Physical and Chemical Profiles in Lake Texoma (Oklahoma -Texas) in Summer 1982 and 1983

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Lake Texoma, a large, relatively shallow reservoir on the Oklahoma -Texas border, is stratified in late summer. In summers of 1982 and 1983 we made weekly determinations of vertical physicochemical profiles and fish distribution at rive stations in the main "deep basin" of the reservoir. This part of the reservoir, formed by the junction of the Red River and Washita River arms of Lake Texoma, has a distinct "chemocline" at which there is characteristically a sharp decrease in oxygen and pH, and an increase in specific conductance. In contrast to many natural lakes, Lake Texoma exhibits a gradual decrease in temperature from surface to bottom, without an abrupt thermocline. Although the basic pattern of stratification was similar from July to early September in both years, there were important differences between years in the depth of the chemocline (defined as depth in meters at which dissolved oxygen dropped below 2.0 ppm). Depth of the chemocline also differed substantially among stations on some of the sampling dates. During stratification in both years, the hypolimnion was anoxic. In both years during maximum stratification fish were concentrated in a few meters of the water column immediately above the chemocline. The vertical location of the chemocline, and the resultant position of the epilimnion and hypolimnion, can be critical factors in plans for withdrawal of water from the reservoir or for fish management.

INTRODUCTION

Limnologists have long understood the physical and chemical stratification of natural lakes; thus patterns of physical and chemical profiles in those systems are well documented (1). Despite numerous studies of physical and chemical profiles in man-made reservoirs (2, 3), patterns of reservoir stratification are not so well-documented or understood as those of natural lakes. Throughout the warm months of 1982 and 1983, we documented vertical physicochemical profiles in the "main basin" (downlake, where Red River and Washita River arms meet) of Lake Texoma (Oklahoma -Texas), with emphasis on similarities and differences among stations. We also evaluated the influence of the physicochemical profiles on the vertical distribution of fish. A partial summary of the 1982 physicochemical data and vertical fish distribution were presented by Matthews et al. (4). Here we present more details of the 1982 results including variation among stations, results for 1983, and a discussion of phenomena related to the position of the "chemocline".

This overview of vertical stratification of Lake Texoma is highly relevant to management of the reservoir. There have been plans by various agencies to use water from the main basin of Lake Texoma for water supply. The vertical location of physicochemical discontinuity in the water column (called a "chemocline" (4), in that the discontinuity is more evident in content of oxygen and dissolved solids than in temperature) is important with respect to withdrawal of water from the reservoir. Water removed from below the chemocline (i.e., in the hypolimnion) may contain chemicals such as ammonia or sulfites that lower water quality. Water removed from above the chemocline (i.e., from the epilimnion) will likely be well-oxygenated, but may (depending upon light penetration, nutrient availability, and inflow rates) contain a much higher density of phytoplankton, or other biotic materials such as fish eggs, larval fish, or zooplankton. Position of the chemocline also has a distinct effect upon vertical distribution of fish. Matthews et al. (4) showed that at maximum stratification the majority of fish in the open waters of the reservoir were suspended in only a few meters of the water column, directly above the chemocline. At that vertical location fish encountered the minimum available temperature without penetrating downward into the virtually anoxic hypolimnion.

STUDY AREA AND METHODS

Weekly from 23 April to 13 September 1982, and from 20 June to 21 September 1983, we measured physicochemical profiles at each of five stations in the main basin of Lake Texoma. The locations of sampling stations for water quality profiles are in Fig. 1; locations of associated echolocator runs to determine vertical fish distribution are in Fig. 1 of Matthews et al. (4). Because of extensive boat traffic in the study area, fixed buoys were not employed; stations were located each week from known points on shore. As a result, the physicochemical profiles were taken near to but not at an absolutely identical point each week. We estimate that within each sampling station the actual location at which the profile was taken varied by no more than 100 m, horizontally, during the study.

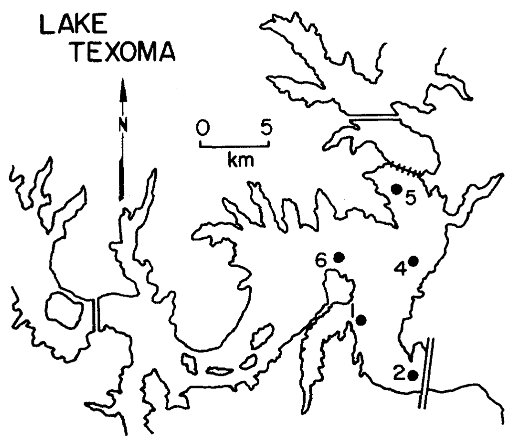

FIGURE 1. Location of physicochemical profile stations in Lake Texoma, 1982 and 1983.

In the following description of each station, the two figures in parentheses represent mean depth in meters in 1982, followed by 1983. Station 1 (26.3 m, 22.6 m) was located within the deep portion of the old Red River channel, immediately south of the Little Mineral Arm cove near the area known as Grandpappy Point (Fig. 1). Station 2 (27.0 m, 24.0 m) was ca. 0.5 km west of the dam in the deepest water of the old river channel that we could locate. Station 3 (not shown in Fig. 1) was not used for physicochemical profiles, but was used as an extra echolocator run for determination of fish depth distribution (Fig. 1 of Matthews et al. (4)). Station 4 (21.8 m, 19.8 m) was located in the old river channel, just offshore from a wide shallow area of submerged flats (Fig. 1). The area is known as Willafa Woods. Station 5 (23.6 m, 18.7 m) was located approximately halfway upstream from Washita Point to the railroad bridge in the Washita River arm of Lake Texoma (Fig. 1). Station 6 (20.8 m, 17.6 m) was immediately north of Preston Point near the point at which the Red River arm of the reservoir joins the common deep basin (Fig. 1).

Physicochemical and echolocator methods were as described by Matthews et al. (4) for both years; therefore they are repeated only briefly here. We used a Hydrolab Surveyor Model 6D to measure temperature, dissolved oxygen, pH, and conductivity at 2-m intervals from surface to bottom at each station. The Hydrolab unit was calibrated in the laboratory on the day of each run, using standard chemical methods. Echolocation of fish was carried out by a Lowrance LRG1510C Grayline recorder for ten minutes at each station on each date. Calibration of the echolocator for interpretation of fish "targets" is described in Matthews et al. (4). All sampling was carried out between 1000 hrs and early afternoon, typically ending by 1400 hrs.

RESULTS

In 1982 the main basin of Lake Texoma showed no trenchant stratification as late as 14 June (4). Throughout June weak discontinuities developed, but they were not persistent. On 21 June 1982, dissolved oxygen exceeded 2 mg/L from surface to bottom at four or the five stations (Table 1). As summer stratification increased during July, the reservoir stratified into a well-oxygenated upper zone (epilimnion), and a poorly oxygenated (later anoxic) lower zone (hypolimnion). At the discontinuity between zones a "chemocline" developed, across which values for dissolved oxygen, pH, and specific

TABLE 1. Depth of "chemocline" (defined as depth in meters at which dissolved oxygen concentration dropped below 2.0 ppm) at five fixed stations in the main basin of Lake Texoma (Oklahoma—Texas) in spring-summer 1982. Numbers in parentheses indicate dissolved oxygen in ppm at the bottom if there was no chemocline at a station.

Date	Station 1	Station 2	Station 4	Station 5	Station 6	Mean	±S.D.
23 Apr 82	(9.8)	(9.2)	(9.9)	(9.8)	(9.6)	—	—
3 May 82	(8.4)	(7.6)	(9.0)	(7.6)	(8.0)	—	—
10 May 82	(7.2)	(8.2)	(8.0)	(7.8)	(7.8)	—	—
19 May 82	(6.4)	(6.7)	(8.5)	(5.9)	(4.9)	—	—
25 May 82	(5.6)	(6.0)	(5.5)	(6.0)	(6.1)	—	—
1 Jun 82	(4.5)	(4.2)	(5.1)	(5.2)	(5.5)	—	—
7 Jun 82	(4.6)	(3.2)	(7.6)	(4.2)	(4.1)	—	—
14 Jun 82	(2.0)	(2.4)	(5.2)	(3.0)	27	—	—
21 Jun 82	27	(2.5)	(3.4)	(2.5)	(3.2)	—	—
28 Jun 82	25	25	—	21	19	22.5	±3.0
8 Jul 82	17	17	19	17	19	17.8	±1.1
12 Jul 82	17	19	17	17	17	17.4	±0.9
19 Jul 82	13	17	15	13	13	14.2	±1.8
26 Jul 82	13	13	11	11	15	12.6	±1.7
2 Aug 82	9	11	13	11	13	11.4	±1.7
16 Aug 82	13	13	14	13	13	13.2	±0.4
23 Aug 82	9	11	18	17	18	14.6	±4.3
31 Aug 82	15	15	17	17	19	16.6	±1.5
7 Sep 82	17	17	19	17	(5.4)	17.5	±1.0
13 Sep 82	21	15	23	19	—	19.5	±3.4

conductance changed markedly. In Lake Texoma, temperature did not change sharply at the "chemocline" (in contrast to natural lakes, in which stratification is mostly thermal). Rather, in Lake Texoma there tends to be a gradual decrease of temperature from surface to bottom, with less dramatic changes in temperature at the transition from epilimnion to hypolimnion than exists for the other measured variables. This is due, at least in part, to the fact that the reservoir is formed by the junction of the very saline Red River and the less saline Washita River. As waters from these two rivers unite to form the main basin, the more dense, saline water moves downward, creating what has been termed a "halocline" (5). Because this vertical level in the water column represents a transition in several chemical parameters including salinity, oxygen, and pH (and probably other water quality features), we use the term "chemocline" (4).

One caveat is in order. In reporting a gradual decrease in temperature with depth, and using the term "chemocline" for the boundary between the epilimnion and hypolimnion, we do not imply that chemical (e.g., salinity) differences are the primary factor causing or maintaining stratification of the main basin of Lake Texoma. Differences in temperature, although slight, result in large differences in density of water at temperatures as high as those in Lake Texoma in midsummer (1). For example, on 16 August 1982, during one of the periods of maximum stratification, the chemocline at Station 5 was between 12 and 14 m. At 12 m, salinity was 640 mg/L and temperature was 28.5 °C; at 14 m, salinity was 770 mg/L with temperature of 26.5 °C. On the basis of tables in Ruttner (6) and Welch (7), the difference in salinity between 12 and 14 m would result in a density difference (assuming 25 °C) of 0.00011 g/mL, whereas the temperature difference from 12 to 14 m would result in a density difference for water (assuming pure water) of 0.00056 g/mL, Although the natural water of Lake Texoma does not rigorously meet the assumptions of pure water at 25 °C, departures from the calculations above would be minimal. These, and calculations for several other stations and times, suggest that even during maximum stratification thermal differences contribute substantially more than chemical differences to the stability of the boundary layer between epilimnion and hypolimnion in the deep basin of Lake Texoma. The most appropriate view is that stratification of the lake would occur without any salinity difference, but that the salinity differences resulting from mixing of Red River and Washita River water accentuate the strength of summer stratification in the reservoir. Hubbs (5) ascribed stratification in the Red River arm of the reservoir to vertical salinity differences. Note that our conclusion does not negate his findings, in that his sites were far uplake from ours.

The position of the chemocline in Lake Texoma can be described in various ways. At this depth there is typically a sharp decrease in dissolved oxygen, an increase in specific conductance, a distinct lowering of pH, and (as indicated above) a gradual decline in temperature. Because of (a) its easy detectability, and (b) its critical significance to the distribution of organisms and a wide variety of reservoir chemical processes, we use the transition in dissolved oxygen concentration as the descriptor of the position of the chemocline. In Tables 1 and 2, we thus provide the depth in the water column at which dissolved oxygen drops below 2.0 ppm. Because our data were taken at 2-m vertical intervals, we have arbitrarily designated the odd-numbered meter between the even-numbered measurements as the chemocline. Thus, if dissolved oxygen decreased from, say, 5.5 ppm at 14 m to 1.5 at 16 m, we assigned the chemocline a depth of 15 m. (More precise interpolation was found impossible on occasions when we did actually document more precisely the actual point of transition, which was often within a few centimeters upward or downward.)

Table 1 shows that from 28 June 1982 until September, dissolved oxygen never exceeded 2.0 ppm at the bottom, i.e., there was a chemocline in the water column at some depth at all stations. On and after 8 July, the chemocline in 1983 was at a relatively uniform depth across stations on any given day (standard deviation among stations was typically less than 2.0 meters). However, as noted in Matthews et al. (4), on 23 August 1982 an internal seiche was observed to be generated by strong south winds that

TABLE 2. Depth of "chemocline" (defined as depth in meters at which dissolved oxygen concentration drops below 2.0 ppm) at five fixed stations in the main basin of Lake Texoma (Oklahoma—Texas) in Summer 1983. Numbers in parentheses indicate dissolved oxygen in ppm at the bottom if there was no chemocline at a station.

Date	Station 1	Station 2	Station 4	Station 5	Station 6	Mean	±S.D.
20 Jun 83	(2.4)	(2.9)	(3.9)	(6.4)	17	—	—
27 Jun 83	21	(2.1)	(2.0)	(4.5)	15	—	—
5 Jul 83	17	21	(2.9)	15	(6.2)	17.7	±3.1
11 Jul 83	15	15	17	15	13	15.0	±1.4
1 Aug 83	11	9	11	(3.4)	11	10.5	±1.0
8 Aug 83	9	9	11	7	9	9.0	±1.4
15 Aug 83	7	7	9	7	11	8.6	±1.7
30 Aug 83	5	13	13	11	11	10.6	±3.3
12 Sep 83	15	15	11	15	15	14.2	±1.8
21 Sep 83	(4.8)	(5.4)	(6.2)	(6.1)	(5.8)	—	—

apparently rocked the epilimnion upon the hypolimnion, producing dramatic differences between south stations (Station 1 and 2) and stations to the north (Station 4, 5, and 6) in depth of the chemocline. Seiches are well-known in natural lakes (1), and have been reported once previously in Lake Texoma (5). Clearly, such events can quickly change the physicochemical vertical profile at any given station on a reservoir, and could, for example, cause dramatic changes in the quality of water being removed from a reservoir by a water intake station operating at a fixed depth. Note also that even on calm days, there can be considerable differences among stations (e.g., 2-4 m vertical range) in depth of the chemocline. Further, there are seasonal changes in the mean depth of the chemocline (Table 1), with stratification first obvious as deep as 22.5 m (28 June), gradually moving upward in the water column to a depth of ca. 11 m by early August, then steadily moving downward with the onset of cooling and wind-mixing in the reservoir (Table 1). Clearly, it would be impractical to assume that any single given depth represents the position of the chemocline (or the "best" depth for fish) in Lake Texoma throughout the course of a summer, or from station to station.

The year 1982 was marked by major inflows from the Red and Washita rivers in late spring and early summer (8), and the reservoir was high and turbid. In contrast, in 1983 there were no dramatic inflow events, water levels remained lower, and the water had greater clarity overall than in 1982. However, in 1983, a pattern of vertical stratification developed similar to that in 1982 (Table 2). Onset of oxygen depletion at the bottom of the water column was about 1 week later (ca. 5 July 1983 at most stations) than in 1982. From 11 July 1983 all stations but one exhibited a decline in dissolved oxygen below 2.0 ppm at some position in the water column. The chemocline was at an average depth of 17.7 m on 5 July, migrated upward as stratification and reservoir respiration continued until it was at 8-9 m in mid-August, then eroded downward and broke up in late September. By 21 September 1983, all stations had dissolved oxygen exceeding 2.0 ppm from surface to bottom. As in 1982, there were considerable differences in 1983 among some stations in the depth of the chemocline. For both years it is clear that depth of the chemocline was not constant for all stations across all dates. There was considerable variation among stations in the vertical position of the chemocline in both 1982 and 1983, although on calm days this difference ranged only from 2 to 4 m. However, awareness of the spatial and temporal scale of such differences may be of value to agencies or water use managers and may provide a model for prediction of such profiles in other shallow, wind-swept southwestern reservoirs.

With regard to vertical distribution of fish in the water column, our results for 1983 mimic those of 1982 (4). For example (Fig. 2), on 1 August 1983, there was a transition to oxygen below 2.0 ppm at an average depth of about 10 m (Table 2). Temperature varied from ca. 30 °C at the surface to 26 °C at the bottom on that date, and pH varied with oxygen. The vast majority of fish detected by echolocation on that date were at a depth of 5 - 10 m in the water column, immediately above the chemocline. Clearly, in Lake Texoma, as in other southern lakes or reservoirs (2, 3), vertical profiles in oxygen, temperature, or other physicochemical variables can influence the depth distribution of fishes.

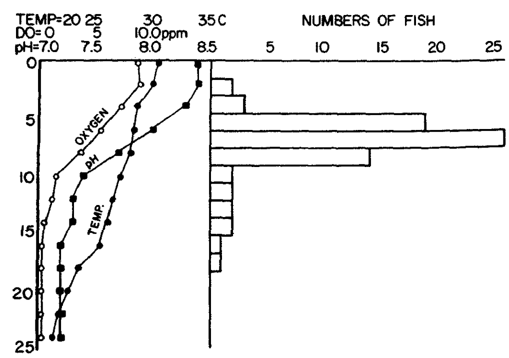

FIGURE 2. Vertical profile of physicochemical conditions and depth distribution of fish in Lake Texoma on 1 August 1983. Surface of reservoir is at top; depth in meters is on left vertical axis.

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