponds[1]

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Thermal properties of many farm ponds of central Oklahoma differ from the better-known properties of large lakes because of the turbidity and relatively shallow depth of the ponds. Small aquatic situations are subject to wider daily fluctuations of temperature than are lakes. Studies of short term changes in temperature may be more informative than annual heat budgets. Young and Zimmerman (1956) indicate that for ecological studies of small organisms that live in shallow waters, the usual temperature determinations may prove meaningless. In the present paper a method of analysis of temperature relations in shallow, rapid-heating habitats is described and measurements of heat absorption in turbid water are reported.

Turbidity of ponds in central Oklahoma is the result of suspended clay particles as well as microscopic organisms. Much of the exposed land surface is Permian red clay (Sheerar, 1932). Clay particles washed into ponds may approach colloidal dimensions. The electrical charge borne by the particles prevents rapid aggregation and subsequent settling (Irwin and Stevenson, 1951). Turbidity-causing particles may stay in suspension for long periods of time, especially with mixing by wind action which is characteristic of ponds in the area.

Temperature of surface water in turbid ponds often exceeds that of non-turbid ponds of similar size and morphology and may even exceed that of the air above it. A small pond with 400 ppm turbidity on July 21, 1962 had a surface water temperature of 36.7 C while the air temperature was 35.0 C.

Stratification tends to be more pronounced in turbid situations. Vertical variation in temperature in two sets of adjacent turbid and clear ponds is shown for two different dates in Figure 1. Temperature change with depth is greater in the turbid than clear ponds. Average temperature decrease per foot of depth in Myer's upstream pond (Figure 1-a, dashed lines) was about 1.5 times that of Myer's downstream pond (solid lines). This agrees with Wallen's (1951) conclusion that there was a greater temperature difference between surface and bottom in turbid than in clear ponds. The second set of vertical pond temperatures (Figure 1-b) are from the ponds studied by Wallen (1951) in which only surface and bottom temperatures were recorded. Summer temperature stratification similar to that in Myer's upstream pond was found by Wallen (1950) in other farm ponds.

Energy of solar radiation incident upon pond surfaces may be reflected, absorbed by the water as heat, or absorbed by photosynthetic organisms and converted to chemical energy and heat. Much of the energy received

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is reradiated, lost as heat of evaporation or in heating of bottom mud, and does not contribute immediately to heating of the water mass. Radiation absorbed by organisms and changed to heat contributes to the temperature of a water body as does metabolic heat although both are negligible for these calculations.

Temperature data were obtained with thermometers employing the electrical resistance change of a thermistor (Donaldson, 1958). A Harco six-gang time switch and a Rustrak recorder were used to make simultaneous recordings of three temperatures. Measurements of turbidity were made with a Bausch and Lomb "Spectronic 20" Colorimeter calibrated in Jackson Candle Turbidimeter units. Continuous measurements of solar radiation are made with a pyrheliometer at the Oklahoma State University Weather Station.

The amount of heat absorbed by the water in a pond during a day or other time period may be measured. The rate of change of temperature with respect to time, $\frac{\partial \theta}{\partial t}$, where θ is the temperature at any depth and t is time, when plotted against time yields a differential equation, the positive integral of which gives a measure of the total temperature change. The total temperature change is multiplied by the volume in cm^3 to obtain heat absorption by the layer in gram calories. Rate of change curves may be prepared for the strata of a pond and the absorptions for all strata then

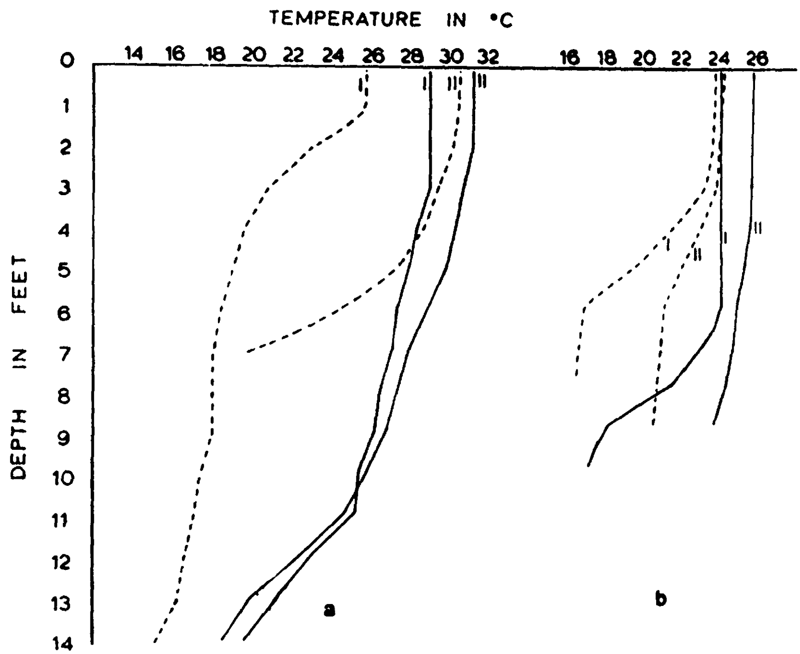

Figure 1. Temperature curves for two sets of adjacent clear and turbid ponds: (a) Myer's ponds, upstream (25 ppm turbidity) dashed and downstream (8 ppm turbidity) solid, I, July 13, 1960; II, July 21, 1960. (b) Berry Ponds, upstream (45 ppm turbidity) dashed and downstream (14 ppm turbidity) solid, I, October 10, 1962; II, October 15, 1962.

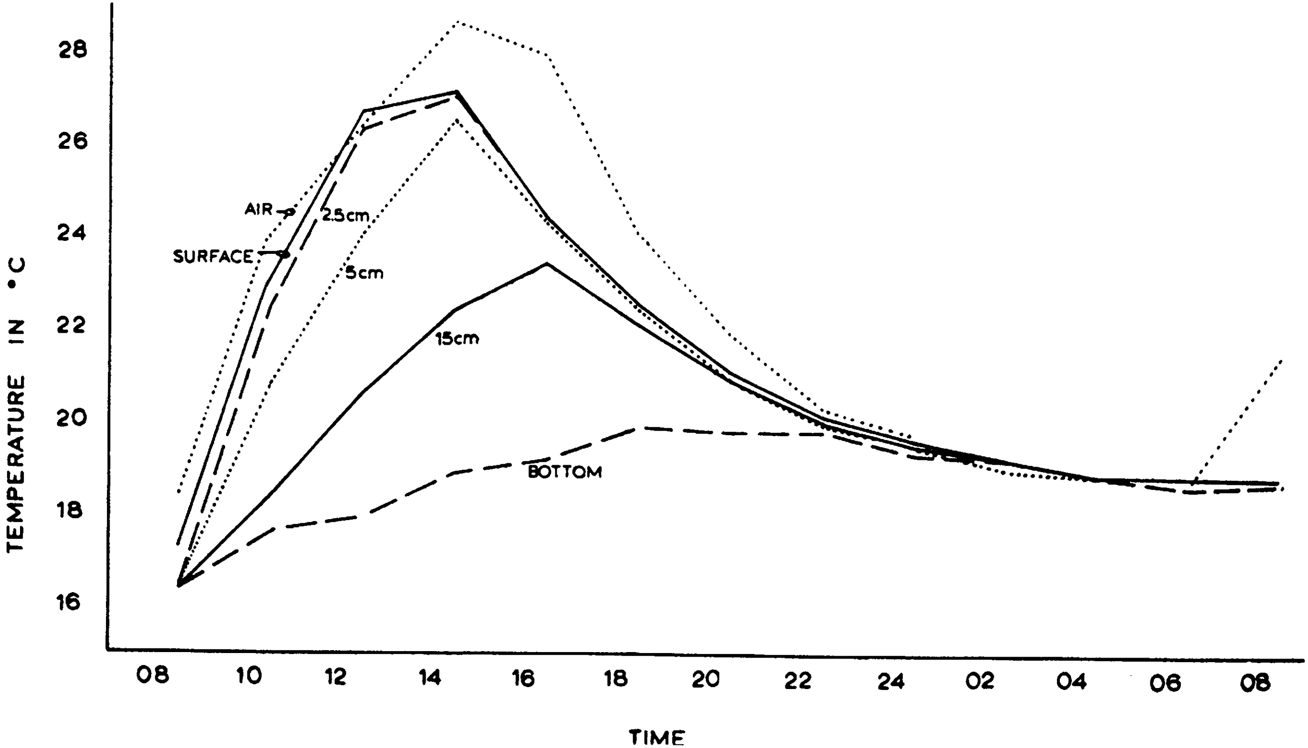

Figure 2. Temperature variation during 24 hours in a shallow temporary pond, 38 cm in depth and 180 ppm turbidity, October 4, 1962.

TABLE I. TEMPERATURE CHARACTERISTICS AND HEAT ABSORPTION IN A SHALLOW, TURBID POND.

depth cm	stratum represented	volume of stratum cm^3	maximum $\frac{\partial \theta}{\partial t}$ °C/hr	total temperature change °C/cm^3	heat absorption KCal
1	0-1 cm	52,000	2.8	20.54	1,068
2.5	1-3 cm	104,000	3.0	22.15	2,304
5	3-6 cm	156,000	2.2	19.83	3,093
15	6-20 cm	444,000	1.1	13.97	6,203
30	20 cm to bottom	376,000	0.6	7.02	2,640
					15,300

may be summed to obtain the total heat absorbed in the pond.

Total radiation on the pond surface may be estimated by multiplying solar radiation as measured by the pyrheliometer in cal/cm²/hr by the surface area. Summing the radiation/hour for the day or other time period yields the radiation available for heating the pond during the period.

The daily temperature cycle of a shallow, temporary pond with a turbidity of 180 ppm is shown in Figure 2 at the surface, bottom (38 cm), and depths of 2.5, 5 and 15 cm on October 4, 1962. Also shown is the temperature cycle of the air above the water surface.

Total solar radiation was 446.7 cal/cm²/day. Radiation on the pond surface of approximately 52,000 cm² was 23,298 kcal. About 65% of the total solar radiation available was used in heating the pond. Heat absorption by each stratum of water, temperature change in a stratum and the volume of the stratum are shown in Table I.

Maximum temperatures were attained at progressively later times with increasing depth. Maximum temperatures were observed at 14:30 o'clock at the surface, 2.5 cm and 5 cm layers; at 16:30 at the 15 cm

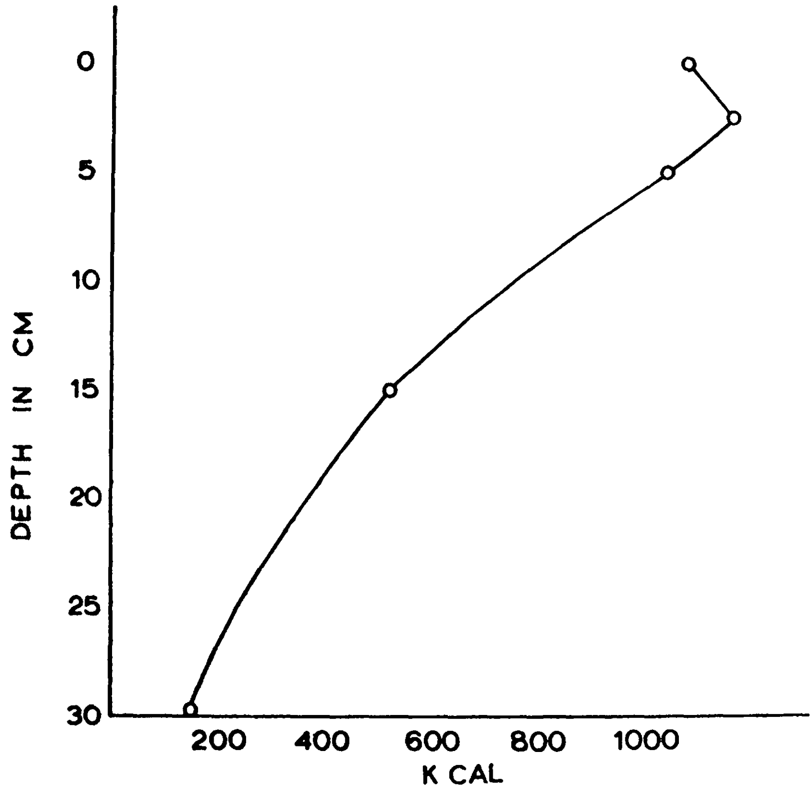

Figure 3. Heat absorption by one cm strata at various depths in a shallow, temporary pond, 38 cm in depth and 180 ppm turbidity, October 4, 1962.

layer; and at 18:30 at the bottom (Figure 2). Rate of change of temperature for the surface and 2.5 cm layer was maximal from 8:30 to 12:30 while the maximal rate persisted until 14:30 at 5 cm. At 15 cm the rate of change was less than nearer the surface and was relatively uniform until the maximum temperature was attained. In the bottom layer the rate of change was low and fairly uniform. The later time at which maximum temperature was attained in the bottom layer was probably the result of heat transfer from upper layers by conduction and turbulence of the water.

Heat absorption by a layer of water one cm in thickness at various depths is shown in Figure 3. The major fraction of absorption occurred in the upper five or six cm with greatest absorption two to three cm below the surface.

The temperature patterns characteristic of turbid and clear ponds are the result of differences in absorption of solar radiation. In shallow situations where radiation penetrates to the bottom, much heat is used in heating bottom mud and the water mass tends to have more uniform temperature conditions. In turbid situations of similar depth radiation is absorbed in the water mass, a greater amount near the surface and less near the bottom, and the bottom mud heats to a lesser extent. Unless there is mechanical mixing, pronounced stratification occurs.

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