Water Quality Changes, from 1987 to 1991, in Broken Bow Lake, Oklahoma

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Water quality data were collected at five sampling sites on Broken Bow Lake from May through August in 1987 and from June through August in 1991 in order to examine temporal trends. Parameters selected for analysis were total phosphorus, chlorophyll *a*, and Secchi disk transparency. Data from all sampling locations were identified by year (1987 and 1991) and by lake sampling location (upper lake vs. lower lake). Using a one-way analysis of variance, results revealed significant water quality changes occurred between 1987 and 1991. Mean total phosphorus concentrations were significantly different between years and between locations as were mean Secchi disk transparencies. For chlorophyll *a*, a significant difference occurred between locations, but not between years. Trophic state values indicate the lake has gone from oligotrophic to mesotrophic, and some areas in the upper portion are nearing eutrophy.

INTRODUCTION

Broken Bow Lake, located in McCurtain County in SE Oklahoma, has been famous for its clear waters, scenic beauty, and pristine surroundings. The lake water quality has been excellent and probably unequaled by any other impoundment in the state. Concentrations of dissolved substances are extremely low and water clarity is exceptional in many areas of the lake. However, area residents have expressed concern over decreasing water clarity in the lake during the past decade.

In 1987, as part of the Tulsa District mission to characterize water quality at every Corps lake in the Tulsa District, Broken Bow Lake was selected for a water quality investigation. The purposes of the investigation were to define existing limnological conditions and to provide a basis for future water quality investigations. Results of the investigation indicated that the lake, particularly the upper end above Bee Creek Cove, has been impacted by watershed inputs. Hypolimnetic oxygen depletion, elevated inorganic turbidity, and increased algal production at upper sampling sites supported this hypothesis (*1*).

Based on results of the 1987 investigation, a similar water quality investigation was conducted at Broken Bow Lake in 1991. The purpose of this investigation was to examine general trends. Parameters analyzed were total phosphorus, chlorophyll *a*, and Secchi disk transparency, all widely accepted indicators of eutrophication.

STUDY AREA

Broken Bow Lake is located on the Mountain Fork River at river km 32.7, about 14.4 km N-NW of the city of Broken Bow (Figure 1). The entire lake lies in McCurtain County. At normal power pool level, the lake has a surface area of 5,751 ha, possesses 290 km of shoreline, and has a volume of 1.1×10^9 m^3. The lake drains an area of about 1,953 km^2 , has a mean depth of 19.7 m, and a maximum depth of 54.7 m. Construction began in October 1961, and the power pool was filled in April 1970. Project purposes are provision for flood control, hydroelectric power, water supply, recreation, and fish and wildlife. The lake includes 1.88×10^8 m^3 for water supply.

METHODS and MATERIALS

Data were collected at five locations on the lake (Figure 1). In 1987, sampling was conducted from May through August, and in 1991, from June through August. Surface water samples were collected in 1-liter, clear, polyethylene bottles. Fifteen sampling trips were taken for data collection.

Secchi disk transparency was measured at each site by using standard procedures (*2*). Persulfate digestion was used in preparation of samples for total phosphorus, and samples were analyzed by the ascorbic acid method (*3*); a Sequoia-Turner Model 390 spectrophotometer equipped for square cuvettes, 1×1 cm, was used. Chlorophyll *a* concentrations were determined fluorometrically (*3*). Fluorescence of the extract was measured on a Turner Model 112 fluorometer equipped with a blue light source, an R-445 photo-multiplier, a blue excitation filter (Turner #47B), and a red emission filter (Turner #25).

Data from all sampling locations were identified by year (1987 and 1991) and by lake sampling location. Data from the dam site and from Stevens Gap sampling locations were combined to represent lower lake conditions because these sites have similar characteristics (i.e., they are deep, open-water areas with similar physicochemical conditions in the main body of the lake below Bee Creek Cove). Data from Holly Creek, Gar Creek, and Panther Creek sampling locations were combined to represent upper lake conditions (above Bee Creek Cove) because these sites also have similar characteristics (i.e., they are shallow, riverine, and in uncleared areas of the lake). Therefore, for statistical analyses, the effects of two independent variables, year and location, were considered.

An analysis of variance (ANOVA) was performed for each indicator variable (total phosphorus, chlorophyll *a*, and Secchi disk transparency). Location (upper lake vs. lower lake) and year (1987 vs. 1991) were introduced as independent factors. ANOVA tests the hypothesis that the means of *k* normal populations are equal, given independent samples of size n_i from the *k* populations and assuming the populations have equal variances. All analyses were made with "SPSS for Windows", Version 6.0.

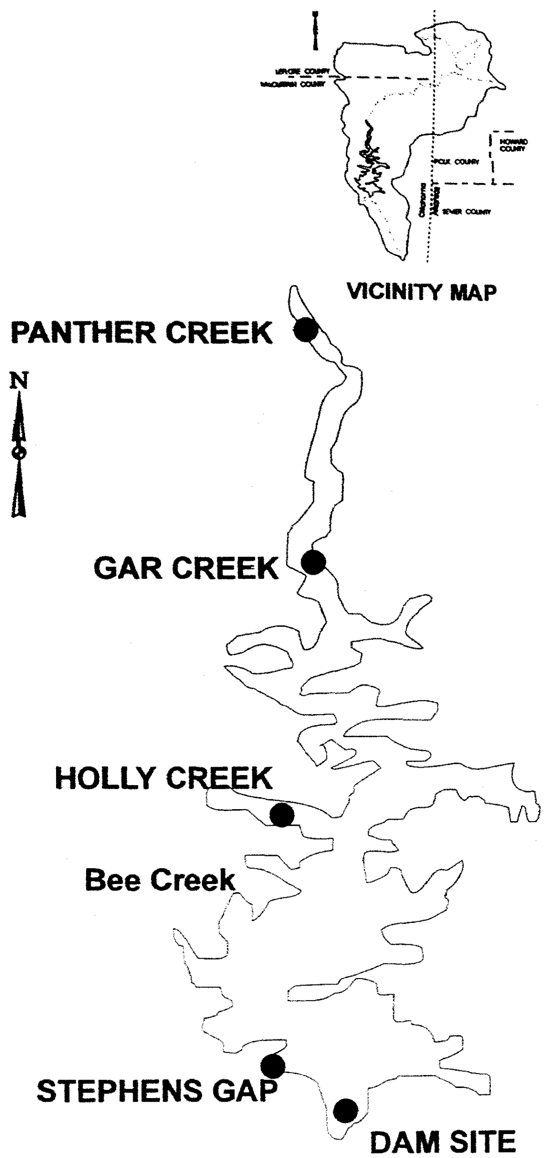

Figure 1. Water Quality Sampling Sites, Broken Bow Lake, OK.

RESULTS

Summary statistics derived for each indicator variable by location and year are presented in Table 1. We made 77 measurements of total phosphorus, 79 measurements of chlorophyll *a*, and 70 measurements of Secchi disk transparency. If a concentration was less than detection limit, the detection limit was used to calculate the mean and as the low end of the range.

Three separate two-way ANOVAs on each indicator variable revealed no statistically significant interaction effects between the independent factors location and year. Therefore, results of the analysis of the effects of each of the two independent factors will be presented separately.

Mean total phosphorus levels are significantly lower in 1987 (0.015 mg/l) than in 1991 (0.026 mg/l) (F=15.41 with P<0.001). Mean phosphorus levels are significantly lower for the lower lake (0.013 mg/l) than for the upper lake (0.030 mg/l) (F=33.55 with P<0.001). The null hypothesis that means are equal is rejected in both cases.

Mean transparency was higher in 1987

TABLE 1. Summary Statistics for Water Quality Indicator Variables, Broken Bow Lake, Oklahoma

Location	Year(s)	Mean±SD[a]	Range(NO)[b]
Total Phosphorus (μg/l)			
Lower Lake	1987	8±3	5–14(13)
Upper Lake	1987	22±13	5–52(16)
All Sites	1987	15[c]±12	5–52(29)
Lower Lake	1991	16±9	5–33(23)
Upper Lake	1991	35±15	15–77(25)
All Sites	1991	26[c]±16	5–77(48)
All Sites	'87,'91	22±15	5–77(77)
Chlorophyll *a* (μg/l)			
Lower Lake	1987	1.61±1.01	0.45–3.9(14)
Upper Lake	1987	5.20±2.49	1.60–10.0(20)
All Sites	1987	3.72±2.68	0.45–10.0(34)
Lower Lake	1991	2.84±4.66	0.20–20.0(20)
Upper Lake	1991	6.97±3.97	1.20–21.5(25)
All Sites	1991	5.13±4.72	0.20–21.5(45)
All Sites	'87,'91	4.53±4.01	0.20–21.5(79)
Secchi Disk Transparency (m)			
Lower Lake	1987	3.0±0.7	1.9–4.3(14)
Upper Lake	1987	1.8±0.6	0.7–2.9(16)
All Sites	1987	2.4[d]±0.9	0.7–4.3(30)
Lower Lake	1991	2.1±0.6	1.0–3.0(18)
Upper Lake	1991	1.3±0.4	0.4–1.8(22)
All Sites	1991	1.6[d]±0.7	0.4–3.0(40)
All Sites	'87,'91	1.9±0.8	0.4–4.3(70)

a Standard deviation of the mean
b Range and number of observations
c Significant difference between means (F=33.55, p<0.001).
d Significant difference between means (F=55.37, p<0.001).

(2.4 m) than in 1991 (1.6 m); the difference is significant (F = 27.99 with $P < 0.001$). Mean transparency is significantly higher in the lower lake (2.5 m) than in the upper lake (1.5 m) (F=55.37 with $P<0.001$). The null hypothesis that means are equal is rejected in both cases.

The mean concentration of chlorophyll *a* for upper sites (6.2 μg/l) was significantly higher than the mean concentration for lower sites (2.3 μg/l) (F=22.96 with $P< 0.001$). Results were less convincing when years were compared (F = 3.45 with $P = 0.067$); the null hypothesis, that chlorophyll *a* levels by year are equal, cannot be rejected.

DISCUSSION

Secchi disk-chlorophyll-phosphorus relationships have been used to predict trophic status of lakes. Vollenweider (*4*) demonstrated that total phosphorus generally increased with lake productivity. A trophic classification system for lakes using mean chlorophyll *a* as the indicator was proposed by Reckhow and Chapra (*5*). Algal biomass was proposed as a single indicator of trophic state of natural lakes since blooms were of interest to the public and algal biomass was correlated with Secchi disk measurements, which are easy to make (*6*). However, this situation may be different for reservoirs.

The trophic classification system proposed by Vollenweider (*4*) uses mean concentrations of epilimnetic total phosphorus (μg/l) to define trophic status as:

Ultra-oligotrophic	<5
Oligo-mesotrophic	5-10
Meso-eutrophic	10-30
Eutrophic	30-100
Hypereutrophic	> 100

On the basis of this classification scheme, the upper portion of the lake would be classified as meso-eutrophic in 1987 and eutrophic in 1991. The lower portion of the lake changed from oligo-mesotrophic in 1987 to meso-eutrophic by 1991. Comparing the mean total phosphorus concentration for all sites in 1987 with the mean for all sites in 1991 shows that the lake was mesotrophic in both years, but moving toward the eutrophic boundary.

The trophic classification system proposed by Reckhow and Chapra (*5*) uses mean chlorophyll *a* concentrations (μg/l) to define trophic status as:

Oligotrophic	<4	Mesotrophic	4-10
Eutrophic	10-25	Hypereutrophic	> 25

On the basis of this classification scheme, for both years the upper portion of the lake would be classified as mesotrophic and the lower portion as oligotrophic. Comparison of the mean chlorophyll *a* concentration for all sites in 1987 with the mean for all sites in 1991 shows that the lake went from oligotrophic to mesotrophic in the 4-year period.

CONCLUSIONS

Statistical analyses of data from Broken Bow Lake revealed significant water quality changes between 1987 and 1991. Increased mean concentration of total phosphorus and decreased water clarity in the upper end of the lake were signs of water quality degradation and increased eutrophication rates. While differences in mean concentrations of chlorophyll *a* were not significant by year, they were by location, another indication of differences in water quality between the upper and lower end of the lake. A noticeable change in water quality occurred at approximately Bee Creek Cove where the lake narrows and becomes riverine.

Slightly more than 90% of the Oklahoma portion of the Mountain Fork watershed above Broken Bow Lake consists of various categories of forest (*7*). About 5% of the watershed consists of pasture and developed land that could potentially contribute excessive nutrients to Broken Bow Lake. The projected growth of confined animal feeding operations in the Little River Basin, which includes the Mountain Fork River and Broken Bow Lake, poses a future threat to water quality unless management practices are instituted that will eliminate or at least minimize nutrient-laden runoff from these places reaching streams that flow into Broken Bow Lake. In addition, logging roads in areas where timber is harvested are sources of sediment and organic matter than can reach the lake. Future increases in logging activities, including road construction, without adequate erosion control, could have a dramatic adverse effect on water quality of streams in the watershed, and subsequently Broken Bow Lake. These potential water quality problems in the Little River Basin are discussed in a draft cooperative river basin study by the U.S. Department of Agriculture (*7*).

Results of this investigation should serve as a notice to area residents and interested agencies that it is time to initiate measures to abate causes of deteriorating water quality in Broken Bow Lake. Because of its economic values as a recreation resource and water supply source, Broken Bow Lake should be protected from further water quality degradation. Local groups and government agencies working together should continue monitoring the water quality of the lake and take action as needed to mitigate environmental damage to Broken Bow Lake and its watershed.

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