Broken Bow Lake Water Quality: 2017

The Broken Bow Lake dam is located in McCurtain County, Oklahoma (OK) at river mile 20.3 on the Mountain Fork River, a tributary of the Little River, about nine miles north-northeast of Broken Bow, OK. The impoundment extends more than fourteen miles north of the dam following the Mountain Fork River channel. The lake and watershed are within Hydrologic Unit Code (HUC) 11140108 (Mountain Fork). Broken Bow Lake is a multi-purpose project for flood control, hydroelectric power, water supply, recreation, and fish and wildlife. Construction began in October 1961 and the conservation pool was filled in April 1970. The project is an integral component of a six reservoir system that provides flood control and other multiple purpose benefits to the Little River Basin. The total drainage area above the dam is ~756 square miles extending into Le Flore County, OK and Polk County, Arkansas (Figure 1). Land use/cover (Dewitz, 2021) in the basin is dominated by forest (74.7%), grassland/pasture (11.6%), and shrub/scrub (6.7%). Bathymetric surveys do not indicate substantial lake capacity loss since impoundment due to sedimentation. Descriptive characteristics of Broken Bow Lake are included in Table 1.

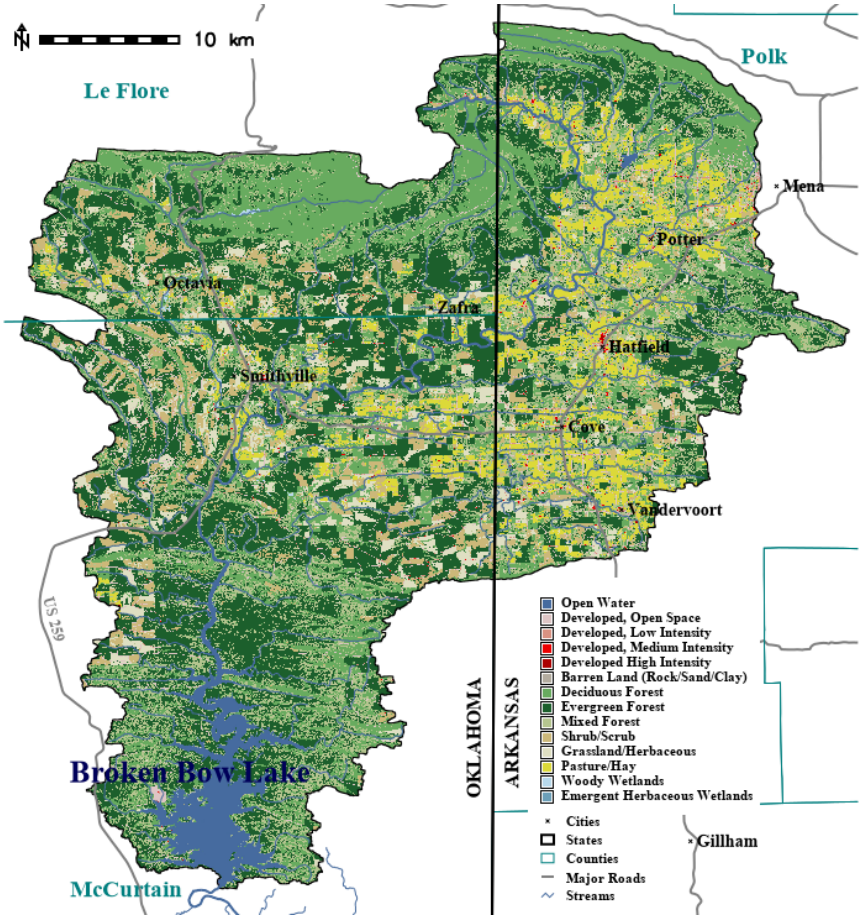

Figure 1. The Broken Bow Lake (Mountain Fork River) Watershed above the Broken Bow Lake Dam.

Table 1. Descriptive Characteristics of Broken Bow Lake, OK.

Parameter	English Units	Metric Units
Lake Elevation (Conservation Pool)	599.5 ft NGVD	183.73 m
Lake Surface Area (Conservation Pool)	14,160 ac	5,730.3 ha
Lake Volume (Conservation Pool)	913,370 ac-ft	$1{,}126.63*10^6$ m^3
Total Drainage Area (contributing)	756 mi^2	1,958 km^2
Mean Depth	64.5 ft	20.57 m
Maximum Depth (Conservation Pool)	179.5 ft	54.7 m
Shoreline Length	220 mi	354 km
Shoreline Development Index	13.2	13.2
Annual Inflow, Average 1930 – 2017 [Water Years]	936,700 ac-ft	$1{,}155.40*10^6$ m^3
Annual Inflow, 2017 [Calendar Year]	514,512 ac-ft	$634.64*10^6$ m^3
Hydraulic Residence Time, 2017 [Calendar Year]	598.5 d	1.64 yr

Data derived from the Tulsa District's Pertinent Data Book (U.S. ACE - Tulsa District, 2004), the FY 2017 Annual Water Control Report (U.S. ACE - SWD RCC, 2018), Tulsa District's Water Control page for Broken Bow Lake (U.S. ACE - Tulsa District, 2024), and a 2010 bathymetric survey (Wilson & Company, Inc., 2011).

Designated beneficial uses of the impoundment created by the Broken Bow Lake Dam include Public and Private Water Supply, Fish and Wildlife Propagation as a Cool Water Aquatic Community, Agriculture, Primary Body Contact Recreation, Aesthetics, and the lake is designated as a Sensitive Public and Private Water Supply (OAC, 2023). Based on the 2022 Integrated Water Quality Assessment prepared by the Oklahoma Department of Environmental Quality (ODEQ 2022), Broken Bow Lake is listed as impaired by cadmium, low dissolved oxygen, and pH affecting Fish and Wildlife Propagation as a Warm Water Aquatic Community, and also by mercury affecting Fish Consumption.

Physical and chemical water quality data were collected in May, June, August, and September 2017 by USACE from six in-lake sites to define existing limnological conditions, provide a basis for future water quality investigations, and to support operational and environmental missions of the Tulsa District. Sampled sites included BBROKS0140 (channel at the dam), BBROKS0141 (Stephens Creek Arm east of Beavers Bend Marina), BBROKS0139 (mouth of Bee Creek Cove), BBROKS0142 (channel east of Holly Creek mouth), BBROKS0138 (channel at mouth of Turkey Creek), and BBROKS0144 (channel north of Panther Creek Mouth). Sites were accessed by boat and samples were collected from locations over the deepest portion of the stream channel (thalweg). Sampling locations are identified in Figure 2.

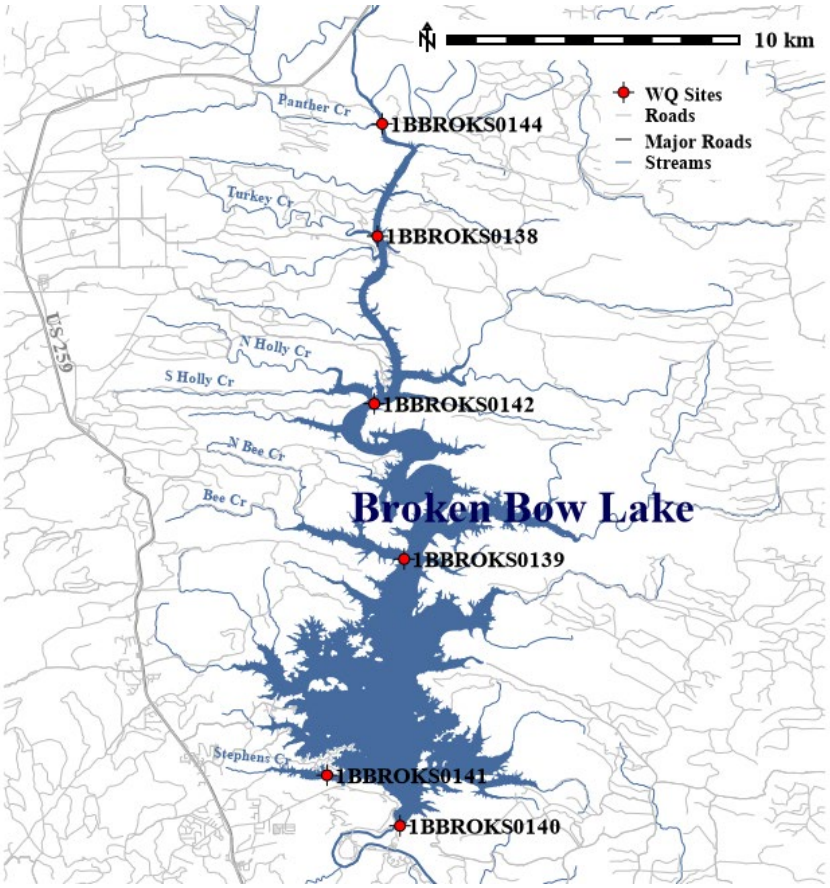

Figure 2. Locations of water quality sampling sites at Broken Bow Lake, OK.

The Mountain Fork River headwaters are in the Ouachita National Forest in Le Flore County, OK. It flows easterly from Le Flore County into Polk County, Arkansas, and west of Mena, Arkansas the Mountain Fork River turns southwest and returns to the extreme northeast corner of McCurtain County, OK. Near Smithville, OK the river bends in a southerly direction. Most of the drainage area is located in heavily timbered and mountainous hill country of the Ouachita Mountain Physiographic Province. The elevation of the headwaters of the Mountain Fork River is greater than 1,700 feet, and surrounding elevations reach 2,670 feet.

The Broken Bow Lake pool was at the conservation pool elevation (599.5-feet) in May, and below that level in June, August, and September 2017. Calendar year 2017 lake elevation, conservation pool elevation, basin precipitation, calculated evaporation rate, and water quality sampling events are shown in Figure 3.

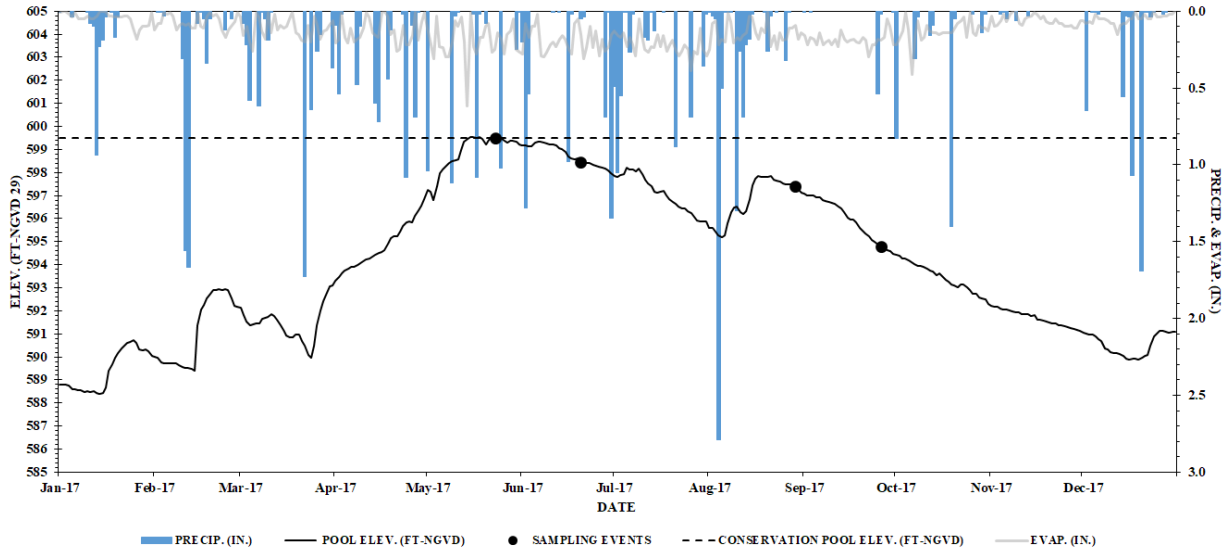

Figure 3. Daily lake elevation (feet, NGVD at 0800 hours), conservation pool elevation (feet), basin precipitation and evaporation (in.), and water quality sampling events at Broken Bow Lake, OK, 2017.

Water temperature ranged from 8.87 to 28.80 ºC peaking in August. Water temperatures ≤10 ºC were observed at BBROKS0140 and BBROKS0139 each sampling month at depths of 24 meters and below, and at BBROKS0141 in May, June, and August at depth. Thermal stratification was observed beginning in May at all sites except BBROKS0144 (upper lake near Panther Creek). The study period lakewide median dissolved oxygen concentration (DO) was 4.24 mg/l. Median DO was lowest at BBROKS0139 and BBROKS0142 (2.75 and 2.93 mg/l, respectively) and highest at BBROKS0138 and BBROKS0144 (6.00 and 7.45 mg/l, respectively). Observed in-lake DO ranged from 0.00 to 9.05 mg/l. DO concentrations <2 mg/l were observed at depth in May and June at BBROKS0138, BBROKS0139, BBROKS0141, and BBROKS0142; and at all sites except BBROKS0144 in August and September. In August and September, at sites with maximum depths of 19-meters or more (BBROKS0139, BBROKS0140, BBROKS0141, and BBROKS0142), 58-77% of the water column was hypoxic. All recorded DO concentrations >8.5 mg/l were observed in May near the surface, and down to 7-meters depth at BBROKS0140. Lakewide total organic carbon concentrations were moderate with a study period lakewide median of 3.67 mg/l. Site median total organic carbon concentrations ranged from 3.09 to 4.53 mg/l, increasing from lower to upper lake sites.

Specific conductance (lakewide median 36.0 µS/cm) was low, consistent with regional geology. Total dissolved solids lakewide median concentration was 34.0 mg/l with comparable medians at all sites. Low chloride and sulfate concentrations (medians 1.62 and 2.54 mg/l, respectively) were observed. Alkalinity levels (lakewide median 10.2 mg/l as $CaCO_3$) imply a system with extremely limited capability of maintaining pH levels. Hardness levels, median 9.49 mg/l as $CaCO_3$, indicate 'soft' water. Observed in-lake pH ranged from 6.04 to 8.12 with 37% of all observations <6.5. Low pH generally corresponded with DO concentrations <2 mg/l. Highest pH was recorded near the surface at BBROKS0139 in May, June, and August.

Lakewide median Secchi depth was 3.28 meters with observations ranging from 0.8 to 5.95 meters. Highest site median Secchi depth was 4.9 meters at BBROKS0140, and lowest was 1.0 meters at BBROKS0144. Lakewide median turbidity was 9.9 NTUs, and only 3% of all in-lake observations were greater than or equal to 25 NTUs. Median lakewide total suspended

solids concentration was 2.34 mg/l, with median upper lake site concentrations (4.67 mg/l at BBROKS0144, and 4.00 mg/l at BBROKS0138) higher than lower lake sites (0.90 mg/l at BBROKA0140 and 1.00 mg/l at BBROKS0141). The euphotic zone at Broken Bow Lake ranged from >12-meters at BBROKS0140 to ~4-meters at BBROKS0138, and <3-meters at BBROKS0144.

Lakewide ammonia concentrations (median 0.06 mg/l) and nitrite plus nitrate concentrations (median 0.04 mg/l) were moderate to low. Median bottom sample ammonia concentration (0.10 mg/l) was higher than the surface sample median (0.06 mg/l). Under one-half (47%) of all nitrite-plus-nitrate sample concentrations were above the analysis detection limit (0.006 mg/l), and highest concentrations were from bottom samples (maximum 0.25 mg/l). Total Kjeldahl nitrogen median concentrations (lakewide 0.26 mg/l) were highest at upper lake sites (0.45 and 0.41 mg/l at BBROKS0138 and BBROKS0144, respectively). Estimated lakewide median surface total nitrogen concentration during the 2017 study was 0.26 mg/l ranging from 0.19 (BBROKS0140) to 0.46 mg/l (BBROKS0144). Total phosphorus concentrations ranged from less than the detection limit (0.004 mg/l) to 0.17 mg/l with a lakewide median of 0.02 mg/l. Just one of thirty-six observations of dissolved ortho-phosphate had a reportable concentration. Nitrogen to phosphorus ratios (N:P) in 2017 were >20 (lakewide median 24) indicating a tendency toward phosphorus limitation of phytoplankton growth.

Chlorophyll-*a* concentrations ranged from 1.6 to 23.5 µg/l, with a lakewide median of 6.6 µg/l. Upper lake site median chlorophyll-a concentrations (12.1 and 16.0 µg/l, BBROKS0144 and BBROKS0138, respectively) were higher than lower lake concentrations (3.1 and 2.9 µg/l, BBROKS0140 and BBROKS0141, respectively). Figure 4, below, summarizes relative abundance and biovolume of divisions of phytoplankton observed at Broken Bow Lake at three sites (lower lake, BBROKS0140; mid-lake, BBROKS0139; and upper lake, BBROKS0138) on three dates in 2017. Abundance was dominated by Cyanophytes (blue green 'algae' that are photosynthetic bacteria) on all three dates. Biovolume shows variable seasonal representation of Bacillariophytes (diatoms), Chlorophytes (greens), Cyanophytes (blue greens), Cryptophytes (flagellated algae), and others, by site. Figure 5 summarizes zooplankton densities observed in 2017 (note the log scale density axis) at the same three sites. Cladoceran, Copepod, and Rotifer densities were comparable by site across dates.

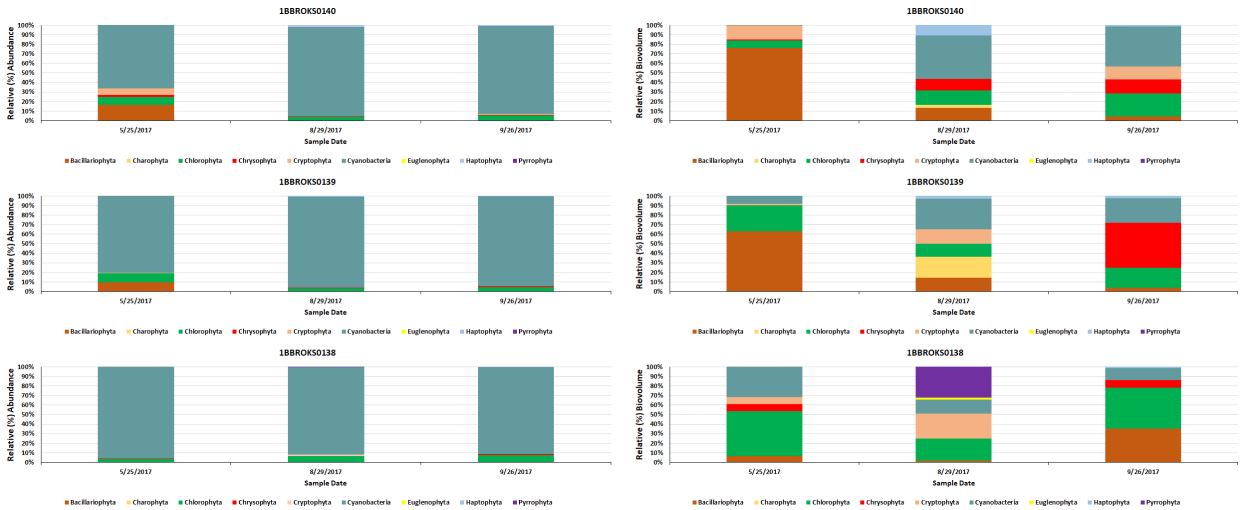

Figure 4. Phytoplankton relative abundance (left) and relative biovolume (right) at BBROKS0140, BBROKS0139, and BBROKS0138 in 2017.

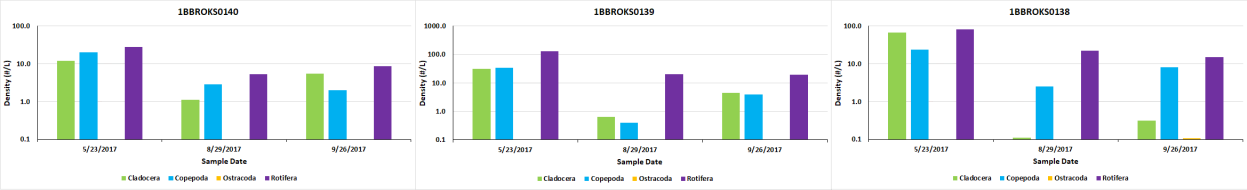

Figure 5. Zooplankton density at BBROKS0140, BBROKS0139, and BBROKS0138 in 2017.

Trophic status of Broken Bow Lake was assessed using all three metrics of Carlson's trophic state index (TSI (Carlson, 1977)) at each lake site and the lake as a whole. Median lakewide indexes based on Secchi depth (TSI(SD)) and surface total phosphorus (TSI(TP)), 43 and 41, respectively were <50, with only upper lake site medians exceeding 50 (TSI(SD) only). The median lakewide TSI value based on chlorophyll-a concentrations (TSI(CHLa)), 49, suggests high level mesotrophy, and median site values show a transition from mesotrophy in the lower lake to eutrophy in the upper lake (Figure 6).

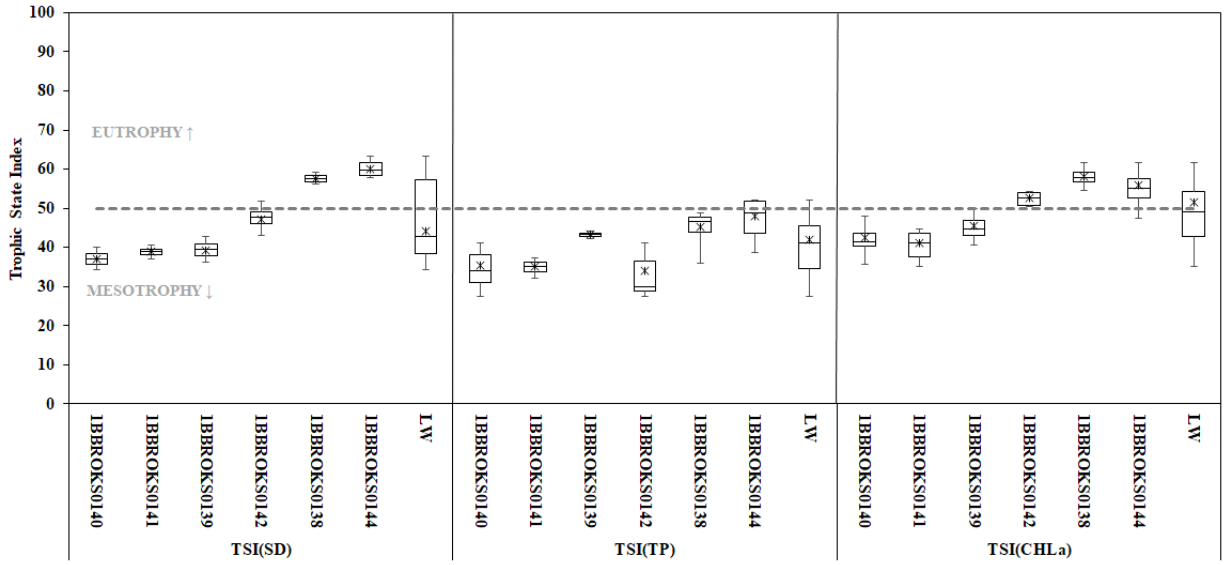

Figure 6. Distributions of Carlson's Trophic State Index (TSI), by sampling site and lakewide (LW), based on Secchi Depth (TSI(SD)), surface total phosphorus (TSI(TP)) and chlorophyll-*a* concentrations (TSI(CHLa)) at Broken Bow Lake, OK, 2017.

Total iron and manganese concentrations (lakewide medians 0.19 and 0.02 mg/l, respectively) were moderate. Median bottom sample iron and manganese concentrations (0.77 and 0.44 mg/l, respectively) were at least 25-times higher than surface medians. Highest iron concentrations were from bottom samples at BBROKS0138 in June (2.89 mg/l) and BBROKS0141 in September (3.37 mg/l). Reportable concentrations of arsenic, copper, nickel, and zinc were noted in all in-lake samples. Reportable concentrations of chromium, lead, nickel, and mercury were present in 22, 25, 92, and 22%, respectively, of all samples collected.

USACE previously conducted water quality sampling at Broken Bow Lake in 1987, 1991-92, and 1997-2000. All efforts documented thermal stratification with hypoxia at depth and associated low pH. Nutrients, both nitrogen and phosphorus, were present at relatively low levels. The 1987, and 1991-92 efforts investigated perceptions of incremental deterioration of water quality, especially in the upper lake. Lower lake water clarity was, and is, exceptional. Chlorophyll-a concentrations have remained stable, or moderately increased, across sampling efforts.