Limnology of Tenkiller Ferry Lake, Oklahoma, 1985-1986

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Water quality data were collected at 14 sampling sites on Tenkiller Lake from October 1985 to November 1986. Concentrations of ortho and total phosphate were high (means of 0.217 and 0.383 mg/L as PO_4 respectively) and elevated in hypolimnetic samples from the upper half of the impoundment. Chlorophyll *a* levels ranged from 1.04 to 55.78 µg/L and significant algal blooms were observed. Noticeable changes in many water quality parameters were observed at approximately mid-lake. High nutrient concentrations, elevated levels of chlorophyll *a*, the increasing incidence of nuisance algal blooms, and trophic state index values indicate that Tenkiller Lake can currently be classified as eutrophic.

INTRODUCTION

Water quality data were collected at Tenkiller Ferry Lake, Oklahoma from October 1985 to November 1986. The study was initiated in response to concern over deteriorating water quality in the Illinois River Basin and the probability of increased nutrient loading from nonpoint sources and municipal effluents. Tenkiller Lake has historically had clear waters and has been a popular site for SCUBA diving, water skiing, and other recreational activities. Project personnel and local residents explain that water clarity has decreased appreciably at Tenkiller Lake in recent years and nuisance algal blooms have occurred with increasing regularity during spring and summer months. The purpose of this study was to collect sufficient baseline water quality data to define current limnological conditions at Tenkiller Lake and to provide a basis for future water quality protection and monitoring.

STUDY AREA

Tenkiller Ferry Dam is located on the Illinois River 20.6 km above its confluence with the Arkansas River. The lake extends approximately 40 km and occupies portions of Sequoyah and Cherokee Counties in northeastern Oklahoma. At normal pool, Tenkiller Lake has a surface area of 5223 ha, possesses 209 km of shoreline, and has a volume of 80650 ha-m. The lake drains an area of approximately 4170 km², has a mean depth of 16 m and a maximum depth of 42 m near the dam. Completed in 1952 by the U.S. Army Corps of Engineers, Tenkiller Lake authorized project purposes are flood control and hydropower.

METHODS

Data were collected at 14 sampling sites on Tenkiller Lake (Fig. 1). Initial sampling was conducted on 8 October 1985. Data were then collected monthly during February and March, biweekly April through September, and monthly during October and November of 1986. Sampling dates were chosen to coincide with those selected by the states of Oklahoma and Arkansas for water quality sampling on the Illinois River above Tenkiller Lake. Overall, the study incorporated 17 sampling trips. Some sites were occasionally inaccessible owing to high water or dangerous winds.

Sampling was generally conducted between 0900 and 1300 h CST by two crews. One crew sampled Sites 1 through 7 while Sites 8 through 14 were sampled by the second crew. Depth profiles of water temperature, pH, dissolved oxygen, and conductivity were recorded with a Hydrolab Model 4041 or Surveyor II. Water depths exceeded the length of the probe cable (20 m) at several sites near Tenkiller Dam. Secchi disc transparency was measured at each site using standard procedures (1).

Water samples were collected at a depth of 0.5 to 1 m at each site in 1-L clear polyethylene containers. Samples for chlorophyll analysis were collected in 2-L opaque polyethylene bottles. Whirl-pak bags were used to collect coliform samples and samples for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) analyses transported in standard 300-mL BOD bottles. Additional hypolimnetic samples were collected at sites exhibiting vertical stratification. All samples were returned to the laboratory on ice and analysis for most parameters performed within 24 hours.

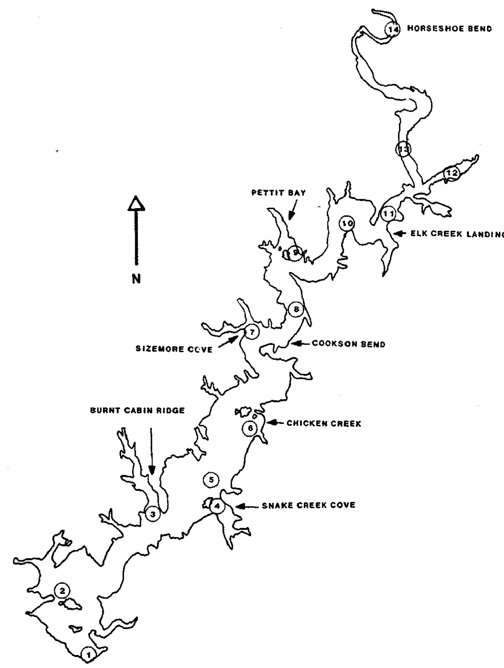

FIGURE 1. Water quality sampling sites, Tenkiller Lake, Oklahoma.

Hach Chemical Company reagents were used in the analysis of total alkalinity, total hardness, chlorides, sulfates (SulfaVer 4), nitrates (NitraVer 5), orthophosphate and total phosphate (PhosVer 3). Hach standard solutions were also used in standard curve preparation for these parameters (2). Spectrophotometric analyses were performed with a Sequoia-Turner Model 390 spectrophotometer equipped to hold 1-cm-square cuvettes.

Nephelometric turbidity values were determined with a Monitek Model 21 nephelometer. Commercially prepared standards were used to calibrate the instrument. BOD (5-day) samples were read with a YSI Model 54A oxygen meter. Analyses for COD and TOC were performed by the Civil Engineering Department of Oklahoma State University, Stillwater. Tulsa City-County Health Department personnel conducted fecal coliform tests.

Chlorophyll *a* concentrations were determined fluorometrically (3). Purified chlorophyll *a* (Sigma Chemical Company) was used in standards preparation and standards checked with EPA quality control samples. Values were not corrected for phaeopigments.

Metals analyses were performed in accordance with USEPA procedures (4). An Instrumentation Laboratory Model 357 atomic absorption spectrophotometer was used in all such analyses.

Statistical analyses were conducted using Statistical Analysis Systems, Inc. (SAS) computer programs (5). Analysis of variance (ANOVA) was performed using the General Linear Models (GLM) procedure and Duncan's multiple range test used in means comparisons. Grand means were used in all means comparisons. A significance level of 0.05 was used throughout the study.

All data collected during this study are available through the EPA STORET water quality database. The agency code for the Tulsa District Corps of Engineers is 11COETUL and primary station identifiers for Tenkiller Lake are OKN0164 through OKN0177 for Sites 1 through 14 respectively.

RESULTS

Overall means, standard deviations (SD), and ranges for all water quality parameters measured during this study are presented in Table 1. Spatial and temporal patterns of surface

TABLE 1. Means, standard deviations (SD), and ranges of values for water quality parameters, Tenkiller Lake, Oklahoma. Values include all sampling sites, dates, and water depths and are expressed as mg/L unless otherwise noted.

Parameter	Mean	SD	Min.	Max.	*n*
Total alkalinity (as $CaCO_3$)	70	12	38	116	298
Total hardness (as $CaCO_3$)	70	13	36	102	298
Turbidity (NTU)	7.0	10.0	0.1	117	298
Secchi disc (m)	1.3	0.8	0.3	3.3	205
Chlorides	6	2	2	12	298
Sulfates	10.0	6.7	3.7	15.0	274
Nitrates	0.40	0.35	<0.10	2.63	284
Orthophosphate (as PO_4)	0.217	0.238	<0.005	1.920	261
Total phosphate (as PO_4)	0.383	0.218	0.012	1.253	201
Chlorophyll *a* (μg/L)	16.95	12.00	1.04	55.78	188
Total organic carbon	16.6	8.8	2.0	54.0	233
Chemical oxygen demand	10.8	7.6	0.0	44.0	234
Biochemical oxygen demand (5-day)	2.0	1.2	0.0	6.4	260
Fecal coliforms (per 100 mL)	34	102	<10	840	148
Water temperature (°C)	20.9	6.7	6.0	31.5	1405
pH (std. units)	–	–	6.2	9.5	1405
Dissolved oxygen	6.9	3.9	0.0	16.4	1405
Conductivity (μS/cm)	170	22	55	365	1405
Total metals					
Ca	24.28	5.17	14.02	40.44	288
Mg	1.47	0.10	1.23	2.24	288
K	2.61	0.40	1.57	4.88	288
Na	3.97	1.38	2.62	9.14	97
Mn (μg/L)	32	19	20	130	97
Fe (μg/L)	366	418	21	5216	288
Zn (μg/L)	27	24	10	203	287

water temperature measured at Tenkiller Lake were similar to those recorded at other Tulsa District Corps impoundments. Surface water temperatures increased throughout spring and early summer and peaked in late July. A maximum surface water temperature of 31.5 °C was measured at Site 12 on 29 July (Table 1).

Vertical thermal stratification began to develop during May 1986 at sites near the lower end of Tenkiller Lake. The thermocline developed at approximately 8 to 12 m throughout the lower half of the lake and was less stable at sites in the upper reaches of the impoundment. Profiles recorded on 26 August were typical of summer conditions (Fig. 2). Because water depths near the dam exceeded the length of the probe cable, temperatures at depths greater than 20 m were not recorded. Surface temperatures at Site 1

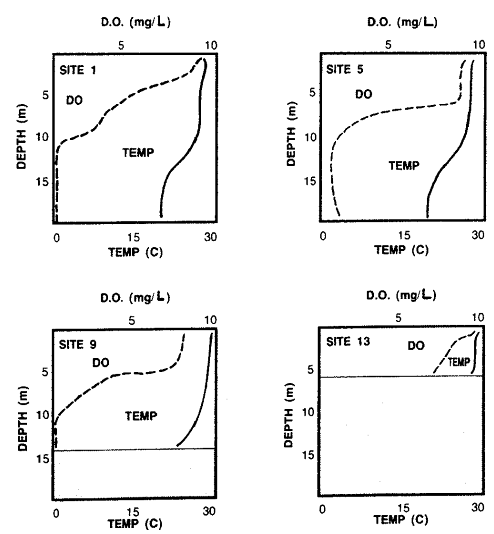

FIGURE 2. Vertical profiles of water temperature (TEMP) and dissolved oxygen (DO) on 26 August 1986, Tenkiller Lake, Oklahoma.

varied by 23.3 ºC over the entire study period while temperatures at 20 m at this site varied by 14.1 ºC. Thermal stratification persisted throughout late September.

Surface dissolved oxygen (DO) levels were highest during February and March, declined through April and May, and fluctuated throughout summer and early fall. Lowest surface DO readings were recorded on 15 October at Sites 1 through 7 under extensive flood conditions. The highest surface DO concentration measured during the study was 16.4 mg/L on 4 March at Site 9 (Table 1). Surface dissolved oxygen concentrations were closely correlated with chlorophyll *a* levels ($r = 0.47$, $p < 0.0001$, $n = 117$) indicating a possible link between algal oxygen evolution and DO dynamics in Tenkiller Lake.

Clinograde oxygen profiles were recorded at Tenkiller sampling sites exhibiting stable thermal stratification, with oxygen depletion occurring at approximately 10 m (Fig. 2). Sampling sites near the upper end of the lake (Sites 12-14) generally remained well-oxygenated because of shallow water depths and adequate wind mixing. Oxygen levels averaged over the entire water column on all sampling dates were highest at Sites 10 and 12 and significantly different from those at Sites 11, 13, and 14 which were, in turn, significantly higher than those at other sampling sites.

Circumneutral pH readings were recorded at all sites throughout the study. Readings varied from 6.2 at the surface at Site 14 on 23 September to 9.5 at the surface at Sites 10 and 11 on 17 June. Little horizontal variation in pH was observed on sampling dates but slight reductions did occur with depth during periods of stratification. A positive, significant correlation existed between surface pH and chlorophyll *a* ($r = 0.49$, $p < 0.0001$, $n = 117$), again indicative of significant algal activity.

Conductivity levels measured during the study were indicative of moderate concentrations of ionized salts. Mean values for this parameter varied little among sites and were generally around 170 µS/cm. Slight increases in conductivity were measured with increasing depth during periods of stratification.

Total alkalinity values were generally indicative of a system well-buffered against drastic pH shifts. Alkalinity values averaged 70 mg/L (SD = 12 mg/L) as $CaCO_3$ over the entire study period and varied little among sites. Alkalinities in surface waters were slightly lower (mean = 67, SD = 13 mg/L) than those from hypolimnetic samples (mean = 75, SD = 9 mg/L).

Tenkiller Lake waters can be classified as soft to moderately hard. Hardness levels averaged 70 mg/L (SD = 13 mg/L) as $CaCO_3$ over the entire study (Table 1) and varied little among sites. As expected, hardness was closely correlated with total concentrations of both Ca ($r = 0.86$, $p < 0.0001$, $n = 274$) and Mg ($r = 0.54$, $p < 0.0001$, $n = 274$).

Chloride levels in Tenkiller Lake were low and varied little with date, site, or water strata. Chloride levels were significantly correlated with total concentrations of Na ($r = 0.63$, $p < 0.0001$, $n = 97$), K ($r = 0.25$, $p < 0.0001$, $n = 274$), and Mg ($r = 0.31$, $p < 0.0001$, $n = 274$). Sulfate concentrations remained fairly stable throughout the study and varied little with date, site, or depth.

Total organic carbon values ranged from 2.0 to 54.0 mg/L and averaged 16.6 mg/L (Table 1). Site-specific means for TOC ranged from 12.7 mg/L (SD = 5.3 mg/L) at Site 1 to 21.2 mg/L (SD = 10.4 mg/L) at Site 10. Means for surface and hypolimnetic samples (15.7, SD = 8.5 and 19.3, SD = 9.3 mg/L respectively) were significantly different. Drastic differences in COD among sites were not observed.

Biochemical oxygen demand levels were generally low and rarely exceeded 4.0 mg/L. Highest BOD values were measured during early spring, but mean levels generally varied little among dates. Slightly increasing levels of BOD were observed with increasing upstream distance from Tenkiller Ferry Dam on most sampling dates. Sites with minimum and maximum mean BOD levels were Site 3 (mean 1.3, SD = 0.9 mg/L) and Site 12 (mean 3.7, SD = 1.5 mg/L) respectively. A significant correlation was observed between BOD and chlorophyll *a* concentration ($r = 0.61$, $p < 0.0001$, $n = 153$).

While fecal coliform counts were generally well below State of Oklahoma standards for public and private water supply and primary body contact recreation (6), significant horizontal variation in this parameter were observed at Tenkiller Lake. Mean fecal coliform counts varied little among Sites 1 through 9, more than doubled between Sites 9 and 10, and increased more than seven-fold between Sites 10 and 14. The highest count (840/100 mL) was recorded on 22 April at Site 14. Counts were frequently less than 10/100 mL.

While extensive sampling and analysis for metals was beyond the scope of this study, limited metals data were collected. Results of these analyses are presented in Table 1. Total Mn concentrations in hypolimnetic samples were approximately twice those in surface samples, indicating possible release of this metal from sediments under anoxic conditions. In contrast, concentrations of total Fe were greatest in surface samples.

Nitrate concentrations in Tenkiller Lake ranged from <0.10 to 2.63 mg/L and were generally below analytical detection limits (0.10 to 0.50 mg/L). Concentrations were generally highest during early spring and fluctuated slightly during summer months. Mean nitrate levels were highest near Tenkiller Dam, decreased toward mid-lake, and increased again in upper reaches of the impoundment. Mean nitrate concentrations at Sites 7 through 9 were significantly lower than those at other sampling sites. Significant differences were not observed between nitrate concentrations in surface and hypolimnetic samples.

Phosphorus commonly limits biological productivity of aquatic ecosystems (7). Phosphorus parameters were therefore of particular importance to this study. It should be noted that values for both ortho and total phosphates are expressed in mg/L as PO_4. Conversion of values to mg/L as P will require multiplication by 0.326.

In general, phosphorus concentrations were high in Tenkiller Lake relative to many other Tulsa District Corps impoundments. Mean concentrations of orthophosphate and total phosphate were 0.217 (SD = 0.238) and 0.383 (SD = 0.219) mg/L respectively (Table 1). Mean values for both parameters were highest at Site 14 and concentrations generally increased with upstream distance from Tenkiller Dam (Fig. 3). Orthophosphate concentrations decreased throughout spring and early summer, increased sharply on 15 July, and fluctuated mildly throughout the remainder of the study. Concentrations of orthophosphate were significantly higher and lower than those at other sites at Sites 14 and 6 respectively.

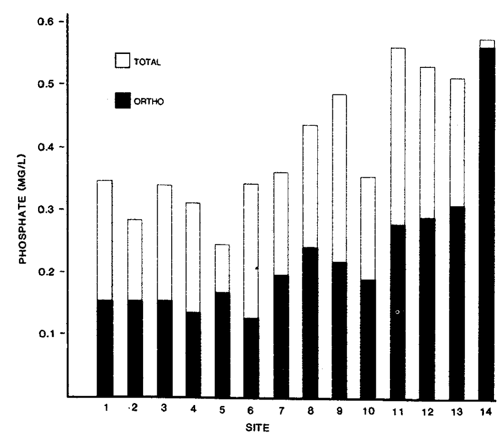

FIGURE 3. Mean ortho and total phosphate, Tenkiller Lake, Oklahoma. Values are means for all sampling dates and water depths.

Highest total phosphate concentrations were measured on 15 July (mean = 0.629, SD = 0.212 mg/L). Concentrations also increased sharply following extensive flooding in early October. With the exception of these dates, total phosphate concentrations remained fairly stable throughout the study. Mean total phosphate concentration was highest at Site 14 and significantly different from those at other sites. Significant differences also existed between means for Sites 2 and 5 and those at other sampling locations.

An important process to phosphorus dynamics in lakes is the release of phosphorus compounds from sediments under anoxic conditions (7). Concentrations of ortho and total phosphate were considerably higher in hypolimnetic samples than those in surface samples at Sites 7 through 11 (Figs. 4 and 5). Only surface samples were collected at Sites 12 through 14 due to shallow water depths, wind mixing, and the lack of a developed hypolimnion. In contrast, hypolimnetic ortho and total phosphate concentrations were similar to, or in some cases lower than those in surface samples at Sites 1 through 6 (Figs.

4 and 5). Nephelometric turbidity was significantly correlated with both orthophosphate ($r = 0.23$, $p < 0.0001$, $n = 261$) and total phosphate ($r = 0.52$, $p < 0.0001$, $n = 201$).

Chlorophyll *a* values ranged from 1.04 µg/L at Site 14 on 20 November to 55.78 µg/L at Site 12 on 23 September 1986. The overall mean for this parameter was 16.95 µg/L with a SD of 12.00 µg/L (Table 1). Highest mean chlorophyll *a* levels were measured on 17 June (30.87, SD = 12.40 µg/L) and concentrations remained high throughout late June and early July. Peaks in mean chlorophyll *a* levels were also observed on 8 April and 23 September (means of 25.13, SD = 9.46 and 20.33, SD = 16.52 µg/L respectively) and levels were lowest on 15 October (mean = 3.28, SD = 0.26 µg/L) following extensive flooding.

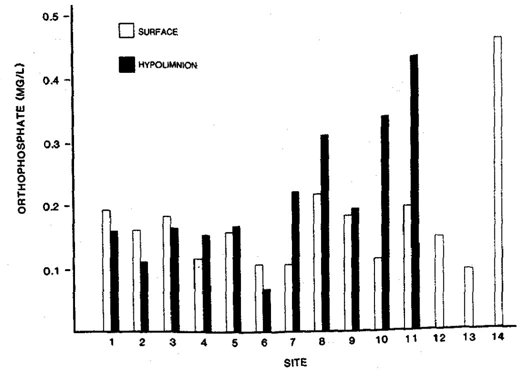

FIGURE 4. Mean orthophosphate concentrations in surface and hypolimnetic samples, Tenkiller Lake, Oklahoma. Surface means computed only on dates when hypolimnetic samples were collected.

Chlorophyll *a* levels generally increased with upstream distance from Tenkiller Ferry Dam (Fig. 6). The exception to this pattern was Site 14 which, in terms of chlorophyll and other parameters, exhibited characteristics common to riverine environments and probably represents a transition zone from a lotic to lentic system. Levels of chlorophyll *a* at Site 14 were significantly lower than those at all other sampling sites. Significantly highest chlorophyll *a* concentrations were measured at Site 12 (mean = 34.54, SD = 14.00 µg/L). Chlorophyll *a* levels were closely correlated with biochemical oxygen demand, dissolved oxygen, and pH (see discussion of these parameters). A significant correlation was not observed between chlorophyll *a* and nephelometric turbidity ($r = -0.13$, $p = 0.09$, $n = 174$).

Highest nephelometric turbidity levels were measured on 15 October at Sites 1 through 7 following heavy flooding in the Illinois River Basin. Apart from this period, highest NTU readings were recorded in April. From 20 May to 23 September, mean turbidity levels varied by only 5.5 NTU. Turbidity levels generally increased with upstream distance from Tenkiller Dam. Highest readings were recorded at Site 11 (mean = 16.6, SD = 26.5 NTU) and lowest readings at Site 1 (mean = 2.7, SD = 4.0 NTU). Mean values for surface and hypolimnetic samples were 7.1 (SD = 8.0) and 6.6 (SD = 14.1) NTU respectively. Turbidity levels were

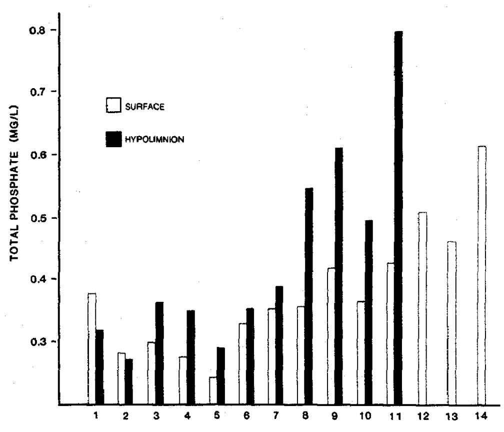

FIGURE 5. Mean total phosphate concentrations in surface and hypolimnetic samples, Tenkiller Lake, Oklahoma. Surface means computed only on dates when hypolimnetic samples were collected.

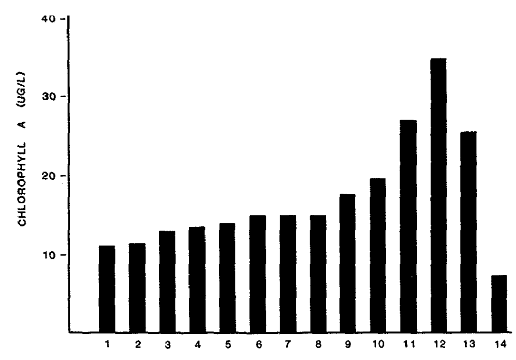

FIGURE 6. Mean chlorophyll *a* concentrations, Tenkiller Lake, Oklahoma.

significantly correlated with a number of parameters including total concentrations of Fe ($r = 0.91$, $p < 0.0001$, $n = 274$), K ($r = 0.50$, $p < 0.0001$, $n = 274$, Mg ($r = 0.56$, $p < 0.0001$, $n = 148$), and phosphorus parameters (see phosphorus discussion).

Secchi disc transparency was greatest near Tenkiller Dam and decreased toward the upper end of the impoundment (Fig. 7). Greatest transparencies were recorded on 3 June (mean = 1.9, SD = 0.8 m) and measurements averaged 0.5 m in the lower half of Tenkiller Lake following early October flooding. Nephelometric turbidity levels were significantly correlated with Secchi disc ($r = -0.59$, $p < 0.0001$, $n = 205$) as were chlorophyll *a* concentrations ($r = -0.28$, $p = 0.003$, $n = 161$).

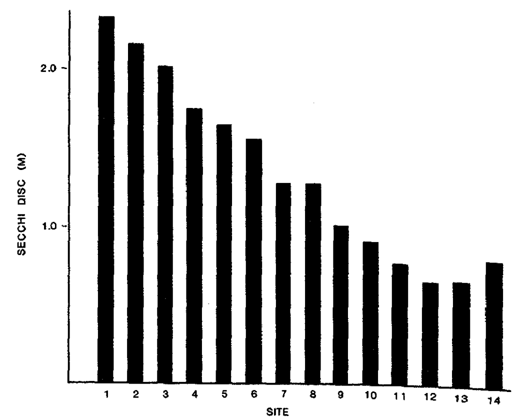

FIGURE 7. Mean Secchi disc measurements, Tenkiller Lake, Oklahoma.

While algal identification and enumeration were beyond the scope of this investigation, several noticeable algal blooms occurred at Tenkiller Lake during the study. For several years, algal blooms imparting a reddish tinge to the water have occurred in early spring at scattered locations on Tenkiller Lake. During 1986, these blooms occurred during March and were most noticeable in Pine Creek Cove near Tenkiller Ferry Dam and in the vicinity of Burnt Cabin Cove (approximately Site 3). Algal samples were collected at this time and the bloom-causing organism identified as the dinoflagellate, *Peridiniopsis polonicum*. While public concern regarding possible toxicity or health-related impacts associated with these blooms has been expressed, reports of toxin production by freshwater dinoflagellates are extremely limited (Lois Hester, pers. comm., 8).

In addition, spring and late summer surface algal blooms were observed in the upper end of Tenkiller Lake. These blooms were particularly prevalent in the area between Sites 13 and 14 and frequently consisted of scattered floating mats of algae. According to project personnel and local residents, these blooms are occurring with increasing frequency at Tenkiller Lake.

DISCUSSION

Considerable water quality degradation in the Illinois River Basin has occurred in recent years. From 1975 to 1986, total phosphorus and total nitrogen loads to the basin increased an estimated 135% and 6% respectively (9). Estimated phosphorus loading to Tenkiller Lake in 1986 was 446,447 kg/yr (8.5 $g/m^2/yr$) – an increase of 97% since 1974-75 (9), and roughly four times the critical value (1.97 $g/m^2/yr$) proposed by Vollenweider (10). Decreased water clarity and the increased frequency and severity of algal blooms in Tenkiller Lake are symptomatic of these changes.

Soballe and Threlkeld (11) described nutrient and phytoplankton dynamics of Lake Frances (Oklahoma-Arkansas), a small (231 ha), rapidly flushed (mean hydraulic residence time 2.4 d) eutrophic reservoir on the Illinois River upstream of Tenkiller Lake. These authors reported advective limitation to phytoplankton standing crop and only slight reductions in total phosphorus from upper reaches of the impoundment to the dam at normal to high flows. Similar results have been reported by others (12, 13). In contrast, the long hydraulic residence time of Tenkiller Lake (mean 250 d) greatly exceeds the one to two weeks required for complete algal response to nutrients in reservoirs (14) and considerable horizontal reductions in total phosphorus occur toward Tenkiller Dam (Fig. 3). These characteristics of both impoundments, combined with a steep basin gradient and high flow velocities, make Tenkiller Lake the ultimate sink for a large percentage of nutrients from the upper Illinois River Basin.

The importance of epilimnetic nitrogen to phosphorus (N:P) ratios in determining algal species composition has received considerable attention (15-18). Smith (15) reported a high incidence of bluegreen (Cyanophyta) algal blooms in lakes with epilimnetic N:P ratios below 29:1 and a scarcity of bluegreens in lakes where this value is exceeded. While total nitrogen data were not collected during this study, some evidence does exist for nitrogen limitation of phytoplankton and shifts in species composition in Tenkiller Lake. Such evidence includes the high percentage increase in phosphorus compared to nitrogen loads to the Illinois River Basin in the past decade (9), continuously high concentrations of orthophosphate at all Tenkiller sampling sites (Fig. 4) and low (often below detection limits) nitrate levels (Table 1). The noxious bluegreen, *Aphanizomenon*, was identified in the upper end of Tenkiller Lake during a 1985 survey conducted by Gakstatter and Katko (19). Surveys conducted during 1974-75 (20, 21) did not detect this species and reported diatom dominance of phytoplankton assemblages.

Historical water quality data for Tenkiller Lake are primarily limited to results of a 1974-75 study by the U.S. Environmental Protection Agency (20) and a 1975 survey by the Oklahoma State Department of Health (OSDH) (21). Limited data were also collected by the Tulsa District Corps of Engineers from June to August, 1979. A comparison of results from these studies and the current investigation is presented in Table 2. Authors of the OSDH study reported that Tenkiller Lake exhibited characteristics indicative of both oligotrophic and eutrophic conditions. They concluded that, in 1975, Tenkiller could be classified as mesotrophic based on nutrient levels and algal species composition.

While caution should be exercised in comparing results of earlier studies with those of the current investigation owing to differences in seasons, sampling locations, and

TABLE 2. Comparison of current and historical water quality data, Tenkiller Lake, Oklahoma. Values are overall means for all sampling sites and water depths and are expressed as mg/L unless otherwise noted. Values in parentheses are number of samples, standard deviation.

Parameter	1974–75[a]	1975[b]	1979[c]	1985–86[d]	Change since 1974–75, %
Total P (as P)	0.057 (104,0.011)	0.042 (43,0.040)	0.056 (10,0.031)	0.125 (201,0.071)	+150
Nitrate	–	0.66 (43,0.54)	–	0.40 (284,0.35)	–40
Chlorophyll (μg/L)	6.65 (16,3.28)	–	–	16.95 (188,12.00)	+155
Secchi disc (m)	1.7 (16,0.6)	–	–	1.3 (205,0.8)	–24
TOC	–	3.1 (39,1.90)	–	16.6 (233,8.8)	+432
COD	–	8.0 (43,6.0)	9.0 (26,4.0)	10.8 (234,7.6)	+35

[a] EPA (20); 4 sampling sites
[b] OSDH (21); 8 sampling sites
[c] Tulsa District Corps of Engineers, unpublished data; 5 sampling sites
[d] Current study; 14 sampling sites

analysis methods, general trends are apparent (Table 2). Data comparisons suggest that total phosphorus and chlorophyll *a* concentrations have increased twofold to threefold since 1975. Over the same time period, Secchi disc transparency has decreased approximately 25% and increases have occurred in TOC (432%) and COD (35%). Interestingly, nitrate concentrations have decreased approximately 40% since 1975. Nitrate uptake by phytoplankton following a shift to nitrogen-limited conditions is a possible explanation for this change. Changes in water quality from impoundment (1952) to 1975 are unknown.

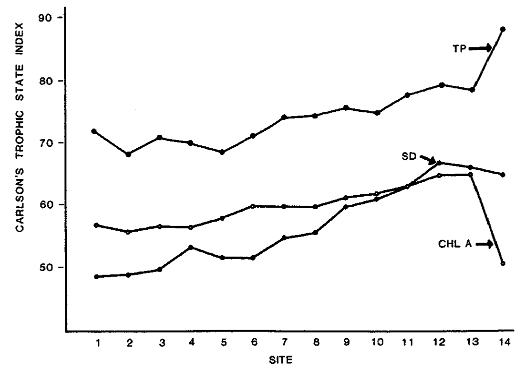

FIGURE 8. Carlson's trophic state index calculated for total phosphorus (TP), Secchi disc (SD), and chlorophyll *a*, Tenkiller Lake, Oklahoma.

In general, results of this study suggest that Tenkiller Lake can be classified as eutrophic. High nutrient concentrations, elevated levels of chlorophyll *a*, and the increasing incidence of nuisance algal blooms support this classification. Data collected during this study also revealed a noticeable change in water quality at approximately midlake (in the vicinity of Sites 7 and 8). Nutrient concentrations and chlorophyll *a* levels were highest in the upper half of the impoundment and the apparent release of phosphorus compounds from sediments in this reach was much higher than that in the lower half of the lake.

In an attempt to describe quantitatively the trophic status of Tenkiller Lake, data from this study were used in the calculation of the trophic state index (TSI) proposed by Carlson (22). While Carlson's index has been criticized for assumptions concerning the relationship between Secchi disc transparency and algal chlorophyll (23-25), it does provide a numerical measure of trophic status and helps alleviate the confusion and ambiguity associated with the traditional descriptive trophic classification system. The TSI scale ranges from 0 to 100 with each major division (10, 20, 30, etc.) representing a doubling in algal biomass. The index number can be calculated using Secchi disc, chlorophyll, or total phosphorus data.

Carlson's TSI values were calculated for each of the three parameters at all Tenkiller sampling sites (Fig. 8). Data from surface samples collected from May to August 1986 were used in these calculations. This period coincides with peak recreational usage and increases the usefulness of the index in communicating the meaning of the TSI to the general public (22). Reasonably good agreement was observed between TSI values for Secchi disc and chlorophyll while values based on total phosphorus (as P) were considerably higher (Fig. 8). Reasons for these differences are unknown, but Carlson admitted that there are problems associated with the phosphorus index, particularly in lakes with high orthophosphate concentrations (such as Tenkiller). He explained that, whenever possible, priority should be given to values based on biological parameters, especially the chlorophyll *a* index.

As a general rule, TSI values of 40, 50, and 60 roughly correspond to the conventional trophic descriptions of mesotrophic, mesoeutrophic, and eutrophic respectively (22). This would place Sites 6 through 13 in the eutrophic category based on the chlorophyll *a* TSI and Sites 9 through 14 in this category based upon the Secchi disc index (Fig. 8).

The trophic classification system proposed by Reckhow and Chapra (26) uses mean chlorophyll *a* concentrations to define trophic status as:

Oligotrophic < 4 µg/L
Mesotrophic 4 - 10 µg/L
Eutrophic 10 - 25 µg/L
Hypereutrophic > 25 µg/L.

Based on this classification scheme, Sites 1 through 10 would be considered eutrophic and Sites 11 through 13 hypereutrophic. In addition, hypolimnetic oxygen depletion rates and chlorophyll *a* concentrations measured in Tenkiller Lake during this study were high in comparison to numerous other Corps of Engineers impoundments evaluated by Walker (14). This lends additional support to classification of Tenkiller Lake as eutrophic.

ACKNOWLEDGEMENTS

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