

## Keystone Lake Water Quality: 2022

The Keystone Lake dam is located in Tulsa County, Oklahoma (OK) at a river mile 538.8 on the Arkansas River, about fifteen miles west of Tulsa, OK. Arms of the impoundment extend upstream of the dam in the Cimarron River channel (~27 miles) and the Arkansas River channel (~22 miles). The lake is in Tulsa, Osage, Pawnee, and Creek Counties, OK. Keystone Lake, within Hydrologic Unit Codes (HUC) 11050003 (Lower Cimarron) and 11050006 (Black Bear-Red Rock), is a multi-purpose project for flood control, water supply, hydropower, navigation, fish and wildlife, and recreation. The project was designed to provide maximum benefits on the Arkansas River when operated in conjunction with the Arkansas River Basin System. Construction began in January 1957 and the conservation pool was filled in November 1964. Keystone Lake is a component of the multi-purpose Arkansas River Basin flood control and navigation system. The total drainage area above the dam is ~74,500 square miles. The Arkansas River extends about ~900 river miles above the Keystone Dam originating in the Rocky Mountains near Leadville, CO. Much of the Arkansas River watershed upstream from Hutchinson, KS is non-contributing. The Cimarron River, a major tributary to the Arkansas River upstream of the Keystone Dam, originates in northeastern New Mexico and flows easterly for almost 700 miles before its confluence with the Arkansas River. The Cimarron River watershed above Waynoka, OK is essentially non-contributing. The full watershed and contributing drainage area (~22,350 square miles) are shown in Figure 1. Land use/cover (Dewitz, 2023) in the basin is dominated by grassland/pasture (~45.5%), cropland (~33%), and forest (7%). Based on a 2020 bathymetric survey (Seaworks Group, LLC, 2020), at the conservation pool elevation of 723 feet (NGVD 29), lake capacity has diminished about 40% since impoundment due to sedimentation. Descriptive characteristics of Keystone Lake are included in Table 1.

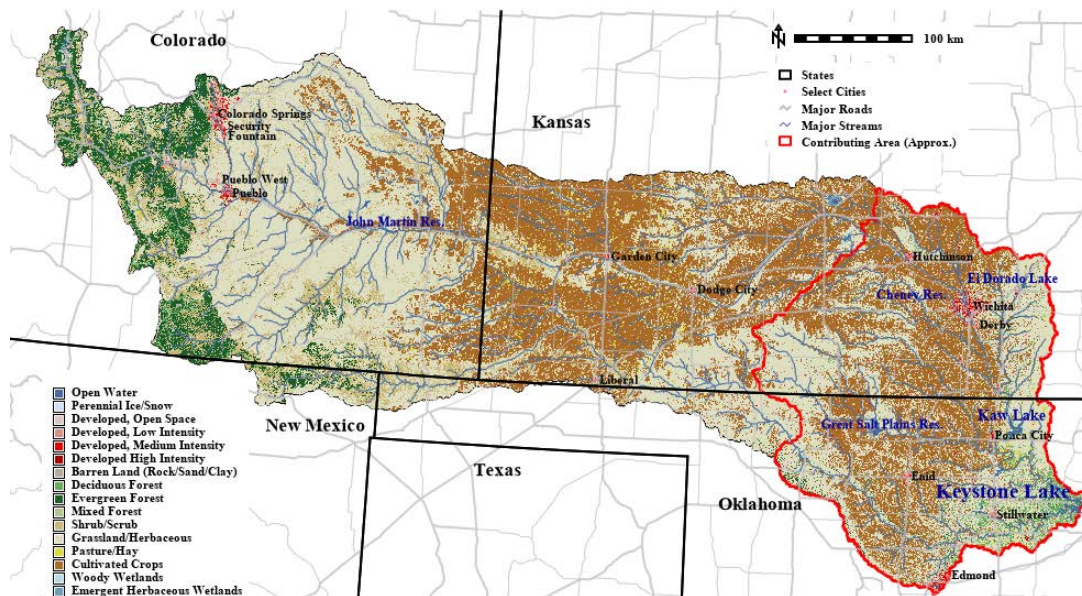


Figure 1. The Keystone Lake (Arkansas and Cimarron Rivers) Watershed above the Keystone Lake Dam.

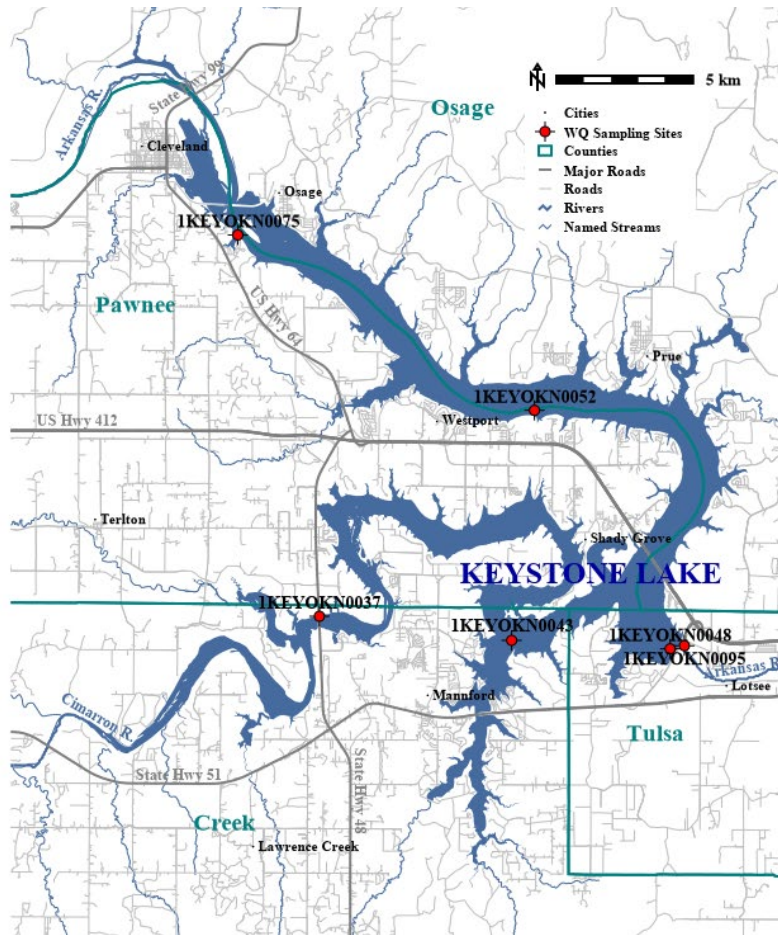
**Table 1. Descriptive Characteristics of Keystone Lake, OK.**

Parameter	English Units	Metric Units
Lake Elevation (Conservation Pool)	723.0 ft. NGVD	220.37 m
Lake Surface Area (Conservation Pool)	16,160 ac	6,540 ha
Lake Volume (Conservation Pool)	400,983 ac-ft	494.61*10 <sup>6</sup> m <sup>3</sup>
Total Drainage Area (contributing)	22,350 mi <sup>2</sup>	57,886 km <sup>2</sup>
Mean Depth	24.8 ft.	7.56 m
Maximum Depth (Conservation Pool)	73.5 ft.	22.4 m
Shoreline Length	322.2 mi	518.5 km
Shoreline Development Index	15.7	15.7
Annual Inflow, Average 1940 – 2022 [Water Years]	5,474,530 ac-ft	6,752.7*10 <sup>6</sup> m <sup>3</sup>
Annual Inflow, 2022 [Calendar Year]	3,258,149 ac-ft	4,018.9*10 <sup>6</sup> m <sup>3</sup>
Hydraulic Residence Time, 2022 [Calendar Year]	47.02 d	0.13 yr

Data derived from the Tulsa District's Pertinent Data Book (U.S. ACE - Tulsa District, 2004), the FY 2022 Annual Water Control Report (U.S. ACE - SWD RCC, 2023), Tulsa District's Water Control page for Keystone Lake (U.S. ACE - Tulsa District, 2023), and the 2020 bathymetric survey (Seaworks Group, LLC, 2020).

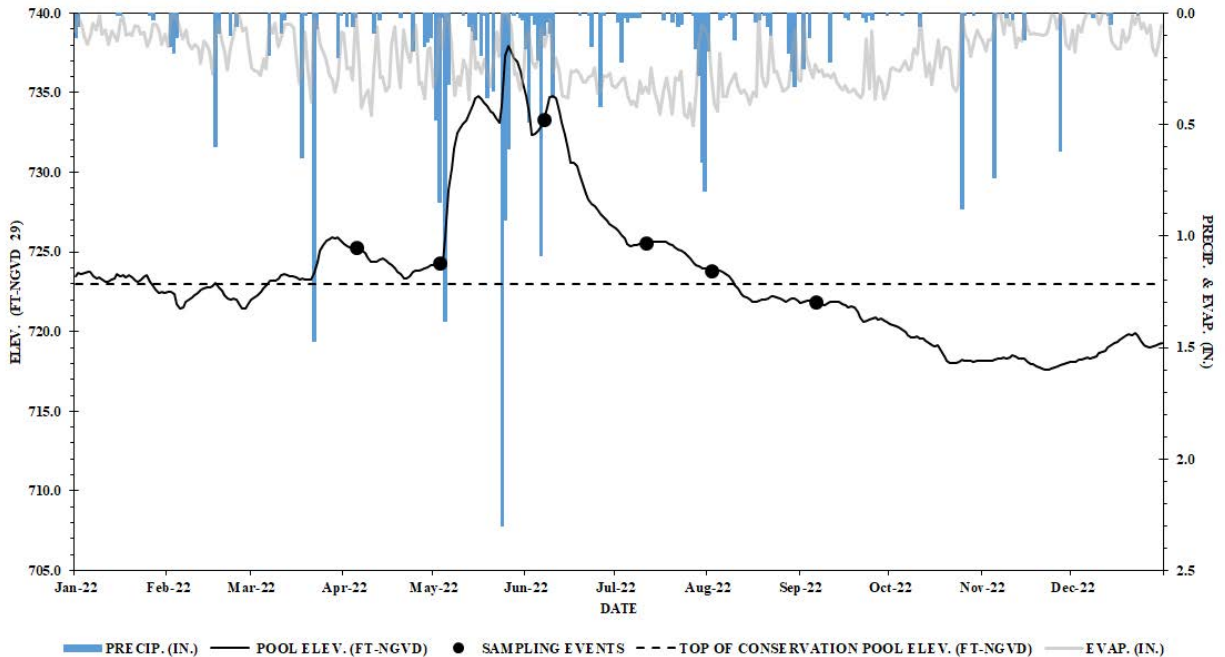
Designated beneficial uses of the impoundment created by the Keystone Lake Dam include Public and Private Water Supply, Fish and Wildlife Propagation as a Warm Water Aquatic Community, Agriculture, Primary Body Contact Recreation, and Aesthetics (OAC, 2023). Based on the 2022 Integrated Water Quality Assessment prepared by the Oklahoma Department of Environmental Quality (ODEQ 2022), Keystone Lake is listed as impaired by turbidity affecting Fish and Wildlife Propagation as a Warm Water Aquatic Community, and the Upper Cimarron Arm of the lake is impaired due to Fish Bioassessments identifying a degraded fish assemblage.

Physical and chemical water quality data were collected monthly by USACE from five in-lake sites and the tailwater beginning 5 April and ending 6 September 2022 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 KEYOKN0048 (channel at the dam), KEYOKN0052 (Arkansas River channel near Old Prue), KEYOKN0075 (Arkansas Arm at Feyodi Creek State Park boat ramp), KEYOKN0043 (Cimarron River channel at mouth of Salt Creek), KEYOKN0037 (Cimarron Arm at State Highway 48 Bridge), and KEYOKN0095 (tailwater below dam). Sites KEYOKN0048, KEYOKN0052, and KEYOKN0043 were accessed by boat from locations over the deepest portion of the stream channel (thalweg). Vertical profiles were not collected in April. Keystone Lake naturally receives relatively high tributary loads of dissolved solids based in part on upstream geology. Sampling locations are identified in Figure 2.



**Figure 2. Locations of water quality sampling sites at Keystone Lake, OK, 2022.**

The Keystone Lake pool was above the conservation pool elevation April through August, and ~2 feet below in September. Calendar year 2022 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 Keystone Lake, OK, 2022.**

To assist reporting, some descriptions of water quality at Keystone Lake refer to lake areas. Sites KEYOKN0052 and KEYOKN0075 represent the Arkansas River Arm of the lake, KEYOKN0043 and KEYOKN0037 represent the Cimarron River Arm, and KEYOKN0048 represents the main mixed body. Water temperatures varied seasonally (ranging from 16.00 to 31.25 °C) peaking in July. July water temperatures recorded in both ‘Arms’ of the lake were >30 °C surface to bottom. All water temperature observations <17 °C occurred in May 2022 at KEYOKN0048 at depth (13- to 20-meters). Thermal stratification was not noted although some evidence of a halocline, stratification due to salinity, was observed in May, June and July at KEYOKN0048. The study period lakewide median dissolved oxygen concentration (DO) was 4.55 mg/l. Median DO was moderately higher in the Cimarron Arm (5.42 mg/l) and lowest at KEYOKN0048 (3.67 mg/l). Observed in-lake DO ranged from 0.65 to 10.84 mg/l. Lowest DO concentrations (<2 mg/l) were observed at depths beginning 10-meters and below at KEYOKN0048 in July, August, and September; at KEYOKN0052 7-meters and below in June and July; and at KEYOKN0043 9-meters and below in June and July. Highest DO concentrations (>10 mg/l) were observed at KEYOKN0043 in May from the surface to 7-meters depth. Lakewide total organic carbon concentrations were moderately high with a study period median of 7.14 mg/l. Observed median total organic carbon concentrations were comparable across lake areas (KEYOKN0048 6.99, Arkansas Arm 6.74, and Cimarron Arm 7.43 mg/l).

Specific conductance (lake wide median 956  $\mu\text{S}/\text{cm}$ ) was high, consistent with regional geology. Cimarron Arm median conductance was 1,149  $\mu\text{S}/\text{cm}$  and Arkansas Arm was 779  $\mu\text{S}/\text{cm}$ . Total dissolved solids median concentration was 690.0 mg/l with lake area medians ranging from 517.0 (Arkansas Arm) to 1,022.0 (Cimarron Arm) mg/l. High lakewide chloride and sulfate concentrations (medians 277.0 and 87.7 mg/l, respectively) were observed, again with higher lake area medians in the Cimarron Arm (405.0 and 102.5 mg/l, respectively). Alkalinity levels (median 141.0 mg/l as  $\text{CaCO}_3$ ) imply a system capable of maintaining pH levels. Hardness levels, lakewide median 186.0 mg/l as  $\text{CaCO}_3$ , indicate ‘hard’ water. Observed in-lake pH (7.08

to 8.92) ranged within regional norms. Highest pH was recorded near the surface at KEYOKN0075 in July. Measurements of pH at KEYOKN0043 in May were >8.5 from the surface to 9-meters depth. Lowest pH was recorded in June at depth at KEYOKN0048 and KEYOKN0043.

Median lakewide Secchi depth was 0.84 meters. Through the sampling period, median Secchi depth was lowest in the Arkansas Arm (0.59 m) and highest in the Cimarron Arm (0.94 m) and KEYOKN0043 (0.92 m). Lakewide median turbidity was 26.9 NTUs, and 61% of all in-lake observations were greater than or equal to 25 NTUs. Median lakewide total suspended solids concentration was 12.0 mg/l, with median Arkansas Arm concentration (21.5 mg/l) higher than the Cimarron Arm (12.0 mg/l) and KEYOKN0048 (5.5 mg/l) lake areas. The euphotic zone at Keystone Lake site KEYOKN0048 ranged from 1.2 to 1.7 meters.

Lakewide ammonia concentrations (median 0.12 mg/l) and nitrite plus nitrate concentrations (median 0.27 mg/l) were moderate to high. Highest site median ammonia concentrations were found in bottom samples at KEYOKN0048 (0.30 mg/l), and highest site median nitrite plus nitrate concentrations were found at KEYOKN0075 (0.55 mg/l, upper Arkansas Arm). Total Kjeldahl nitrogen concentrations (lakewide median 0.74 mg/l) were comparable in all lake areas. Estimated lakewide median surface total nitrogen concentration during the 2022 study was 1.05 mg/l. Total phosphorus concentrations lakewide ranged between 0.20 and 0.49 mg/l (median 0.30 mg/l). Detectable concentrations of dissolved ortho-phosphate, lakewide median 0.15 mg/l, were present in 91% of samples collected. Nitrogen to phosphorus ratios (N:P) in 2022 were <10 (median 3.33) indicating a tendency toward limited nitrogen availability and the potential for phytoplankton dominance by cyanophytes.

Chlorophyll-a concentrations (in-lake) ranged from 5.6 to 68.9 µg/l, with a median concentration of 25.8 µg/l. Median lake area chlorophyll-a concentrations were highest in Arms of the lake (Arkansas Arm, 37.6 µg/l; Cimarron Arm, 31.4 µg/l). Figure 4, below, summarizes relative abundance and biovolume of divisions of phytoplankton sampled at select Keystone Lake sites. Cyanophyte (blue green 'algae' that are photosynthetic bacteria) abundance dominated the latter half of the sampled period (July to September), while biovolume shows a varying seasonal representation of an array of phytoplankton divisions related to site-specific water quality conditions. Figure 5 summarizes zooplankton densities observed in 2022 (note the log scale density axis) at KEYOKN0048, KEYOKN0052, and KEYOKN0043. Cladocerans, Copepods, Rotifers, and Bivalves were generally well represented across the sampling period.

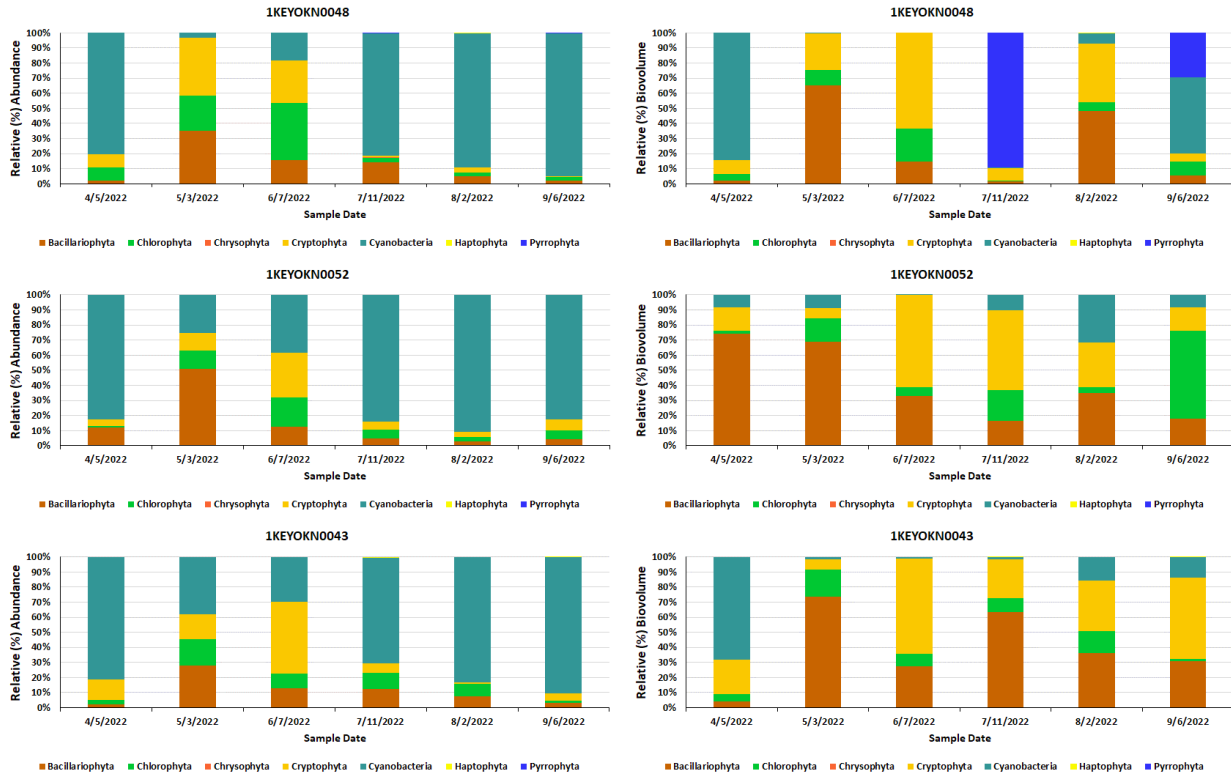


Figure 4. Phytoplankton relative abundance (left) and relative biovolume (right) at KEYOKN0048, KEYOKN0052, and KEYOKN0043 April through September 2022.

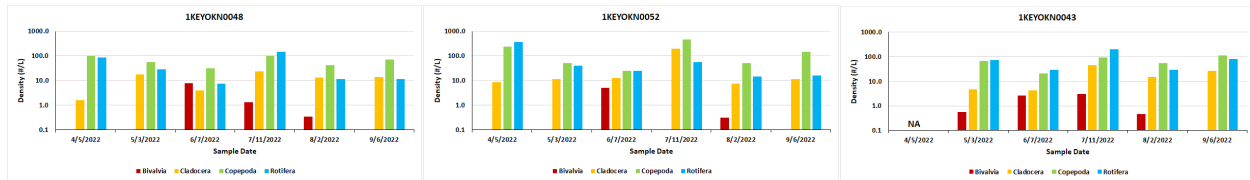
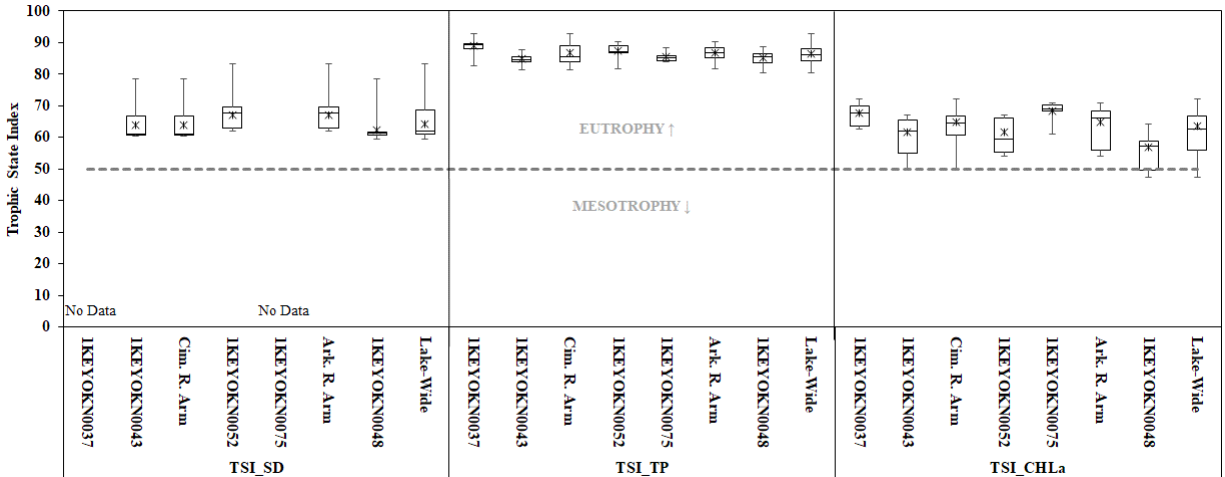


Figure 5. Zooplankton density at KEYOKN0048, KEYOKN0052, and KEYOKN0043 April through September 2022.

Trophic status of Keystone Lake was assessed using all three metrics of Carlson's trophic state index (TSI) at each in-lake site and the lake as a whole. Median lakewide indexes based on Secchi depth (TSI(SD)) and chlorophyll-a concentrations (TSI(CHLa)) were >60.0. The lakewide median surface total phosphorus index (TSI(TP)) value was 86.1. The median lakewide index developed from chlorophyll-a concentrations (TSI(CHLa)), 62.5, indicated a eutrophic waterbody (Figure 6).



**Figure 6. Distributions of Carlson's Trophic State Index (TSI), by sampling site and lakewide, based on observations of Secchi Depth (TSI(SD)), surface total phosphorus concentrations (TSI(TP)), and chlorophyll-a concentrations (TSI(CHLa)) at Keystone Lake, OK, April through September 2022.**

Total iron (median 0.16 mg/l) and manganese (median 0.08 mg/l) concentrations were moderate. Reportable concentrations of arsenic were found in all in-lake samples collected, with a median concentration of 0.0055 mg/l. Reportable concentrations of copper, nickel, and zinc were noted in all in-lake samples. Reportable concentrations of chromium and lead were present in 92, and 81%, respectively, of all samples collected. No detectable mercury concentrations were noted. Results of water quality parameters from the tailwater (KEYOKN0095) were comparable to data collected in-lake at KEYOKN0048.

USACE previously conducted water quality sampling at Keystone Lake, OK in 1978 - 1979, 1996, and 2009. One prior effort (1996) indicated temporary summer month thermal stratification with associated hypoxia at depth. Nutrients, both nitrogen and phosphorus, were present in concentrations sufficiently high to support a highly productive system. Median lakewide chlorophyll-a concentrations have steadily increased across sampling efforts. Iron and manganese concentrations were high shifting to moderate across efforts.