Appendix G. Water Quality

Draft Kansas River Reservoirs Flood and Sediment Study

October 2023

U.S. Army Corps of Engineers
Kansas City District

Kansas River Reservoirs Flood and Sediment Study

APPENDIX G Reservoir Water Quality

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1.0 INTRODUCTION AND OBJECTIVES

1.1 Introduction

Water quality is a broad topic including physical, chemical, and biological characteristics of surface waters in the Kansas City District with potential impacts to nearly all components of the Kansas River Flood and Sediment Study.

As outlined in Corps Engineering Regulation – *Water Quality and Environmental Management for Corps Civil Works Projects (ER 1110-2-8154, 2018)*, "water quality is an integral component of all Corps civil works missions." The Kansas City District Water Quality Program works within the guiding principles of ER-8154 to ensure that all applicable state and federal water quality standards are met, water quality degradation of Corps resources is avoided or minimized, and project responsibilities (i.e., project authorizations, authorized project purposes, and applicable regulatory requirements) are attained.

The Kansas City District Water Quality Program has maintained a long-term and robust water quality monitoring and data collection program to meet the needs of all lake Projects. Chemical, physical and biological parameters are measured to evaluate water and lake bed sediment quality. The Corps uses this data to describe conditions and changes from the inflow streams, within the main lake, and outflow focusing on eutrophication, nutrients, sediment, herbicides, metals, and contaminants. This data is critical to investigating problems that may arise, such as harmful algal blooms (HABs), bacteria issues, and fish kills as well as design and implement modifications to improve water management procedures.

1.2 Objectives

It is the objective of this section to provide the baseline water quality information needed to properly evaluate potential management strategies/measures for ecosystem restoration and water quality protection and improvement as outlined herein.

1.3 Study Area

Detailed information regarding USACE and USBR project purposes, history, and physical design features and other project specific pertinent data are referenced in Section 3.2.2 Kansas River Basin Reservoir System of this document. Detailed information regarding historical water quality at Kansas City District lakes and watersheds is provided in various Project specific water quality reports (USACE, 2010-2019). The locations of federal reservoirs within the Kansas River Basin are shown in Figure 1-1.

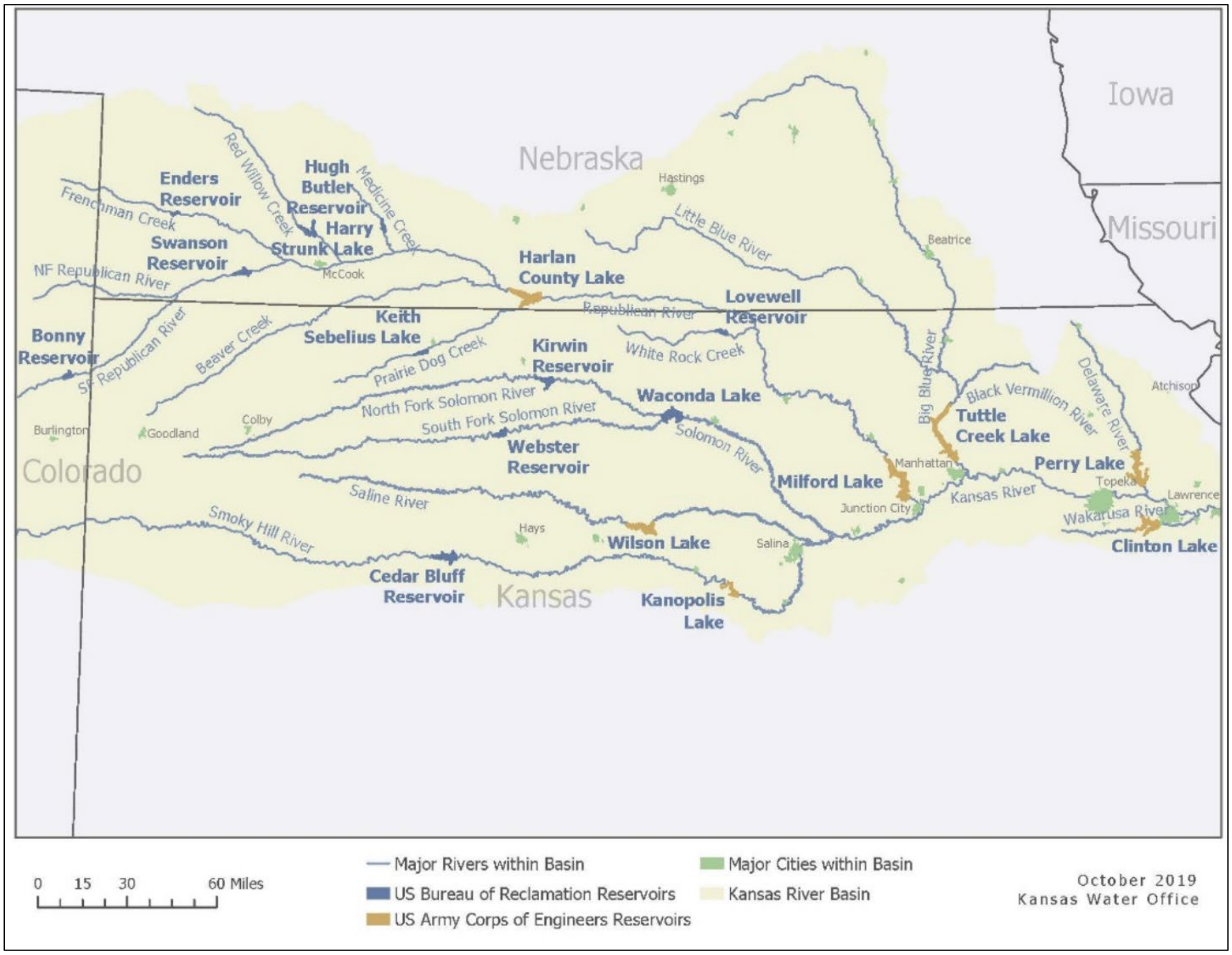


Figure 0-1. The Kansas River Watershed.

Man-made lakes are usually termed “reservoirs” or “impoundments,” depending on designated use and regional preferences. To provide consistency, this report uses the term “lake” to describe standing water that has not been officially designated by another name.

2.0 METHODS

2.1 General

Water quality data used for this document is a compilation of available data from Kansas Department of Health & Environment and USACE Kansas City District Water Quality Program in accordance with NWK Project Work Plan and Quality Assurance Project Plan (QAPP) for the NWK District Water Program (USACE 2019). Detailed information regarding historical water quality at Kansas City District lakes and watersheds is provided in various Project specific water quality reports (USACE, 2010-2019). Annual lake reports for water quality monitoring at Federal Bureau of Reclamation lakes was provided by Kansas Department of Health & Environment-Bureau of Water, Watershed Planning, Monitoring and Assessment. (https://www.kdheks.gov/befs/lakes_monitoring.htm). General sampling dates and sample location maps located in the body of this document. Data quality management issues for the study were likewise addressed in this document.

2.2 Baseline Water Quality Sampling

Kansas City District Water Quality Program monitors baseline status and trends of water quality conditions at Kansas City District projects for at least thirty years. Baseline definition is the least rigorous constraint of our data set considering 18 lakes per month with minimal concurrent sampling is planned. Every attempt is made to avoid runoff conditions and sampling is rescheduled if local rainfall exceeds one inch in 24 hours prior to sampling. However, high water and runoff is included in the data set and typically appears as outliers. Monitoring entails the collection of inflow (i.e., major streams flowing to lake), in-lake from each major tributary arm of lake, and outflow (i.e., directly below the dam) data for water quality problem identification and to provide a sufficiently robust water quality database for watershed and reservoir environmental modeling. Consequently, lakes with more tributary arms will have more in-lake water quality sites and generally more variation in the results. In-lake data collection includes sampling of both lake waters and sediments in accordance with established Kansas City District standard operating procedures (SOP's) (USACE 2003). A summary of available in-lake sediment quality data is provided in the body of this document while a more comprehensive report on sediment characteristics for all Kansas City District lakes is in the appendix (James 2009).

2.3 Water Quality Sampling

Water quality sampling is conducted April-September by Kansas City District personnel at standardized inflow, lake, and outflow sites. Inflow sites, pesticide, total metals, and bottom chemistry samples are collected every 3rd year due to funding limitations. Sample sites have been spaced to account for differences in sub watersheds and water quality influence on their respective lake arm as well the horizontal gradients common to large reservoirs. Sample location coordinates have been recorded using an on-board and/or hand-held global positioning systems (GPS) to facilitate navigation to these sites. Inflow sites are typically collected from the river thalweg from bridges. In-lake sample sites are located in the river channel of lake arms. Outflow sites are located in the thalweg and typically collected from shore, fishing access in the USACE outlet parks, or bridges within a mile of the dam.

Field data recorded at each site included Secchi disk transparency and vertical profiles of water temperature, dissolved oxygen (DO), pH, conductivity, and nephelometric turbidity. Vertical profiles of field water quality parameters were recorded at the surface (0.3-meter (m) depth) and at 1-m depth intervals throughout the entire water column. Profile data were electronically logged and downloaded to a personal computer (PC) to minimize data transcription errors.

Surface water samples for physical, chemical, and biological laboratory analyses are collected at an approximate depth of 0.3 m at each site while bottom samples are collected 0.3 m from bottom sediments. Lake bed sediments samples are collected using a petite ponar dredge from standardized lake sample locations and typically analyzed for nutrient and metal concentrations. Dredging project discussions/proposals have increased bed sediment analysis including pesticide and potential industrial contaminants. Chlorophyll *a* samples to describe productivity are a composite sample of three grab samples taken from top, middle, and bottom of photic zone as measured by Secchi disc.

Analytical parameters initially employed for water samples as well as laboratory methods used for each constituent are included in Table 2-1. The list includes a broad range of common limnological parameters including those important for water supply evaluation, watershed conservation metrics, and those necessary to support water quality modeling efforts. Field sampling intensity has periodically increased by up to 100% to meet modeling data needs and to evaluate watershed conservation and/or Total Maximum Daily Load (TMDL) development. Parameters have been eliminated from routine sampling that were consistently below analytical detection limits, those that exhibited little spatial and temporal variability, and those for which data were being collected using field instruments (e.g., nephelometric turbidity). Parameters listed below will be referred to by common name or commonly used symbology (i.e, total phosphorus, TP) in the body of the text to simplify nomenclature.

Table 2-1. Analytical Parameters and Methods for Water Samples.[1]

Category	Parameter	Analytical Method
Nutrients	Total phosphorus–P	EPA 365.2 / SM 4500-PE / EPA 6010B
Nutrients	Total ortho-phosphorus-P	EPA 365.2 / SM 4500-PE / EPA300.0
Nutrients	Nitrate + Nitrite – N	EPA300.0
Nutrients	Ammonia – N	EPA 350.1
Nutrients	Total Kjeldahl (TKN) –N	EPA 351.2 / I-4515-91
Inorganics	Total alkalinity	SM 2320-B
Solids	Total suspended solids	EPA 160.2 / SM 2540-D
Total Metals	Arsenic, Copper, Iron, Lead, Manganese, Nickel, Zinc, Mercury, Selenium, Cadmium, Chromium	EPA 200.7 / 200.9
Total Anions	Bromide, Chloride, Sulfate	EPA 300.0
Other	Chlorophyll *a*	EPA 445.0
Other	Total organic carbon	SM 5310-C
Organics	Chlorinated pesticides	SW-846 8081 A
Organics	Chlorinated herbicides	SW-846 8081 A

Note: [1/] Sample analysis completed by USACE contract or federal labs from 2010 to 2019.

Kansas Department of Health and Environment (KDHE) provided physical and chemical data for use in this report collected and analyzed for US Bureau of Reclamation lakes and streams from 2010-2019 according to their published Lake and Wetland Chemistry and Monitoring Plan (KDHE 2014a).

2.4 Statistical Analyses

Statistical graphic analyses were conducted using Statistica V13.5 (TIBCO Software Inc) and Microsoft Excel for 365 V16. For hypothesis testing, differences were considered statistically significant at $\alpha = 0.05$ for water quality samples using either parametric or non-parametric analysis dependent upon normal data distribution identified by Shapiro-Wilk test. Laboratory results reported herein include results which may be estimated as half of the minimum detection limit based on the assumption that a range of all values between the minimum detection limit and zero could be present. This conservative approach is an acceptable way to reduces analysis bias and avoid skewing data (United States Environmental Protection Agency, 1991).

Box-and-whisker plots were used for illustration of much of the data throughout this report. These plots are used to compare distributions, quickly and visually, across groups, using quartiles. Figure 2-1 is a generalized presentation of how these plots can be interpreted.

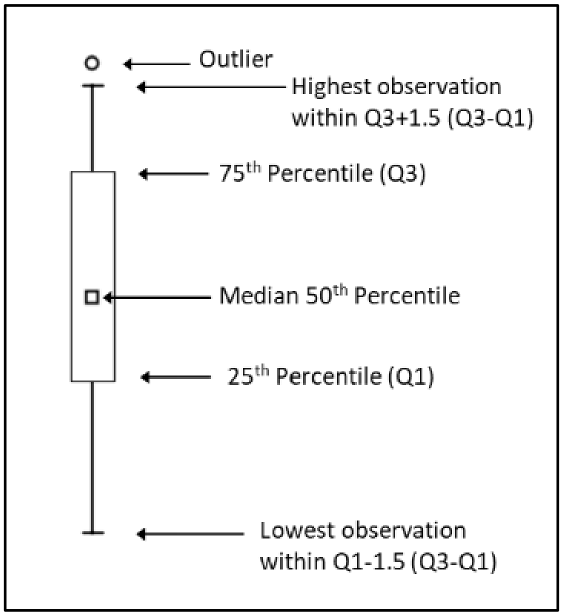


Figure 2-1. Box and Whisker Plot Example.

2.5 Residence Time

Water residence time is calculated as an estimate of how long a compound will remain in a lake's system. This variable is determined by the flow (inflow or outflow) and storage volume of the lake, as well as the sedimentation (i.e., loss of storage) received by a lake over time.

Residence time was calculated using HEC-ResSim (Hydrologic Engineering Center – Reservoir System Simulation) to model two different scenarios; existing conditions (0-year FWOP) and future without project conditions (100-year FWOP). Each reservoir was modeled with historically observed average daily inflows for both scenarios over a 100-year timeframe with change of storage volume due to sedimentation as the experimental variable. HEC-ResSim generated estimated lake storage, discharges, and evaporation from these simulations. Observed average residence time was also calculated for the 1990-2022 period for comparison to 0-year FWOP simulation.

The general equation to estimate the average residence time of a lake is dependent on the storage of the lake, inflows, and outflow. This equation works with inflow or outflow and is defined as follows:

$$RT = \frac{Avg\ Storage}{Avg\ Flow}$$

3.0 LAKE WATER QUALITY

3.1 USACE Lakes Water Quality

The availability of high-quality water for commercial, industrial, and residential uses is vitally important for the water users of Kansas. Activities to further protect and improve the water quality of Kansas to avoid degradation of the State's water resources are imperative for current and future water users. State natural resource agencies have designated 16 of the 18 lakes in the Kansas River Basin as "impaired" from nutrient related impacts (e.g., excess nitrogen and/or phosphorus, general eutrophication, excess chlorophyll/algae measures, dissolved oxygen sags resulting from algal blooms) resulting primarily from agricultural runoff. Most lakes in the Kansas City District exceed EPA Ecoregional Nutrient Criteria (EPA 2001) for both total phosphorus and nitrogen with Kansas River Basin Lakes ranking at the top (Figure 3-1). Inflow streams flowing into Basin lakes are frequently impaired from a range of pollutants including, but not limited to, fecal bacteria, herbicides like atrazine, and chemical contamination from naturally occurring compounds found in ground water flowing through geological deposits forming chloride and sulfate salts, selenium, and arsenic. Excess nutrients can lead to Harmful Algal Blooms (HABs) under ideal growing conditions. HABs have impacted six lakes in the Kansas River Basin since 2011. Milford Lake has been the hardest hit, with HAB warnings impacting recreation 7 of the last 10 years.

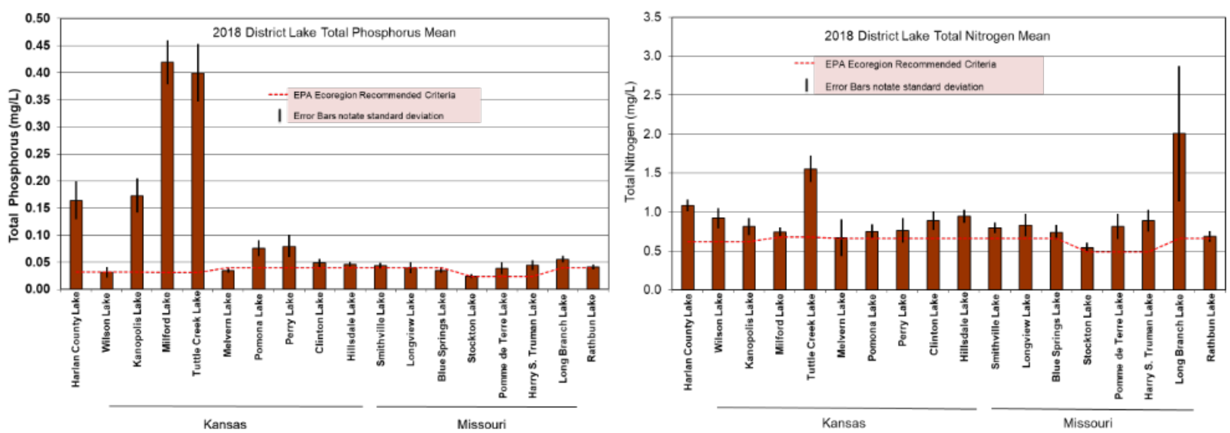


Figure 3-1. Kansas City District Lakes Phosphorus and Nitrogen Concentrations for 2018. *Representative average annual phosphorus and nitrogen concentration of 18 Kansas City District lakes in 2018.*

Nutrient rich runoff and soil loss from fields and stream banks work in tandem to compound water quality problems and are linked to the most frequent Kansas lake impairment summarized as eutrophication. Excess nutrients frequently lead to potentially harmful algae blooms while accumulation of sediment in lakes reduces storage capacity for water use. Reduced volume means less dilution and equates to higher concentration of all compounds stored in the lake system. This age-related process leads to increasing susceptibility of reservoirs to contamination and internal loading of nutrients, metals and compounds stored in lake bed sediment.

Results for individual parameters and comparisons are described in detail in the following sections. In general, discussion of water quality results in the following sections will primarily focus on general water quality overview or baseline conditions with descriptive comparisons between sample locations within the lake/watershed from 2010 to 2019.

3.1.1 Harlan County Lake

Harlan County Lake is a 13,000-acre impoundment on the Republican River in Nebraska. The Republican River flows from Harlan County Lake through fertile agricultural land into Milford Lake and then into the Kansas River. The primary water quality threats to Harlan County Lake are nutrients, sediment, and toxic cyanobacteria blooms (Figure 3-2). Drought conditions have also impacted Harlan County Lake by reducing the surface acreage by nearly 50% in 2004, 2005, and 2014. During normal water level years, the lake experiences a 4-6 ft. summer drawdown related to irrigation releases. Dredging has occurred to maintain boat access in coves with two marinas. Blue-green algal blooms have occurred periodically with health alerts for the USACE swim beach, including algae toxin, being reported by Nebraska Department of Energy and Environment (Nebraska DEQ Beach Watch).

Figure 3-2. Harlan County Lake Boat Ramp in Shallow Cove During Harmful Algal Blooms. *(USACE 2007).*

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics like flow, water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological response.

Water quality sampling events by Kansas City District staff were conducted monthly at Harlan County from 2010-2019 coinciding with the typical recreational season (April-September) (Figure 3-3). Dry/drought periods were observed at the end of 2013 with surface elevation falling below 1930' while recovery period is apparent beginning in 2015. Flooding and corresponding high-water period were observed in 2019 as inflows exceeded 12,500 cfs.

Average water residence time for Harlan County Lake of 23.8 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Harlan County Lake average water residence time was the longest of all Kansas River Watershed lakes in this study. Extended residence time allows for longer dilution and settling time as well as biological attenuation of agricultural runoff which improves water quality downstream of Harlan County. Accumulation of sediments and storage of sediment bound contaminants have negative implications for water quality as extended water residence time is a contributor to eutrophication including negative impacts to temperature and oxygen profiles from algal growth and potential increase in harmful algae blooms, increase potential of internal nutrient loading and loss of pool volume.

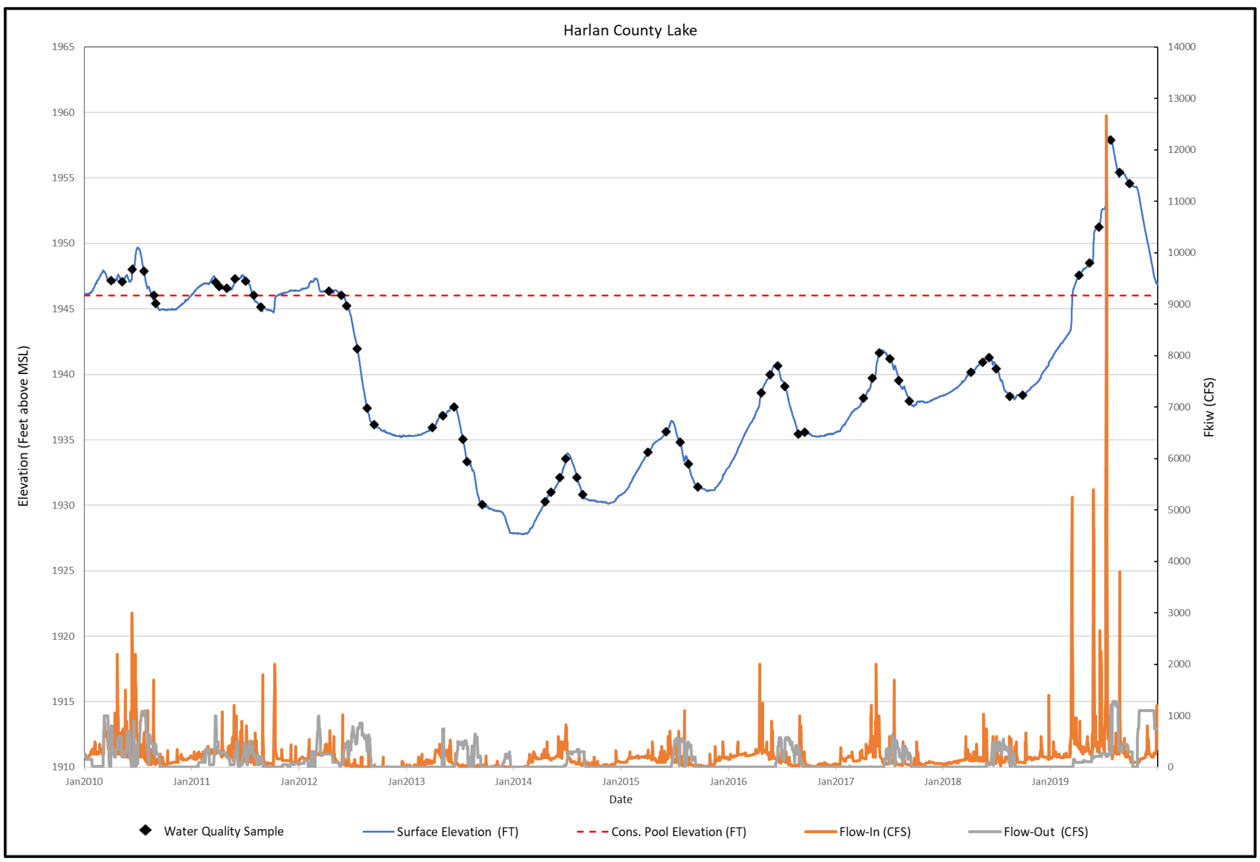


Figure 3-3. Time Series of Daily Water Surface Information 2010 - 2019.

Series includes daily water surface elevation, inflow, out, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.

Water Quality Sample Locations

Historic water quality sample sites at Kansas City District lake projects are generally named in decreasing numeric order from inflow site(s) to the outflow site below the dam (Figure 3-4). To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

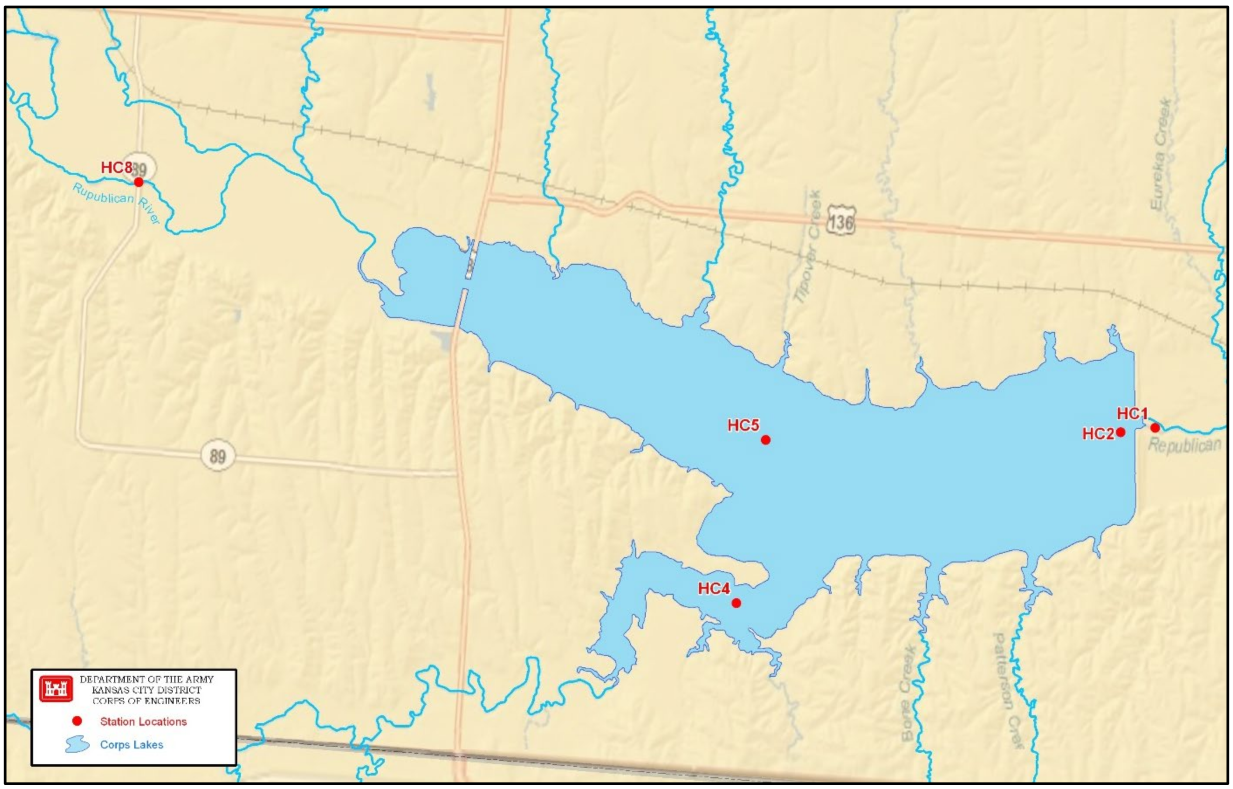


Figure 3-4. Map of Historic Harlan County Reservoir USACE Water Quality Sample Sites.
Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow.

Impaired Waters and Total Maximum Daily Loads

Harlan County Lake is listed in the most recent (2018) Nebraska 303(d) list of impaired waters due to excessive total phosphorus and total nitrogen concentrations. Nebraska Department of Environmental and Energy (NEDEE) and U.S. Environmental Protection Agency (EPA) work with water quality partners to reduce nutrient inflow into Harlan County Lake to improve water quality. Eutrophic conditions, indicative of excessive algae production, is an impairment with wide ranging impacts ranging from taste and odor problems in drinking water to objectionable algal growth interfering with recreational activities with potentially toxic conditions. In 2018, Harlan County Lake ranked above average among District Lakes for both total phosphorus and total nitrogen measured at the site nearest the dam (Figure 3-1). Both total phosphorus and total nitrogen 10-year mean values (Table 3-1) as well as 2018 nutrient measures exceeded recommended nutrient criteria set by NEDEE and EPA Ecoregion (Figure 3-1).

Inflows/Outflow

Lakes and reservoirs store sediment and associated chemical compounds with the water contained. Sediment, suspended particles, and soluble chemicals enter reservoirs from runoff, groundwater, and inflow streams. Different nutrient and geological sources associated with inflows and source water influence water quality in physical, chemical, and biological composition. Nutrient balance in receiving waters has direct implications on trophic state and is linked to types of plant and algae species or primary production in the lake. Water exiting through the dam or outlet works of Corps' lakes can be very different than inflows as large amounts of nutrients, pesticides, and metals are attenuated (i.e., processed/converted to other forms, diluted) or stored in the lake causing a sink effect (Satoh et al., 2002). Physical water quality changes include changes in temperature, turbidity, and dissolved oxygen concentrations in outflows depending on timing of release and typically related to release of anoxic water during stratified periods or potential for supersaturation during flood releases in water released from dams. Proportion of anoxic water mixed into releases is typically low at Harlan County Lake with few low oxygen periods documented.

Harlan County Lake is in the Republican River Basin which is includes portions of Nebraska, Colorado, and Kansas. Much of the basin is highly productive agricultural lands which help support the local economy. Complex water management issues centered on limited water supplies and contributions from non-point source nutrient pollution have influenced Harlan County Lake water quality for much of the lake's history (EPA Region VII, 1974). As case in point, between April 2004 and September 2006, no samples could be collected from the inflow site on the Republican River near the town of Orleans, Nebraska due to lack of water. The following section is an overview and comparison of water quality data upstream and downstream of Harlan County Lake.

Herbicides have been monitored at Harlan County Lake by Kansas City District Water Quality personnel since 1996. The list of herbicides detected have included mostly chlorinated species and chemical constituents of atrazine, alachlor, metolachlor, cyanazine, metribuzin, simazine, acetochlor, 2, 4-D, and glyphosate. EPA regulation of herbicide licensing to reduce chemical persistence and mobility in the environment have reduced the number and concentration of chemicals detected in Kansas City District Water Quality samples. Total atrazine and alachlor concentrations peak during planting season in the spring and are associated with runoff events as herbicides mobilize and enter the Republican River in concentrations typically much higher than those exiting through the outlet. Median concentrations of atrazine in Figure 3-5 are slightly lower in the inflow than the median at the outflow as an artifact of fewer samples being collected from inflows during the period of analysis. Concentrations of atrazine, as well as detectable levels of alachlor in the outflow (Figure 3-5), persist below Nebraska DEE Water Quality Criteria for protection of aquatic life of 12 ug/L and 76 ug/L, respectively.

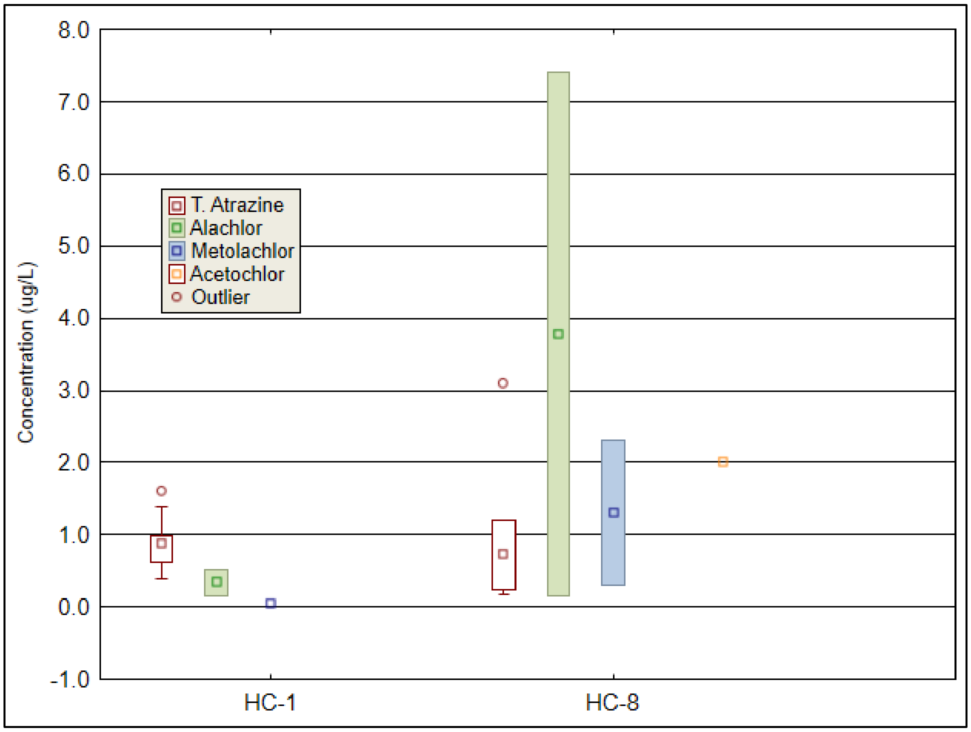


Figure 3-5. Herbicide Concentration upstream and downstream of Harlan County Lake from 2010-2019.

Herbicide concentration measured from surface samples collected at Harlan County Lake inflow (HC-8) and outflow (HC-1) USACE water quality sample sites from 2010-2019.

Nutrient concentrations in the Harlan County Lake and watershed are considered high as defined by "impaired waters" status as outlined in NEDEE 303(d) list of impaired waters. Fertile agricultural watersheds in Nebraska are likely to provide excess nutrients to inflow streams (Manning et al., 2020) with different delivery rates and fate in Harlan County Lake and downstream. In the rural landscape, nitrogen deposition is more likely associated with agriculture or fertilizer application (Arbuckle and Downing 2001; Boyer et al., 2002) while phosphorus loading is associated with soil erosion and farming practices as well as sewage effluent and runoff from urban watersheds (Downing and McCauley 1992; Withers and Jarvie 2008).

Total nitrogen and bioavailable forms of nitrate/nitrites decreased from the inflow site to the outlet from attenuation and denitrification/biological uptake (Figure 3-6). Ammonia nitrogen increases from anoxic conditions found in the bottom strata near the dam leads to seasonal increases in ammonia in releases from Kansas City District lakes. Consequently, ammonia in concentrations at the outlet were significantly higher than those measured at the inflow site (Figure 3-6).

Inflow total phosphorus concentrations were significantly higher than outflow while seasonal increases of soluble orthophosphate related to anoxic conditions negated some attenuation of soluble phosphorus from algae uptake in Harlan County Lake (Figure 3-6).

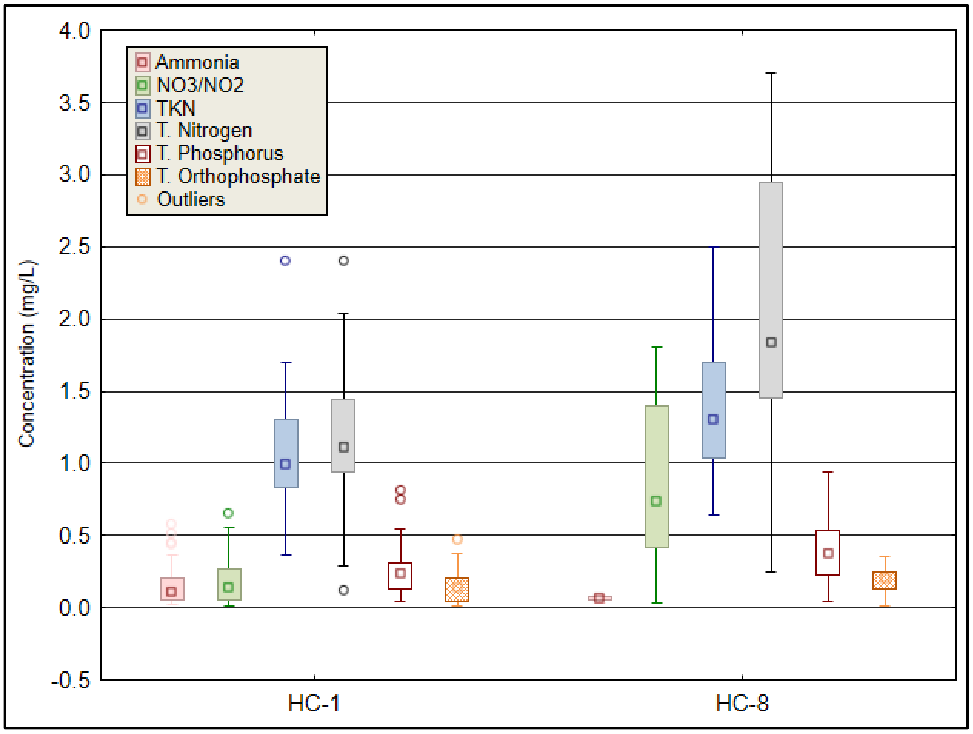


Figure 3-6. Nutrient concentration upstream and downstream of Harlan County Lake from 2010-2019.

Nutrient concentration measured from surface samples collected at Harlan County Lake inflow (HC-8) and outflow (HC-1) USACE water quality sample sites from 2010-2019.

Influences on light availability or water clarity include, but not limited to, inorganic sediment, organic carbon, turbidity, and phytoplankton (i.e., chlorophyll-a) (Testa et al., 2019). Light availability is a critical metric which influences biological productivity through light limitation of photosynthesis. Total suspended solids and turbidity results were significantly higher and more variable at the inflow site than in the outlet during our analysis period (Figure 3-7). Organic carbon was slightly higher in the outlet than inflow samples from the river, likely attributed to abundance of living and dead phytoplankton cells in the water released from the lake environment upstream in comparison to a relatively low densities of phytoplankton found in the riverine environment at the inflow.

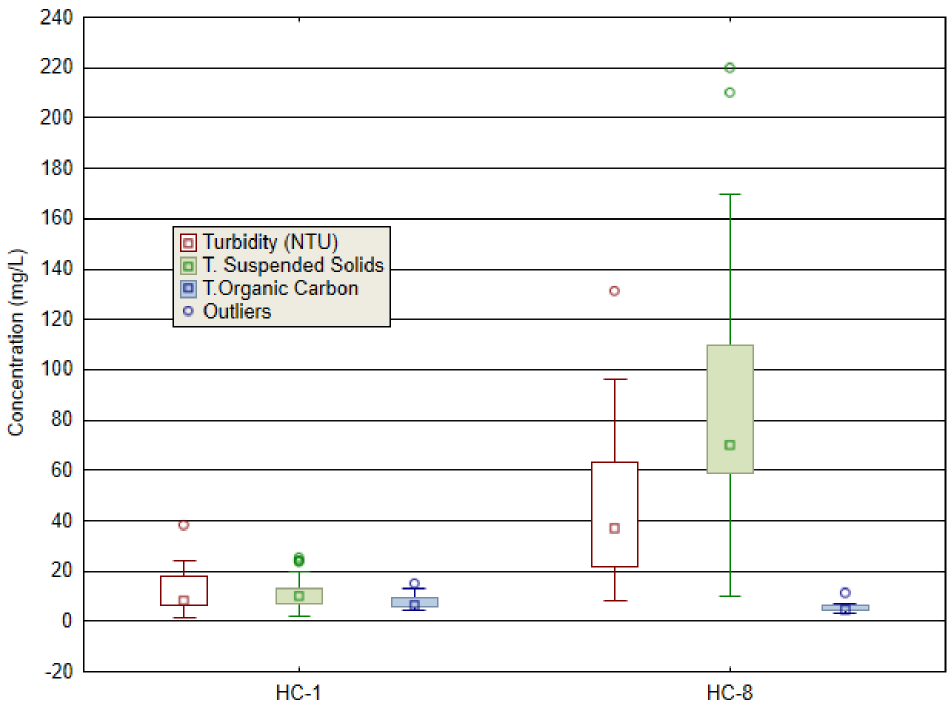


Figure 3-7. Water clarity metrics upstream and downstream of Harlan County Lake from 2010-2019.

Water clarity metrics from measured from surface samples collected at Harlan County Lake inflow (HC-8) and outflow (HC-1) USACE water quality sample sites from 2010-2019.

Metal compounds can be found in surface samples at all sample sites on Harlan County Lake and inflow but increase seasonally below the thermocline during stratified conditions in late summer. Anoxic conditions near the lake bottom in summer months contribute to the most efficient sampling window to evaluate metal released by redox conditions impacting water quality of releases from lower strata while inflow streams give a more direct relationship to metals released in the watershed that will eventually make their way to the lake. Like many lakes in Kansas City District, Harlan County Lake outlet and inflow samples contained moderate to high concentrations of naturally occurring iron, manganese, and arsenic (Figure 3-8), including samples exceeding EPA drinking water standards for arsenic (maximum allowable concentration 10 ug/L or ppb). EPA classifies iron and manganese as secondary contaminants (e.g., causing altered taste, odor, and color of drinking water). Water suppliers remove metals and contaminants from finished products.

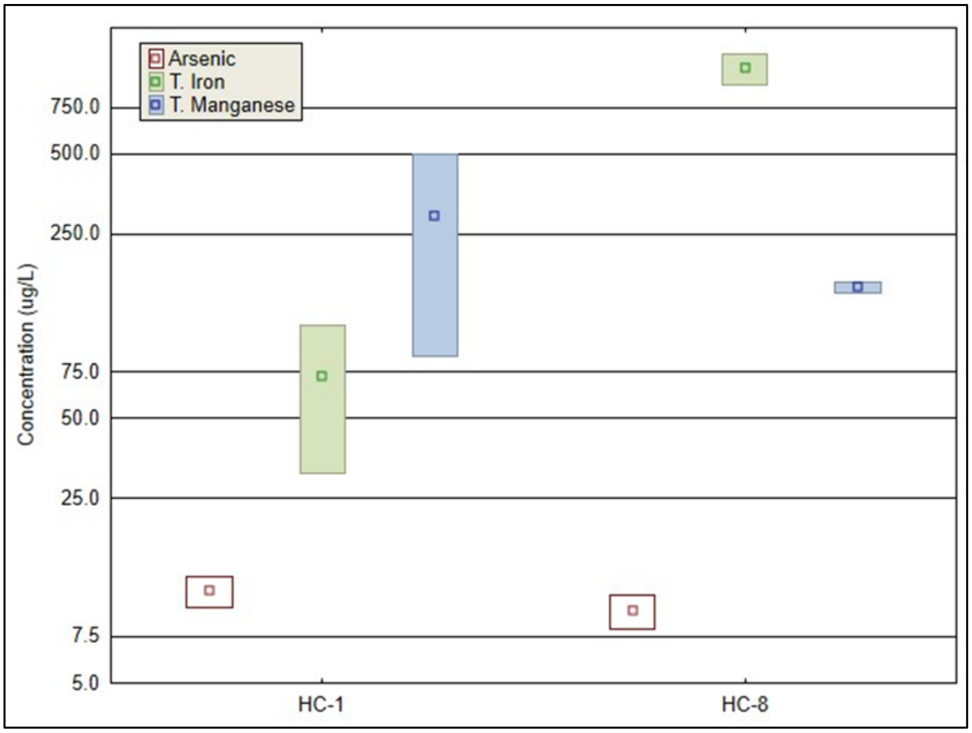


Figure 3-8. Total metal concentration upstream and downstream of Harlan County Lake from 2010-2019.

Total metal concentrations measured from surface samples collected at Harlan County Lake USACE water quality sample sites inflow (HC-8) and outflow (HC-1) USACE water quality sample sites from 2010-2019.

Lake Water Quality

Nutrient rich runoff and soil loss from fields and stream banks work in tandem to compound water quality problems linked to the most frequent Kansas City District lake impairment summarized as eutrophication. Excess nutrients often lead to algal blooms while accumulation of sediment in lakes not only reduce storage capacity for water use, but reduced volume means less dilution and buffering potential leading to concentration of compounds stored in the lake system. This age-related process makes older reservoirs more susceptible to contamination and internal loading of nutrients, metals and compounds stored in lake bed sediment.

Physical and chemical attenuation (e.g., dilution, dispersion, chemical changes, and uptake by organisms) of compounds and settling of suspended matter leads to a general decrease in concentration of many constituents of water quality, often interpreted as improved water quality, as water moves through a reservoir system (Bosch et al., 2009). Smaller lakes and/or shorter linear distance between sample locations dampen this effect. This process will be evident with many analytes in graphic representations in lake water quality sections as the lower lake sites, near the dam, have smaller numeric sites names (e.g., HC-2) and are positioned on the left side of the graphs represented on x-axis while upper lake sites with larger numeric values in the site name (e.g., HC-5) will be on the right side of the graph. The following section functions to overview chemical and physical data from surface samples at 3 lakes sites, evaluate chemical and physical differences between surface and bottom strata at the site near the dam and stratification, and discuss phytoplankton and cyanobacteria data.

Herbicide concentrations measured at Harlan County Lake sites were found at low levels with the most common, total atrazine, reported below EPA drinking water criteria of 3 ug/L (EPA 1995) at all three sites including outliers at upstream locations (Figure 3-9). Median and interquartile range for total atrazine concentration was similar at all three sample locations. Most sample results for the other four herbicides in Figure 3-9 are reported as below detection limits. However, at least 2 data points of reportable results are documented at HC-5 for alachlor, metolachlor, and cyanazine for three sampling events from 2010-2019.

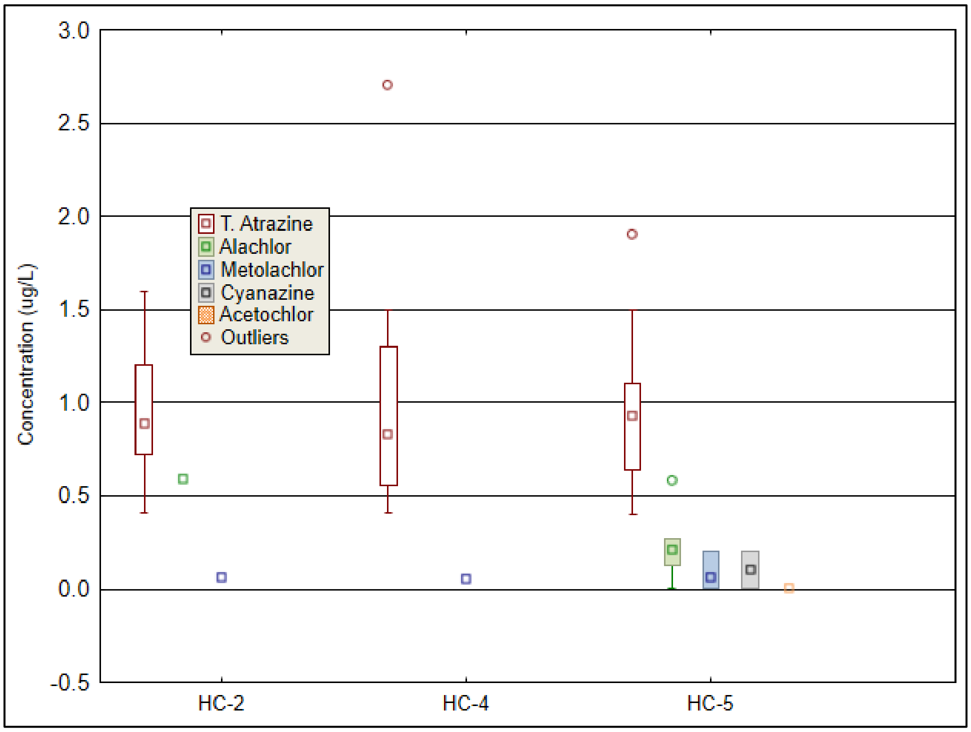


Figure 3-9. Harlan County Lake Herbicide Concentration from 2008-2019.
Herbicide concentration measured from surface samples collected at Harlan County Lake USACE water quality sample sites HC-2, HC-4, and HC-5 collected from 2008-2019.

Excess nutrients have been a concern at Harlan County Lake for much of its seventy-year history. In a National Eutrophication Survey commencing in 1972, Harlan County Lake was classified as hypereutrophic and was ranked last for trophic quality (i.e., soluble phosphorus, Secchi depth, chlorophyll *a*, dissolved oxygen sag) of nine Nebraska impoundments of concern for accelerated eutrophication (EPA Region VII, 1976). In the 2019 (most recent) Kansas City District Water Quality report, total phosphorus medians from all lake sites exceeded hypereutrophic thresholds and were at least 6 times higher than NEDEE phosphorus criteria (0.062 mg/L) (USACE, 2019). Excessive phosphorus, duration of flood water storage, and increased water clarity during the hottest part of the summer were optimum conditions for blue-green algal blooms which can dominate the phytoplankton community during late summer months. Water level fluctuations and turbid conditions at Harlan County Lake allow emergent macrophytes (e.g. bulrush (*Scirpus* spp.), cattail (Typha spp.), sedges (Carex spp.)) opportunities in shallow water lake fringe and cove areas at Harlan County Lake. Internal sources of orthophosphate released by bottom sediments are also a frequent occurrence in late summer as soluble phosphorus concentrations increase without inflows from June-September (USACE, 2019).

Total phosphorus median and 50% of all phosphorus records (interquartile range) collected from 2010-2019 from all lake sites (Figure 3-10) were above the Trophic State Index (TSI) hypereutrophic threshold (0.096 mg/L) (Carlson 1977). Soluble orthophosphate which feeds planktonic algae growth is proportionally high at all lake sites.

Nitrogen found in nitrate/nitrite compounds is the primary form assimilated by aquatic plants into food web and converted to organic forms of nitrogen as part of the TKN measured in water. Conversion of soluble forms of nitrogen to organic forms (i.e., algae cells) is a common form of denitrification observed in eutrophic lakes which can lead to nitrogen limitation of primary production in summer months (Xiaofeng et al., 2012). Ten-year sample results indicate TKN comprises most of the total nitrogen found in Harlan County with forms available to aquatic plants and algae (i.e., nitrate-N and ammonia-N) comprising the smallest amount (Figure 3-10). Kansas City District water quality program's seasonal bias highlights this process as sampling season is scheduled April-September annually. The general nutrient pattern observed in Harlan County and other hypereutrophic Kansas City District lakes is when high phosphorus concentrations are measured in surface waters and algae growth is high (i.e., not light-limited), TKN is also elevated. Conversely, where phosphorus and algae are low, TKN is also low. High algae biomass is not theorized to be caused by the high TKN, but rather the algae comprise much of the organic-N in the TKN measurements as described by Heiskary and Lindon (2010).

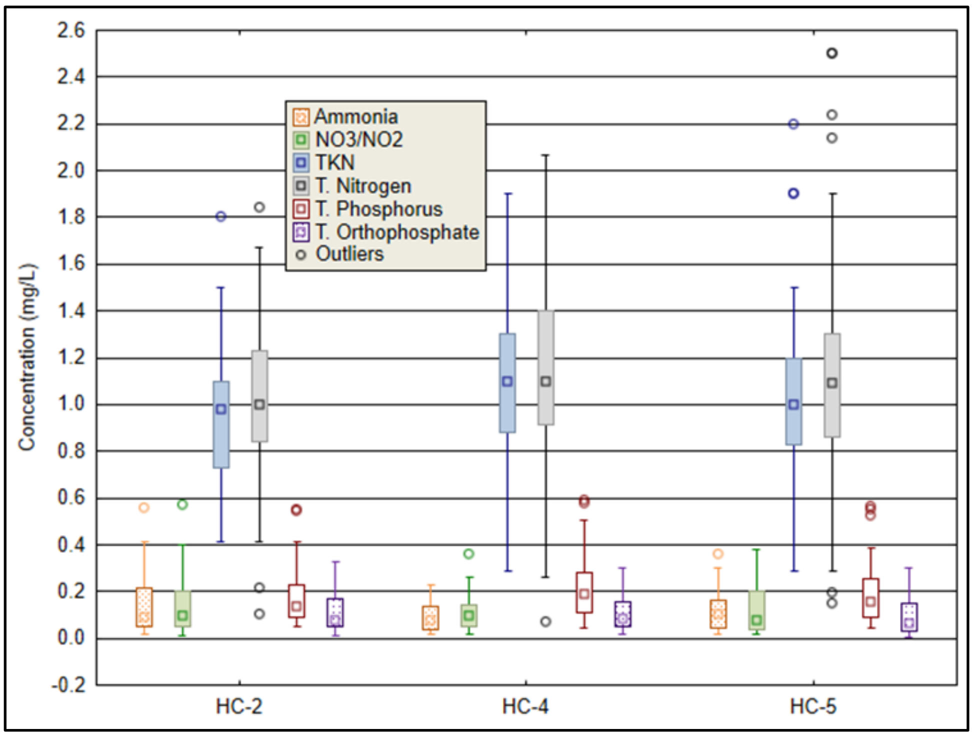


Figure 3-10. Harlan County Lake Nutrient Concentration from 2010-2019.

Nutrient concentration from surface samples collected at Harlan County Lake USACE water quality sample sites from 2010-2019.

Influences on light availability or water clarity include, but not limited to, inorganic sediment, organic carbon, turbidity, and phytoplankton (i.e., chlorophyll-*a*) (Testa et al., 2019). Light availability is a critical metric which is influences biological productivity through light limitation of photosynthesis. Harlan County Lake photic zone as measured by the Secchi disk depth at the site near the dam (HC-2) is within the eutrophic range (0.5m-2m) of the Trophic State Index (Carlson 1977) while upper lake sites are tending toward hypereutrophic classification. Upper lake sites exhibit less water clarity as a result of higher turbidity, suspended solids, and chlorophyll from phytoplankton growth (Figure 3-11). Total organic carbon concentration was similar among all sites. Figure 3-11 illustrates lower lake site (HC-2) has significantly lower turbidity and greater Secchi depth measurements than the upper sites when comparing median value of HC-2 to interquartile range of upper lake sites, respectively.

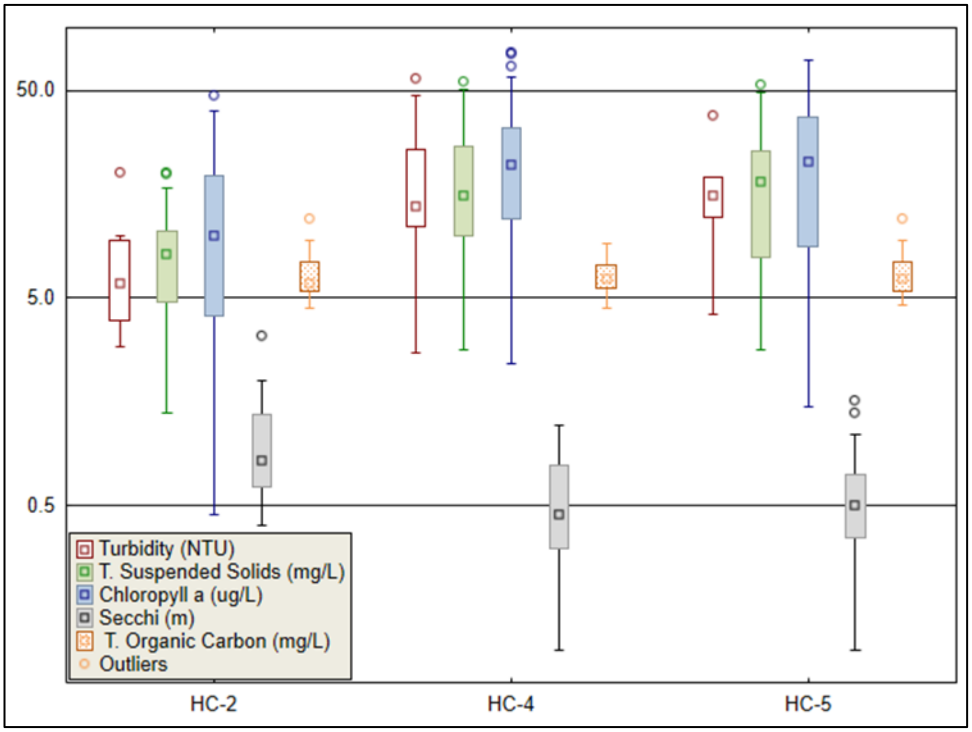


Figure 3-11. Harlan County Lake Water Clarity metrics from 2010-2019.

Water clarity metrics measured from surface samples collected at Harlan County Lake USACE water quality sample sites from 2010-2019.

Total metal concentrations of three detectable metal compounds reported in sample results from Harlan County Lake sites illustrate the process of attenuation as concentrations diminish as water moves from inflows toward the dam Figure 3-12. Small sample size due to limited sampling effort and several metals reporting as below minimum detection level have limited the utility of data. Ranked in order of relative abundance, iron, manganese, and arsenic were present at all Harlan County Lake USACE water quality sample sites from 2010-2019. Differences in total metal sample results between lake sites are not able to be determined Due to small sample size and non-detect results.

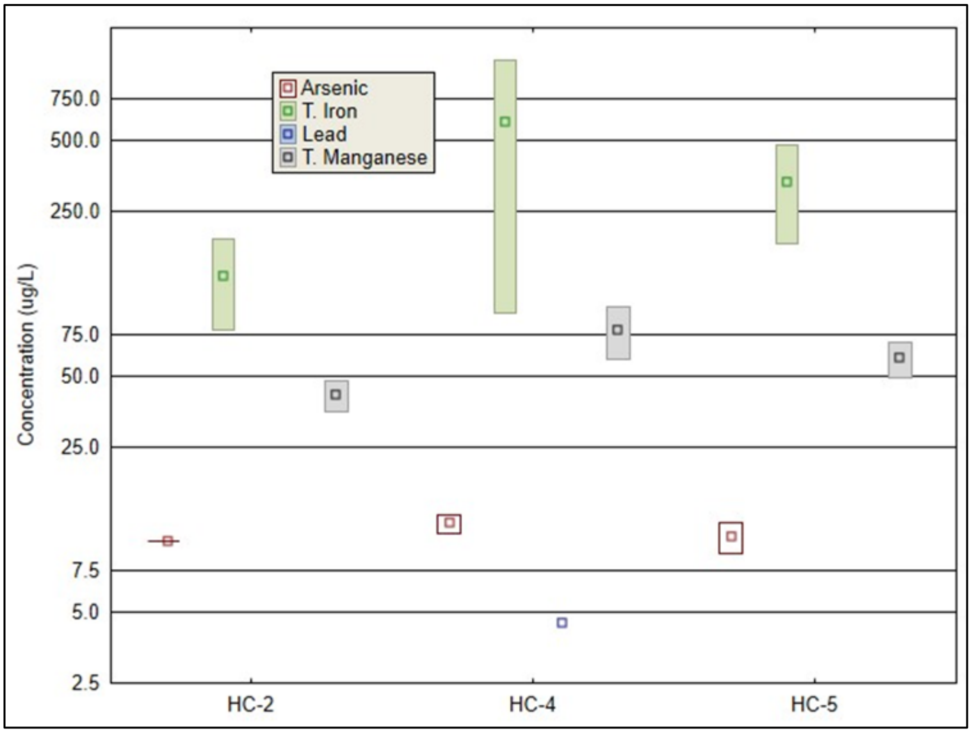


Figure 3-12. Harlan County Lake Total Metals from 2010-2019.

Total metals measured from surface samples collected at Harlan County Lake USACE water quality sample sites HC-2, HC-4, and HC-5 from 2010-2019.

Harlan County Lake typically undergoes thermal stratification in the lower one-third near the dam during July and August while upper lake sites are generally mixed throughout the summer (USACE, 2019). Water density from temperature and salinity, distribution of heat, in-lake currents, and wind action all play a role in this process (Wetzel 2001). Physical changes in water composition during stratified conditions from water temperature and density differences lead to chemical and biological changes in the absence of oxygen (anaerobic conditions). Figure 3-13 provides a representative compilation of temperature and dissolved oxygen profiles for site HC-2 showing different levels of thermal stratification observed near the dam at Harlan County Lake. The graph from July 2017 represents a year when weak thermal stratification occurred as temperature and dissolved oxygen gradually declined with depth while dissolved oxygen did not reach zero. When weak stratification occurs, biological needs of fish and aquatic organisms are met with suitable temperature and oxygen providing relatively large percentage of water column as suitable habitat. Chemical processes are similar to mixed conditions when short duration and relatively small volume of anoxic conditions exist near the bottom allowing for redox reactions to release metals and nutrients in the presence of anaerobic bacteria tied up in sediments. The middle graph is from July 2015 when strong thermal stratification persisted for July and August. During these conditions, fish and aquatic life adapt to the top 6 meters of the stratified portion of Harlan County Lake while metals, phosphates, nitrates and sulfide compounds release from lake bed sediments into the lower strata under anoxic conditions. August 2013 is a depiction of a short-term oxygen sag with very low oxygen throughout the water column due to excessive biochemical oxygen demand and limited photosynthesis (e.g., dark rainy weather). This condition is frequently associated with wastewater releases into a riverine environment but can occur in reservoirs depending on weather patterns or during turnover; when inflow events consist of low D.O water with high BOD; or when releases from dams have localized influence on oxygen dynamics.

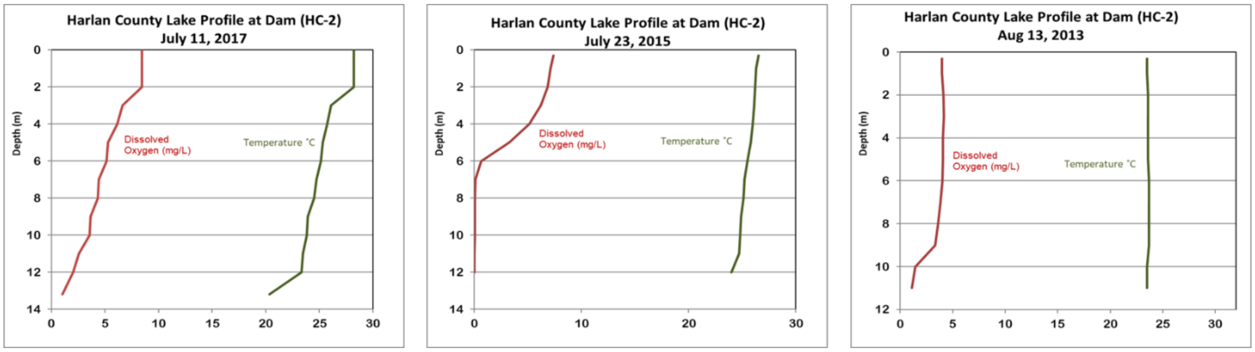


Figure 3-13. Harlan County Lake Representative Temperature and Dissolved Oxygen Profiles. *Representative temperature and dissolved oxygen profiles from Harlan County Lake USACE water quality sample sites from 2017, 2015, and 2013.*

A summary of descriptive statistics for chemical analysis results at site nearest the dam is found in Table 3-1. Bottom samples are typically collected from Kansas City District lakes every third year with total metals collected during peak stratified month of August when stratified conditions are most likely. When the lake is mixed or not stratified, bottom sample results are nearly identical to surface sample results for most analytes. Anaerobic conditions allow for oxidation/reduction reactions to release chemical compounds, including metals, which we are trying to quantify with bottom samples. Non-detection or result below minimum detection level occur on occasion and have been included in sample results (Table 3-1) as the value of half of the reported minimum detection limit to reduce bias based on the assumption that the analyte is present at a concentration below laboratory quantification (EPA, 1991). Sample size, sampling effort, and non-normal distribution constraints are best addressed with the use of descriptive statistics are used to describe and summarize sample results. Nitrogen results were similar at surface and bottom samples, including ammonia. Orthophosphate, metals, and suspended solids are typically concentrated in the bottom during the few months when lakes are stratified. Comparison between surface and bottom samples during stratified months highlight differences which are dampened when all months are combined. No statistical differences between surface and bottom samples were detected.

Table 3-1. Water Quality Summary Statistics for April 2010 through September 2019.[1]

Parameter	Sample Depth	Mean	SE[2]	SD[3]	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.09	0.01	0.12	0.56	0.04	0.01	60
Ammonia (mg/L)	Bottom	0.09	0.04	0.14	0.54	0.02	0.01	13
NO3/NO2 (mg/L)	Surface	0.10	0.01	0.11	0.57	0.05	0.01	60
NO3/NO2 (mg/L)	Bottom	0.12	0.03	0.11	0.41	0.08	0.01	13
TKN (mg/L)	Surface	0.92	0.04	0.30	1.80	0.98	0.15	58
TKN (mg/L)	Bottom	0.95	0.09	0.31	1.80	0.84	0.64	13
Total Nitrogen (mg/L)	Surface	1.00	0.04	0.33	1.84	1.02	0.11	59
Total Nitrogen (mg/L)	Bottom	1.07	0.08	0.29	1.83	0.97	0.68	13
Total Phosphorus (mg/L)	Surface	0.17	0.01	0.11	0.55	0.14	0.05	60
Total Phosphorus (mg/L)	Bottom	0.21	0.05	0.18	0.74	0.17	0.07	13
Total Orthophosphate (mg/L)	Surface	0.10	0.01	0.08	0.33	0.07	0.01	58
Total Orthophosphate (mg/L)	Bottom	0.16	0.05	0.15	0.71	0.12	0.01	13
Chlorophyll a (ug/L)	Photic Zone	16.68	3.46	24.68	160.00	10.00	0.45	51
Total Organic Carbon (mg/L)	Surface	7.30	0.87	4.10	24.00	5.90	4.50	22
Total Organic Carbon (mg/L)	Bottom	8.93	1.64	5.90	27.00	7.30	4.60	13
Total Iron (ug/L)	Surface	134.05	55.95	79.12	190.00	134.05	78.10	2
Total Iron (ug/L)	Bottom	210.00	10.00	14.14	220.00	210.00	200.00	2
Total Manganese (ug/L)	Surface	41.70	6.30	8.90	48.00	41.70	35.40	2
Total Manganese (ug/L)	Bottom	353.00	291.00	411.54	644.00	353.00	62.00	2
Total Suspended Solids (mg/L)	Surface	8.76	0.73	5.67	35.20	8.10	1.40	60
Total Suspended Solids (mg/L)	Bottom	13.95	1.16	4.19	21.00	15.00	8.40	13

Notes: [1/]Chemical and chlorophyll-*a* samples taken from Harlan County Lake near dam site HC-2.
[2/]Standard Error = SE; [3/]Standard Deviation = SD.

Surface and bottom physical water quality results were selected from water quality profiles to compile descriptive statistics summary found in Table 3-2. Differences in sample size can be attributed to different equipment (i.e., the number of probes on a multi-probe data sonde) being used for data collection. Temperature and dissolved oxygen sensors are present on all data sondes used by Kansas City District Water Quality Program while pH, conductivity, and turbidity sensors are only available during intensive surveys which occur every three years. Calibration issues or sensor failure also account for a minor reduction in number of sample results presented in Table 3-2. Turbidity differences between bottom and surface samples is attributed to settling of solids and metals throughout months and at locations with or without stratification.

Table 3-2. Harlan County Lake Physical Water Quality Summary for 2010 – 2019.[1]

Parameter	Sample Depth	Mean	SE[2]	SD[3]	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	8.5	0.2	1.9	13.9	8.4	4.0	167
Oxygen, Dissolved (mg/l)	Bottom	6.3	0.2	3.0	12.9	6.8	0.1	174
pH (Standard Unites)	Surface	8.5	0.1	0.3	8.9	8.6	7.6	53
pH (Standard Unites)	Bottom	8.3	0.1	0.4	8.9	8.4	7.2	56
Secchi Depth (m)	Surface	0.7	0.1	05	3.3	0.7	0.1	147
Specific Conductance (µS/cm)	Surface	660.4	7.5	54.5	754.4	656.0	477.9	53
Specific Conductance (µS/cm)	Bottom	650.3	13.8	103.7	768.0	659.9	472.1	56
Turbidity, Field (NTU)	Surface	23.1	5.9	42.7	284.9	12.0	1.0	53
Turbidity, Field (NTU)	Bottom	119.8	40.2	287.4	1621.0	26.7	1.0	51
Water Temperature (°C)	Surface	20.5	0.5	6.1	31.3	22.7	6.5	167
Water Temperature (°C)	Bottom	19.5	0.4	5.9	28.9	21.2	6.3	174

Notes: 1/ Summary statistics for physical water quality parameters, from all sites and dates, Harlan County Lake, April 2010 through September 2019.
2/ Standard Error = SE 3/ Standard Deviation = SD.

Harlan County Lake is a hypereutrophic lake with nearly ideal physical and chemical conditions for production of Harmful Algae Blooms (HABs). An abundance of soluble orthophosphate and a low (i.e., less than 12) TN:TP ratio are two frequent water quality conditions associated with proliferation of blue-green algae which could produce toxins in freshwater (Downing, J. A., and E. McCauley. 1992; Xiaofeng, et al. 2012) and have been present at HAB prone lakes in Kansas City District (USACE 2019). Reduced water clarity from inorganic turbidity in the upper lake is likely the factor limiting cyanobacteria at Harlan County Lake. Zebra mussels have increased Secchi measures at all Kansas City District lakes within 5 years of colonization which has led to an increase in HABs at zebra mussel infested lakes. The algal toxin microcystin is monitored by the Neb raska Department of Environment and Energy weekly at swim beaches from May-September. This common toxin, produced by numerous species of cyanobacteria, is used to issue Public Health Alerts for beaches as outlined by DEE public web document (http://dee.ne.gov/NDEQProg.nsf/OnWeb/SWMA). Health Alerts have been issued at the reservoir twice in the past ten years, 2013 and 2019. The average concentration of microcystin typically peaks in early July before releases from the reservoir increase for downstream irrigation needs (Figure 3-14). Average monthly toxin concentration from Harlan County beach monitoring is below EPA recommended recreational warning threshold of 8 ppb (EPA 2019).

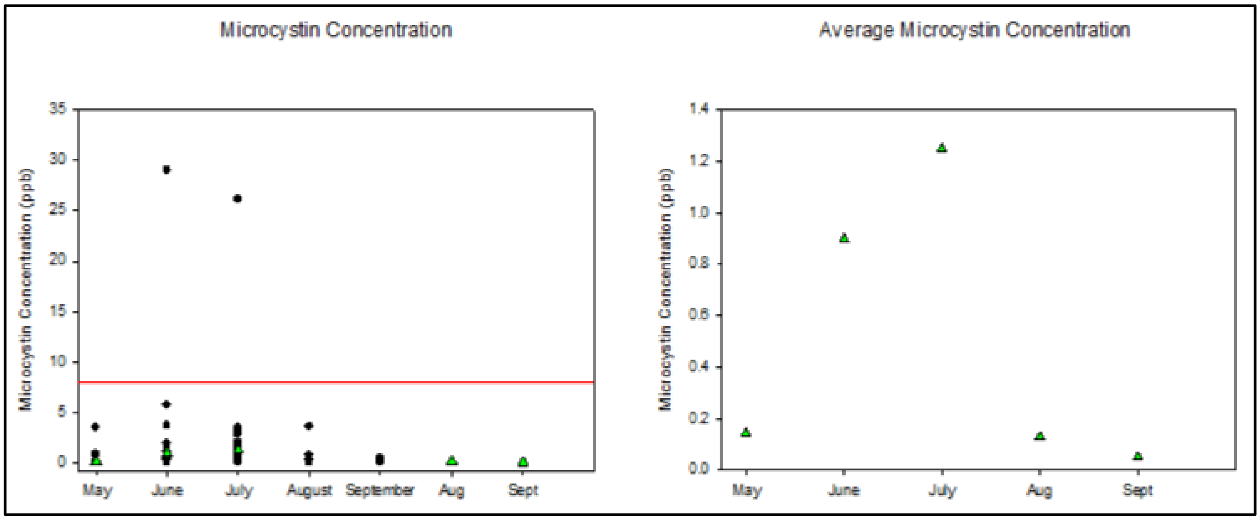


Figure 3-14. Harlan County Swim Beach Total Microcystin and Average Microcystin – 2010-2019.
Total microcystin and average microcystin concentration measured at Harlan County swim beaches from 2010-2019 (Courtesy of Nebraska Department of Environment and Energy).

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release phosphorus back into the water column causing HABs and other water quality issues (Pettersson 1998; Søndergaard et al. 2003) or when sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). Numerical sediment quality guidelines (SQC) including sediment quality objectives, criteria and standards have been developed and used by government agencies for ecosystem protection. Assessing sediment quality of prospective dredged materials and evaluating ecological risk assessments is a critical step for reservoir sustainability discussions (Long and MacDonald 1998). Several publications have outlined methodologies for assessing sediment quality relative to the potential for adverse effects on sediment-dwelling organisms in freshwater systems (MacDonald et al., 1992; US EPA. 1992, 1997; Ingersoll et al. 1996, 1997; Smith et al. 1996). A unified approach for sediment quality assessment based on freshwater ecosystem effects (MacDonald et al., 2000) allows lake owners, management agencies, and regulatory agencies to make informed decisions based on consensus-based concentration thresholds derived from aquatic toxicology data and EPA recommendations for common metals found in USACE Kansas City District lakes. Kansas City District initiated collection of baseline lake sediment data in 2016 (Table 3-3) to gather baseline sediment nutrient and trace metal contamination data at standardized lake water quality sites. Based on long-term monitoring water quality sample results, less likely contaminants like polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), and chlorinated pesticides are not frequently included in lake bed sediment samples.

Median nitrogen, phosphorus, iron, and manganese concentrations reported in lake bed sediment results from Harlan County Lake ranked near the lowest of Kansas City District Lakes in the Kansas River watershed (Figure 3-15). Nitrogen and phosphorus concentrations from Harlan County Lake were within the reported range, but less than average when compared to results from a lakes from Southeast and Northern United States (Barko, J.W. and R.M Smart. 1986). Total metal concentrations from Kansas City District sample results (Table 3-3) did not exceed the “probable effect concentration” (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000). In this study, it was surmised that increasing trends of As, Sr, and Se in the Republican and Solomon River basins may be related to natural conditions and increased irrigation.

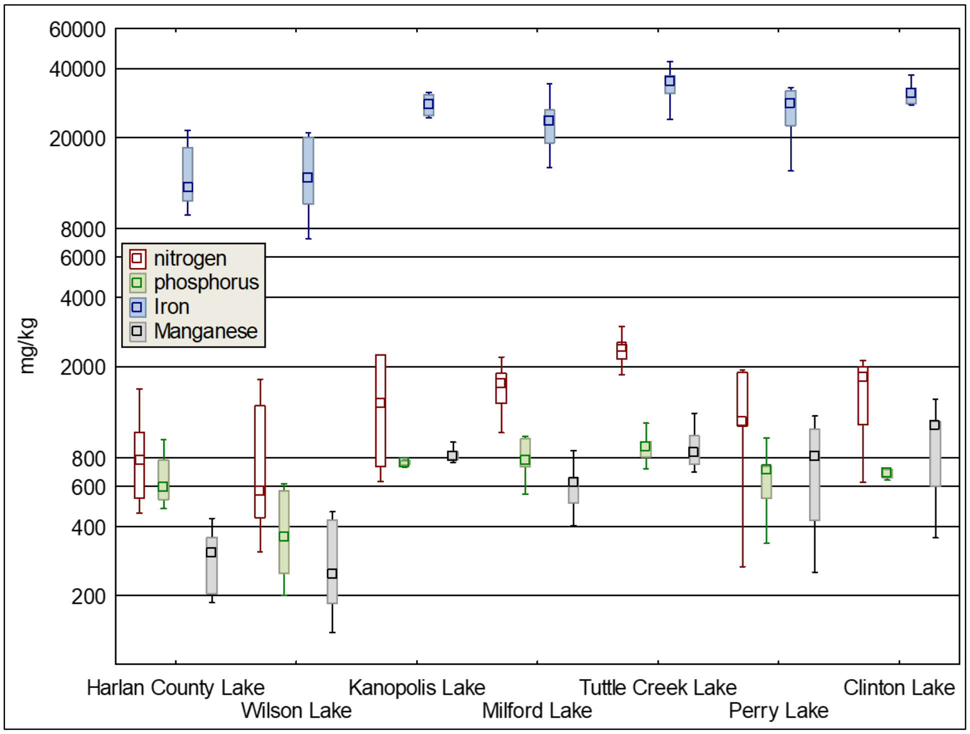


Figure 3-15. Kansas River Watershed USACE Lake bed sediment results 2008-2019.

Data compiled from all USACE bed sediment samples for select nutrient and metals from all Ks. River Watershed Lake sites collected from 2008-2019.

Table 3-3. Harlan County Lake bed sediment chemical concentration 2017 and 2020.

Station	Date mm/dd/yyyy	Time hhmm	Ammonia Nitrogen mg/kg	Nitrate-Nitrite Nitrogen mg/kg	Total Kjeldahl Nitrogen mg/kg	Phosphorus mg/kg	Arsenic mg/kg	Copper mg/kg	Iron mg/kg	Lead mg/kg	Manganese mg/kg	Nickel mg/kg	Zinc mg/kg	Cadmium mg/kg	Chromium mg/kg	Total Solid %	T. Mercury mg/kg
HC-2	9/13/2017	1000	206	<5.2	2210	770	9.0	19.1	19600	16.8	412	20.0	75.7	0.97	23.1	31.9	
HC-4	9/13/2017	1100	98.1	<4.6	1600	672	9.1	20.4	21500	16.7	407	22.8	86.1	1.0	23.2	35.8	
HC-5	9/13/2017	1030	26.1	<3.1	534	479	5.8	7.8	10600	8.4	186	12.2	40.6	0.46	11.5	58.8	
HC-2	9/24/2020	1000	118	1.11	667	778	14	19.2	20700	13.4	434	18.5	70.5	1.81	28.4		0.0216
HC-4	9/24/2020	1020	15.8	<3.1	574	656	13.2	15	18100	10.3	295	16.2	61.2	ND	23		0.0206
HC-5	9/24/2020	1050	7.27	7.4	458	525	13.6	8.64	10800	6.31	246	12.8	36.6	ND	13.7		0.0144

3.1.2 Milford Lake

Milford Lake is the largest lake in Kansas (15,709 acre) built on the Republican River in Kansas. The Republican River flows from Harlan County Lake through fertile farm country into Milford Lake and then into the Kansas River. The primary water quality threats to Milford Lake are summarized by current Total Maximum Daily Load (TMDL) for eutrophication are nutrients, sediment, toxic cyanobacteria blooms and dissolved oxygen sags.

In 2011, Kansas Department of Health and Environment (KDHE) worked with USACE and stakeholders to develop and implement public policy for addressing recreational health risks associated with HABS and began using analytical results to provide recommendations to public lake managers (i.e., federal, state, city etc.). From 2011-2015, HABs appeared to be a chronic issue with significant impacts to recreation and the local economy. In 2015, the KDHE designated three zones (Zones A, B, and C) to increase management flexibility for HABs which tend to cluster on the downwind or leeward side of Zone C. Zone-specific public health advisories have been used effectively in Kansas to allow recreational use of lakes when HABS are confined to relatively small and discrete areas. Perry Lake and Tuttle Creek Lake were also delineated into management zones. Current KDHE HAB policy and resources can be found at: Harmful Algal Bloom | KDHE, KS.

Watershed conservation efforts have increased in priority for state and local rankings to address Milford Lake hypereutrophic conditions and chronic HABs. Impacts from HABs has been implicated in local economic impact from decrease in tourism/recreational visitation and changes property value and as well as a potential threat/increased cost to downstream water supply (Pearce. 2020)(Graham et al. 2012). Two programs lead the way for watershed improvements at Milford Lake. The Watershed Restoration and Protection Strategy (WRAPS) program is a KDHE planning and management tool used to identify watershed restoration and protection needs, establish management goals, establish plans (e.g., EPA approved 9-Element Watershed Plans) and implement goals to address water resource concerns (https://www.kdheks.gov/nps/wraps/). Most priority goals/targets of the WRAPS Plans for subbasins in the Kanas River Watershed align with strategies and measures included in this study. The WRAPS process is in the implementation and monitoring phase of their process to administer programs using Best Management Practices (BMPs) to reduce phosphorus loads originating in Kansas by 617,204 lbs/yr., nitrogen loads originating in Kansas by 2,341,263 lbs/yr. and sediment load reduction goal of 32,999 tons/year.

Milford Watershed Regional Conservation Partnership Program (RCPP) is a collaborative effort between Kansas Water Office and regional entities to improve water quality in Milford Lake and upstream. The program is a result of a $2.88 million grant awarded through the Natural Resources Conservation Service (NRCS).

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics related to flow (i.e., volume, load, and concentration), water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological response. Figure 3-16 illustrates reservoir hydrologic data with overlay of water quality sampling events.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September). Low inflow periods were observed at the end of 2012 with surface elevation falling below 1,138 ft while recovery period is apparent beginning late spring of 2013. Significant flooding with a corresponding high-water period was observed in 2019 as inflows peaked at 20,000 cfs with six or more events exceeding 10,000 cfs from March through August. Surface elevation of Milford Lake peaked at 30.8 ft above conservation-pool elevation (CPE) and exceeded CPE for 268 days in 2019. Nutrient budget (i.e., nutrients entering, nutrients loading from internal sources, nutrients leaving) and hydraulic residence time impact water quality and HABs at Milford Lake.

Milford Lake average water residence time of 7.7 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Milford Lake average water residence time is slightly below average of 10.8 months for 7 USACE Kansas River Watershed lakes in this study. The shorter residence time at Milford Lake allows for less time for dilution, settling, and biological attenuation of agricultural runoff. This has implications for the water quality downstream in the Republican River.

The importance of water residence time at Milford Lake extends to sediment accumulation and the storage of sediment-bound contaminants. Seasonal variations in water quality are noticeable, particularly in late summer. During this period, water residence time rapidly increases due to reduced inflows linked to summer weather patterns, coupled with managed outflow reductions to maintain lake surface elevation targets. Consequently, there is an increase in soluble nutrient concentrations from plant sources, in addition to external nutrient contributions from inflow streams, concurrent with reduced outflows.

These conditions during summer often lead to increased algal growth and the potential for Harmful Algal Blooms (HABs), as discussed in subsequent sections.

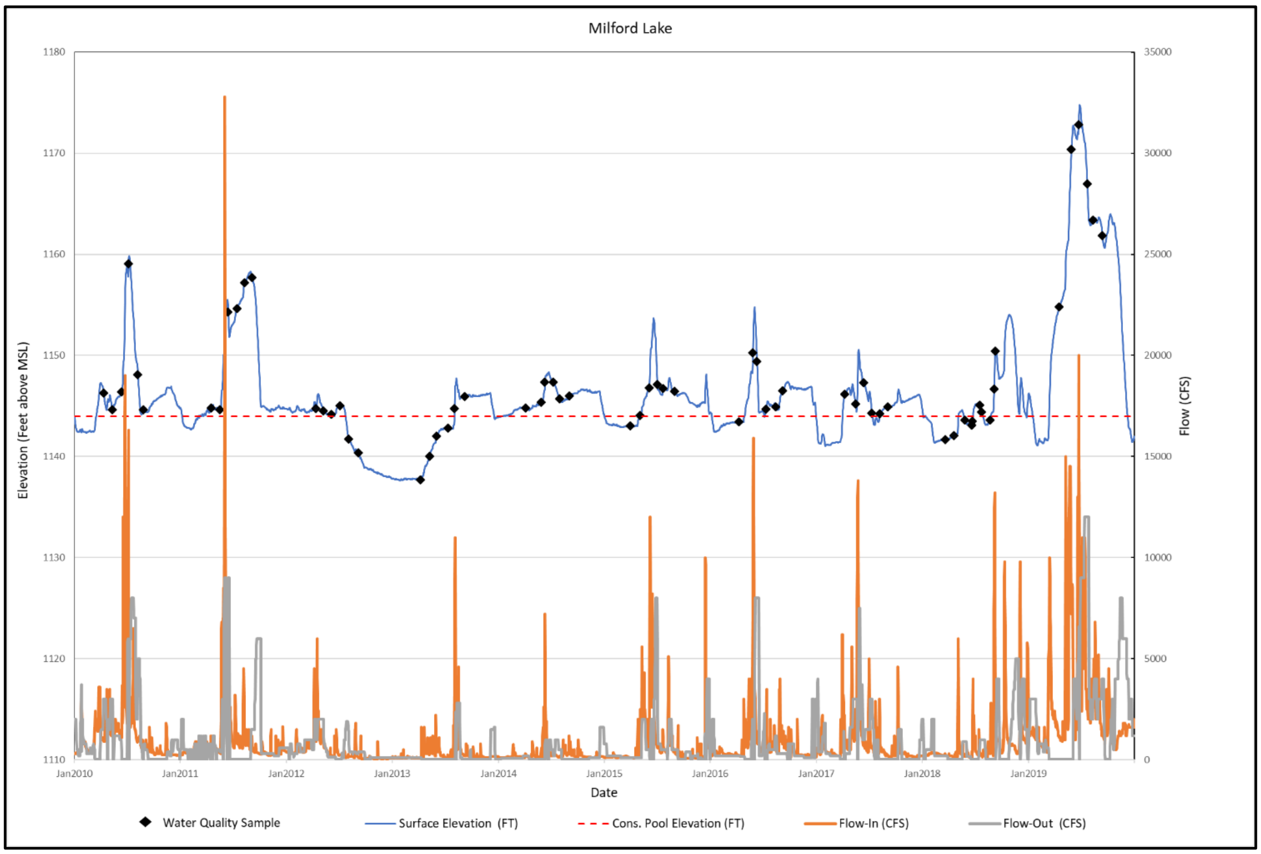


Figure 3-16. Milford Lake Time series of daily water surface information.

Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue - Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.

Water Quality Sample Locations

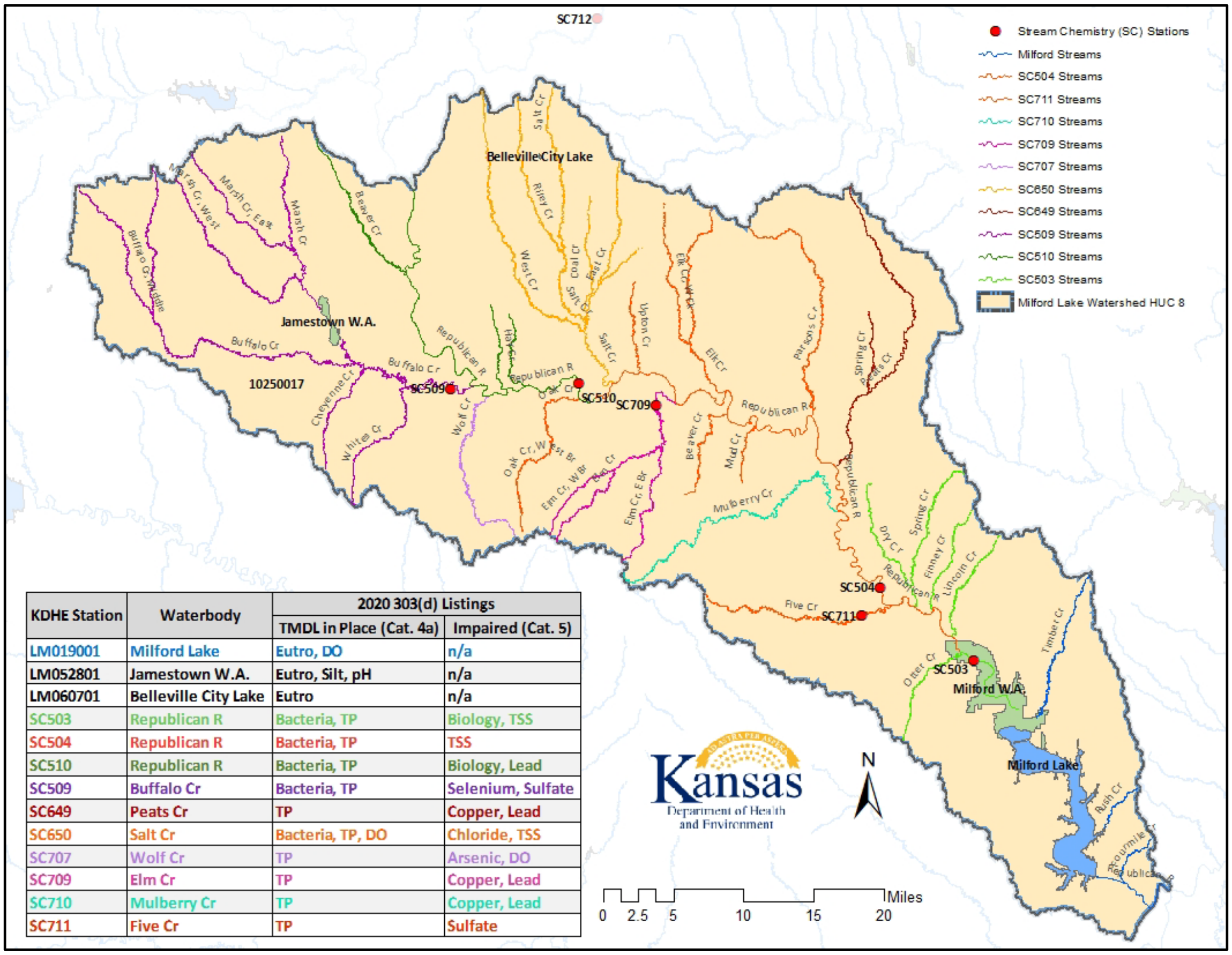
Historic water quality sample sites at Kansas City District lake projects are generally named in decreasing numeric order from inflow sites to the outflow site below the dam (Figure 3-17). KDHE HAB management zones have been added to map for reference. To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

Figure 3-17. Milford Lake historic USACE water quality sample sites. *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow sites as well as KDHE HAB management zones.*

Impairments

The Milford Lake watershed includes ten impaired stream segments listed on the 2020 303(d) list (Figure 3-18) impacted primarily by metals, salt compounds, and/or sediments. Inflow streams appear to attenuate chemical impairments to levels below state water quality standards before they enter Milford

Lake near the town of Wakefield, KS. Nutrient and sediment impacts, directly related to HABs and low dissolved oxygen, persist in Milford Lake as Eutrophication TMDL supports.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM019001	Milford Lake	Eutro, DO	n/a
LM052801	Jamestown W.A.	Eutro, Silt, pH	n/a
LM060701	Belleville City Lake	Eutro	n/a
SC503	Republican R	Bacteria, TP	Biology, TSS
SC504	Republican R	Bacteria, TP	TSS
SC510	Republican R	Bacteria, TP	Biology, Lead
SC509	Buffalo Cr	Bacteria, TP	Selenium, Sulfate
SC649	Peats Cr	TP	Copper, Lead
SC650	Salt Cr	Bacteria, TP, DO	Chloride, TSS
SC707	Wolf Cr	TP	Arsenic, DO
SC709	Elm Cr	TP	Copper, Lead
SC710	Mulberry Cr	TP	Copper, Lead
SC711	Five Cr	TP	Sulfate

Figure 3-18. Impaired waters and TMDLs of Milford Lake and watershed.
Impaired waters and TMDLs of Milford Lake and watershed from 2020 303(d) list (Courtesy of KDHE).

Inflow/Outflow

Lakes and reservoirs store sediment and associated chemical compounds carried by inflows and runoff. Sediment, nutrient, contaminant, and geological sources in the watershed and associated inflows influence lake water quality including water clarity, nutrient concentration, chemical contamination, and element ratio and nutrient balance in receiving waters. These factors also have implications for biological response in the streams and receiving waters including trophic state and which type of plants and algae dominate the primary production in the system.

Nutrient sources, geology, and land-use are primary influences on water quality in inflow streams in the watershed which influence Milford Lake. Water exiting through the dam or outlet works of Corps' lakes can be quite different than the inflows as large amounts of nutrients, pesticides, and metals are processed and/or stored in the lake causing a sink effect (Satoh, et al. 2002). Chemical compounds solubilized under anoxic conditions when lakes are thermally stratified are seasonal exceptions. Dissolved oxygen concentrations below state water quality standards in outflows related to release of anoxic water rarely occur at Milford lakes due to infrequent thermal stratification. Supersaturation during flood releases can potentially result in poor water quality downstream of dams. However, this concern is not documented and is unlikely to be an issue at Milford Lake Dam. This is due to relatively minor pressure differences as water exits the dam and the presence of turbulence, which facilitates the equilibration of gas pressure.

Atrazine is the most common herbicide detected in Milford Lake inflows and outflow. Herbicides are not listed as impairments for Milford Lake by KDHE. Slightly less than 50% of inflow sample results for total atrazine at the inflow site near Clay Center are below the EPA drinking water criteria of 3 ug/L (EPA 1995) while no samples from the outflow exceeded criteria (Figure 3-19).

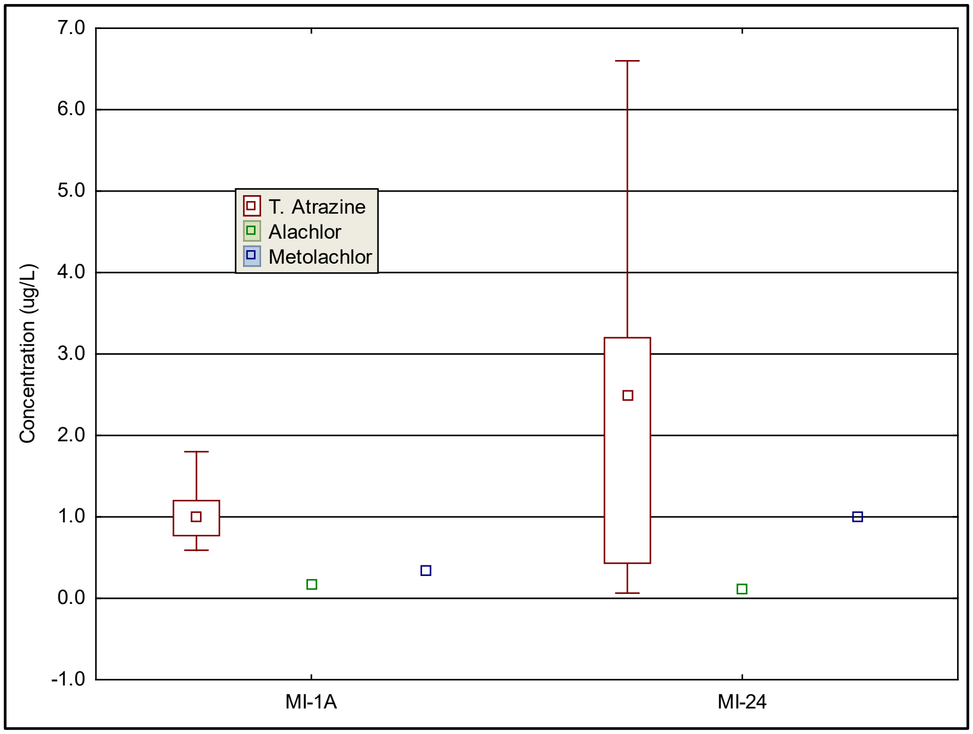


Figure 3-19. Herbicide concentration upstream and downstream of Milford Lake from 2010-2019.
Herbicide concentration from surface samples collected at Milford Lake outflow (MI-1A) and inflow (MI-24) USACE water quality sample sites from 2010-2019.

Fertile agricultural watersheds in northern counties of KS provide excess nutrients to inflow streams, Milford Lake and downstream. In the rural landscape, nitrogen deposition is more likely associated with agriculture or fertilizer application (Arbuckle and Downing 2001, Boyer et al. 2002) while phosphorus loading is associated with soil erosion and farming practices as well as sewage effluent and runoff from urban watersheds (Downing and McCauley 1992, Withers and Jarvie 2008).

Total nitrogen and organic nitrogen (TKN) concentration decreased significantly from the inflow site to the outlet from attenuation and denitrification/biological uptake (Figure 3-20). Median bioavailable forms of nitrate/nitrites were similar at inflow and outflow sites but more variable in the inflow, likely associated with runoff events. Ammonia nitrogen increases from anoxic conditions found in the bottom strata near the dam leads to seasonal increases in ammonia in releases from Kansas City District lakes. Consequently, ammonia in concentrations at the outlet exceeded those measured at the inflow site (Figure 3-20).

Inflow total phosphorus median concentrations and interquartile range were similar to outflow results with outliers more common in inflow due to rain events with potential runoff. Seasonal increases of soluble orthophosphate related to anoxic conditions at the dam resulted in median and maximum orthophosphate concentrations outflows exceeding those found in the inflow (Figure 3-20).

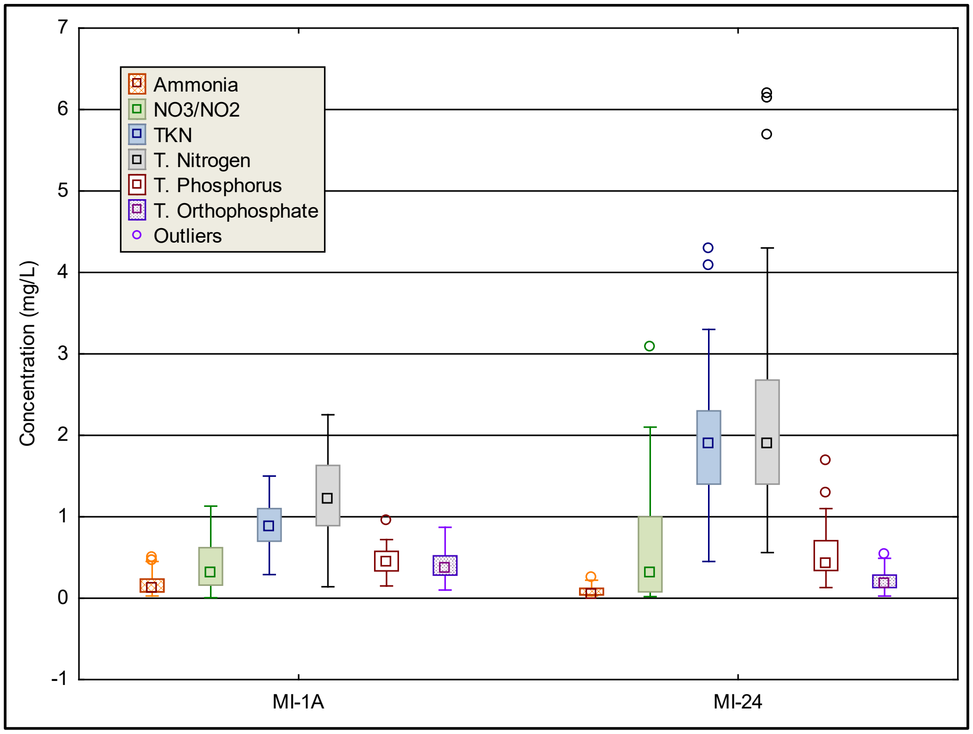


Figure 3-20. Nutrient Concentration upstream and downstream of Milford Lake from 2010-2019. *Nutrient concentration measured from surface samples collected at Milford Lake outflow (MI-1A) and inflow (MI-24) USACE water quality sample sites collected from 2010-2019.*

Water clarity improves as water moves from the river through Milford Lake to the outflow. The Republican River inflow site can be described as more turbid with significantly more suspended solids than the outflow (Figure 3-21) as median turbidity and TSS from MI-24 exceed all data records from the outflow site (MI-1A) during the 10-year period. Total organic carbon concentration was similar between the two sites.

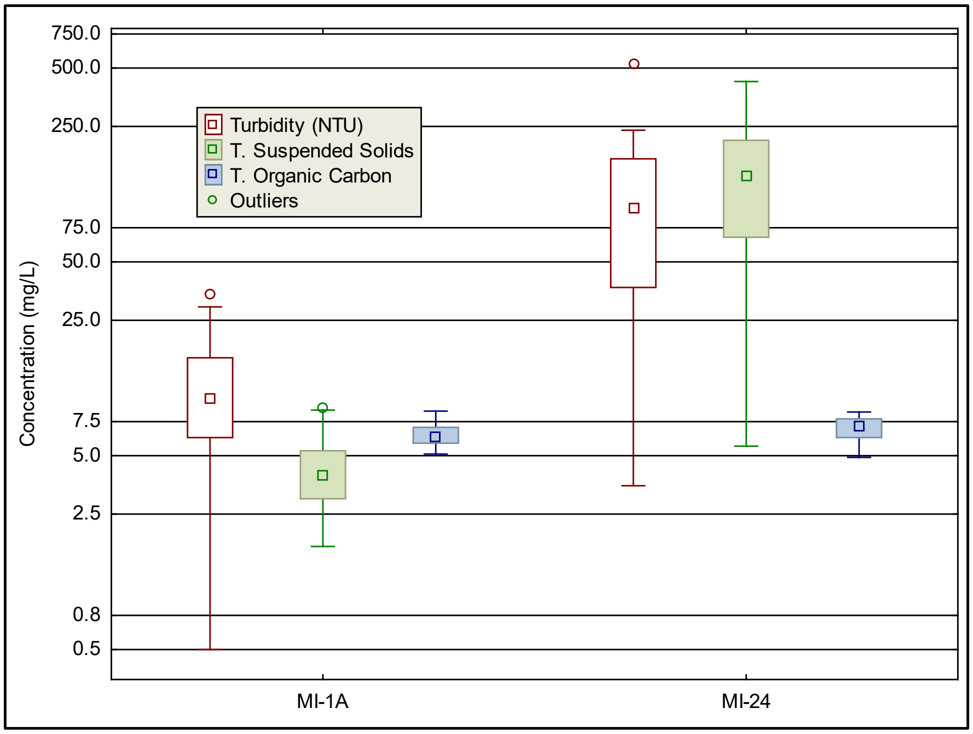


Figure 3-21. Water clarity metrics upstream and downstream of Milford Lake from 2010-2019. *Water clarity metrics measured from surface samples collected at Milford Lake outflow (MI-1A) and inflow (MI-24) USACE water quality sample sites from 2010-2019.*

Anoxic conditions near the lake bottom in summer months create the most efficient sampling strategy to quantify metal/metalloids solubilized from lake bed sediment under redox conditions, which can impact water quality of releases from lower strata. Inflow streams give a more direct relationship to metals released in the watershed that will eventually make their way to the lake. Median concentrations of iron and manganese were significantly greater in the outflow samples than those collected from the inflow site (Figure 3-22). Median and interquartile ranges were similar between inflow and outflow sites for lead and arsenic. Milford Lake outlet and inflow samples contained moderate to high concentrations of naturally occurring iron, manganese and arsenic. However, samples did not exceed EPA drinking water standards for arsenic (maximum allowable concentration 10 ug/L or ppb). EPA classifies iron and manganese as secondary contaminants (i.e., altered taste, odor and color of drinking water). Water suppliers remove metals and contaminants from finished products.

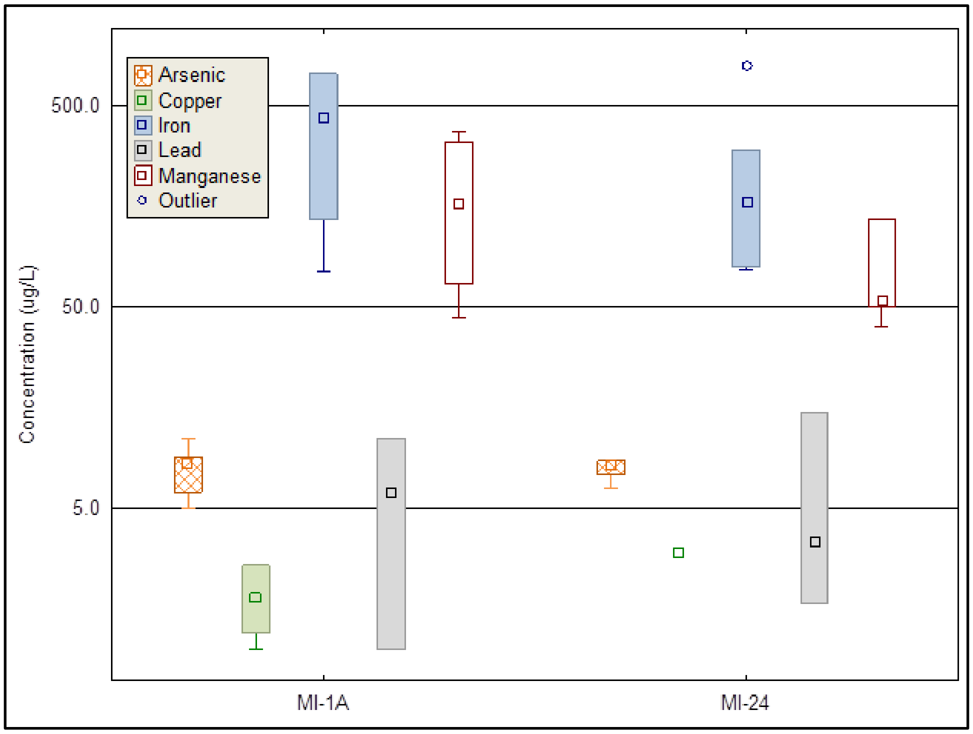


Figure 3-22. Total metal concentration measured upstream and downstream of Milford Lake from 2010-2019. Lake Water Quality. *Total metal concentration measured from surface samples collected at Milford Lake outflow (MI-1A) and inflow (MI-24) USACE water quality sample sites from 2010-2019.*

Milford Lake has been listed as impaired by KDHE and is classified as hypereutrophic due to excessive nutrients, specifically biologically available orthophosphate. A TMDL for Milford Lake was developed to prioritize phosphorus reduction in the watershed to address frequent HAB issues. Milford, largest lake in Kansas (15,709 A), was built on the Republican River for flood control, water supply, downstream water quality, fish/wildlife conservation, navigation support, and recreation.

Excess nutrients frequently result in phytoplankton dominance, including (HABs), in Milford Lake where rooted macrophytes are uncommon. Meanwhile, the accumulation of sediment in lakes not only reduces storage capacity for water use but also diminishes volume, resulting in decreased dilution and buffering potential. This reduction in capacity contributes to the concentration of compounds stored within the lake system. This aging-related process renders older reservoirs more susceptible to contamination and the internal loading of nutrients, metals, and compounds stored within lake bed sediment.

USACE and KDHE pesticide sample results indicate three common herbicides detected in Milford Lake are found in higher concentrations in the Republican River and diminish as water moves through the lake. Concentrations of atrazine exceeding EPA drinking water criteria of 3 ug/L is apparent in at least 25% of samples (Figure 3-23) while concentrations of atrazine were less variable and less concerning at lower lake sites. KDHE Lake and Wetland Monitoring Program Reports (KDHE 2007; 2010) also discuss detection of pesticides in Milford Lake at levels below state water quality standards.

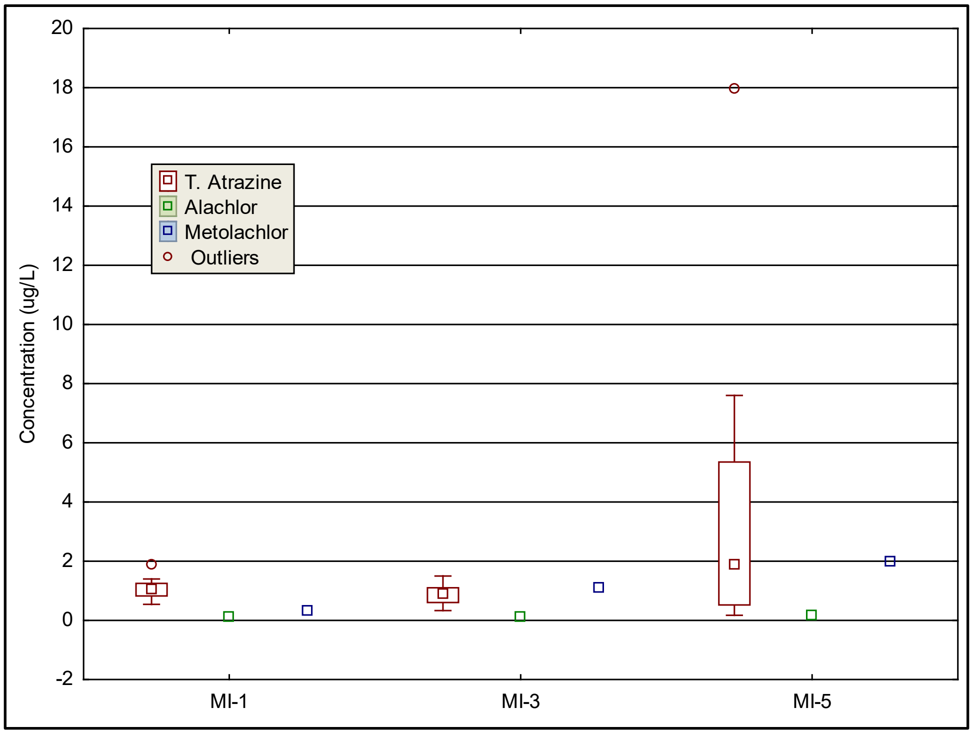


Figure 3-23. Milford Lake herbicide concentration from 2010-2019.

Herbicide concentration measured from surface samples collected at Milford Lake USACE water quality sample sites from 2010-2019.

Controlling eutrophication is important to most lake managers, but it is critical to hypereutrophic systems (Jeppesen et al. 2003) as undesirable conditions develop for aquatic life and longevity and utility of the reservoir come into question (Smith et al. 1999). Hypereutrophic conditions are present when chlorophyll *a* concentration exceeds 30 µg/L (KDHE, 2014) or phosphorus concentrations exceed 0.096 mg/L (Carlson, 1977). Mean total phosphorus for Milford Lake near the dam (MI-1) from 2010-2019 was 0.39 mg/L or 4 times greater than the hypereutrophic threshold (Figure 3-24). Plant available orthophosphate typically comprises more than 70% of the total phosphorus measured during summer months at all stations (USACE, unpublished data 2010-2019) but comprised 87% of total phosphorus near the dam (Table 3-4). An intensive Milford nutrient study conducted by USGS in 2018 reported orthophosphate comprised 77% or more of the total phosphorus at 28 of 30 sample sites during July, August, and October. (Leiker et al., 2021). Kansas City District Water Quality Program also increased sampling effort during 2018 to better describe nutrient movement and sources in Milford Watershed. Median total phosphorus concentrations decreased from the Republican River and at each lake site along the gradient from upper to lower lake while lake sites experienced steady increases in total phosphorus from May through October (Figure 3-24). This pattern of phosphorus attenuation as water moves through the lake and a steady increase in phosphorus measured at lake sites throughout the summer months is frequently observed at Milford Lake except when flood conditions increase and homogenize nutrient concentrations lake-wide (USACE 2010-2019).

Nutrient sample data from 2010-2019 Milford Lake illustrates a positive trend in total phosphorus (Figure 3-25) while no trends were apparent in nitrogen analytes or sediments. A negative trend in total nitrogen to total phosphorus ratio, important to cyanobacteria dominance of phytoplankton community (Elser et al. 2007. Downing and Mckauley 1992) is apparent at Milford Lake (Figure 3-26) and several other district lakes with HABS. A detailed statistical trend analysis including seasonally adjusted comparisons are discussed in Future Without Project section.

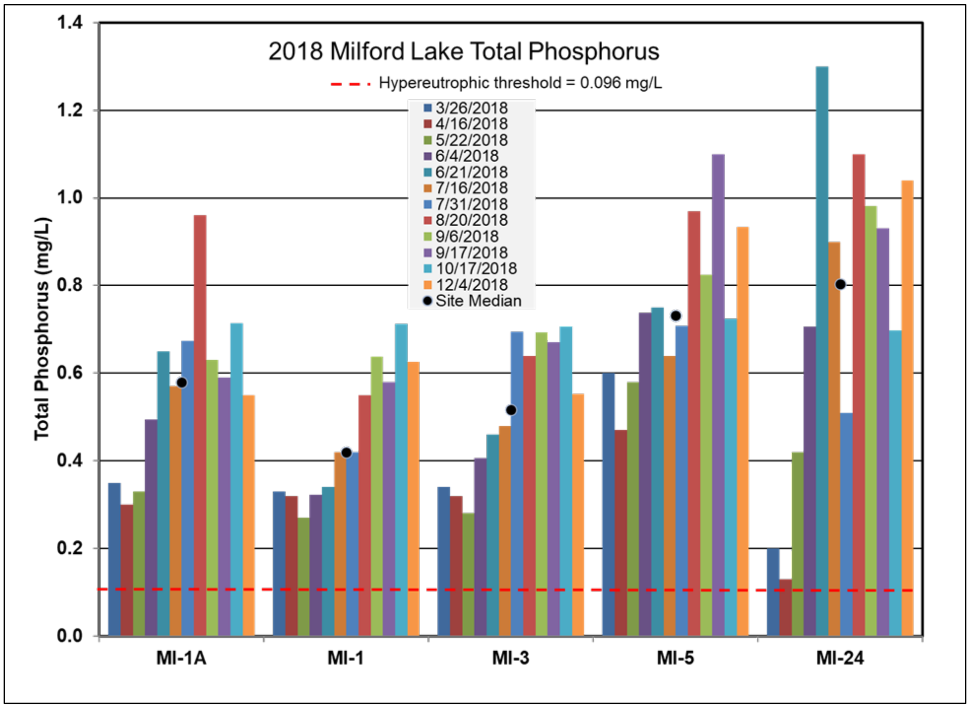


Figure 3-24. Milford Lake total phosphorus concentration from March-December 2018. *Measured from surface samples collected at all standard USACE water quality sample sites.*

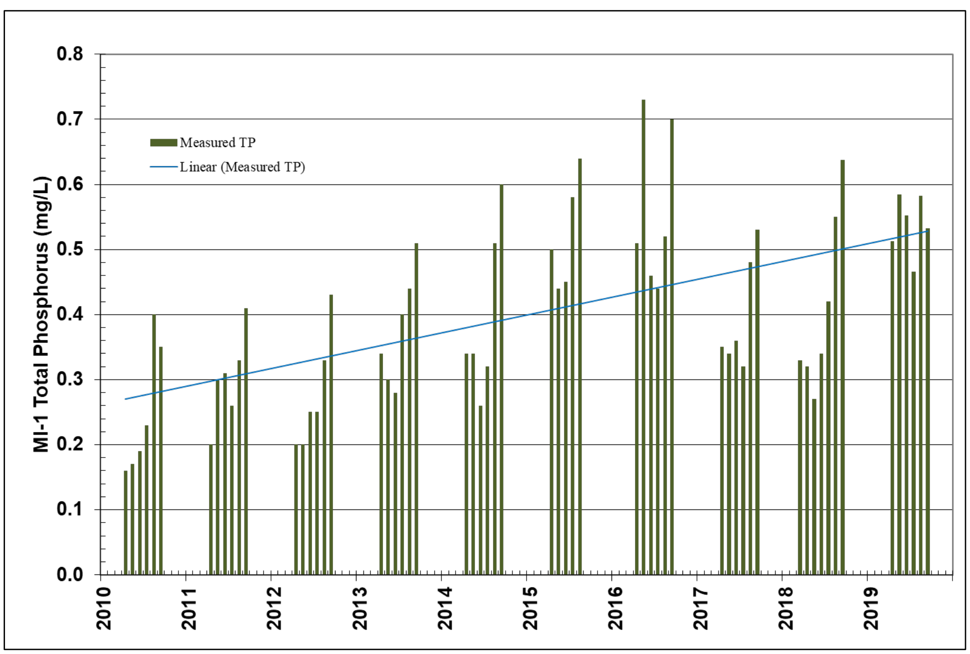


Figure 3-25. Milford Lake total phosphorus concentration and linear trend line from 2010-2019. *Measured from surface samples at site MI-1 near dam.*

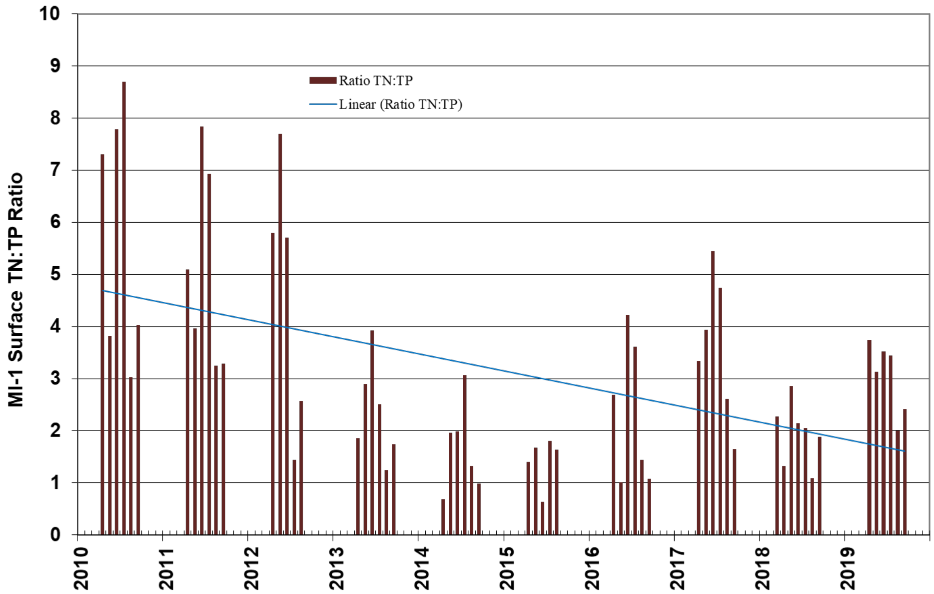


Figure 3-26. Milford Lake ratio of total nitrogen to total phosphorus and linear trend line from 2010-2019. *Calculated from measured surface samples at site MI-1 near dam.*

Historic water quality data trends and increasing HABS at Milford Lake were the impetus to plan for adjustments to lake level management to plan for a functional draw-down during the spring and summer of 2016. The drawdown was planned to reduce cyanobacteria akinete availability and limit internal nutrient loading from lake bed sediment to potentially reduce HABs (Kansas Water Office 2016). Large inflows prevented the successful drawdown. Lake level management to impact nutrient and HAB dynamics and reduce hydraulic residency time during HAB season continues to be the least cost prohibitive and low risk HAB remediation tool. Research on this topic was proposed in 2019 and supported by 12 USACE Districts with similar need (USACE-Environmental Laboratory Engineer Research and Development Center. 2019). Confounding rain events have influenced water management decisions in 2017 and 2019 while evaluations of lake level management actions on HABs were in progress. Anecdotal evidence of low HAB duration/intensity during low water periods in 2012-2013 and during periods with larger releases during prime HAB seasons as observed June-August of 2017 (Figure 3-27), and the absence of HABs during August flood releases of 2019 support the theory that operational changes to lake level management may be a tool to mitigate HABs.

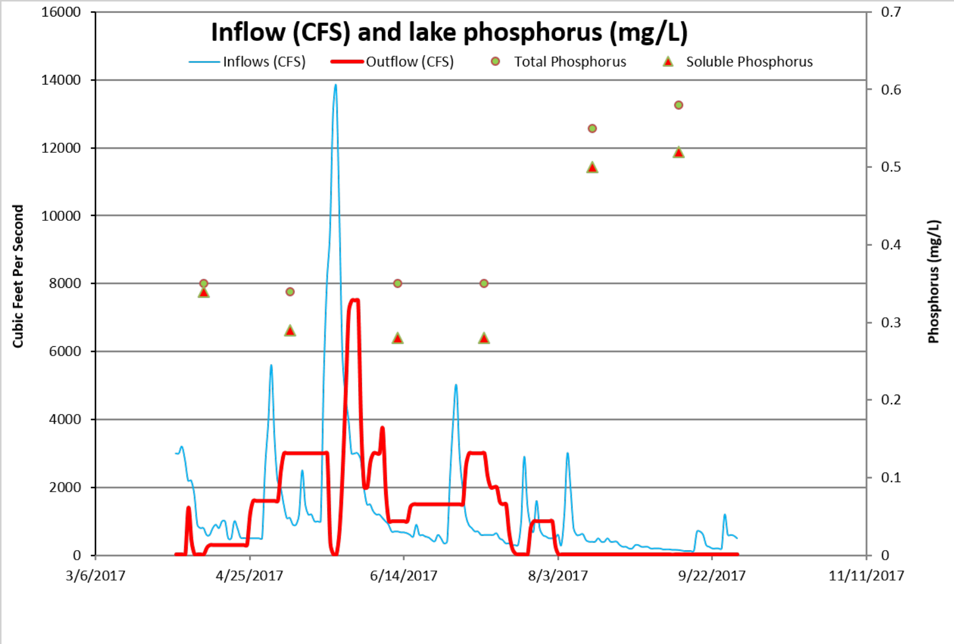


Figure 3-27. Milford Lake phosphorus concentrations and hydraulic data April-September 2017. *Measured from surface samples at site MI-1 near dam.*

Ten-year nutrient data in Figure 3-28 indicate nitrate/nitrite and ammonia nitrogen were similar between the three lake sites, except outliers at the upper lake site. Median total nitrogen and TKN at the upper Milford Lake site exceeded the interquartile range of the lower lake site at the dam, likely due to presence of organic matter and algae present in higher concentration in upper lake samples. Median and maximum total phosphorus was greatest in the upper lake (MI-5) from 2010 to 2019 while median and minimum orthophosphate was lowest at this sample location (Figure. 3-28), indicating biological uptake of orthophosphate by phytoplankton during summer months.

Mass balance estimates using Kansas City District intensive sampling results from 2018 indicate Milford Lake acts as a phosphorus sink, with considerably greater mass of total phosphorus entering the lake from inflows than leaving through the outlet (Figure 3-29). Brief periods of net loss of phosphorus from Milford Lake were evident in June and July 2018. Stored phosphorus in Milford Lake will increase internal loading risk as the lake ages and contributes to degraded water quality and harmful algal bloom risks despite watershed conservation/nutrient reduction measures directed at runoff and external loading (Juracek 2014; Pettersson 1998; Søndergaard et al., 2003)

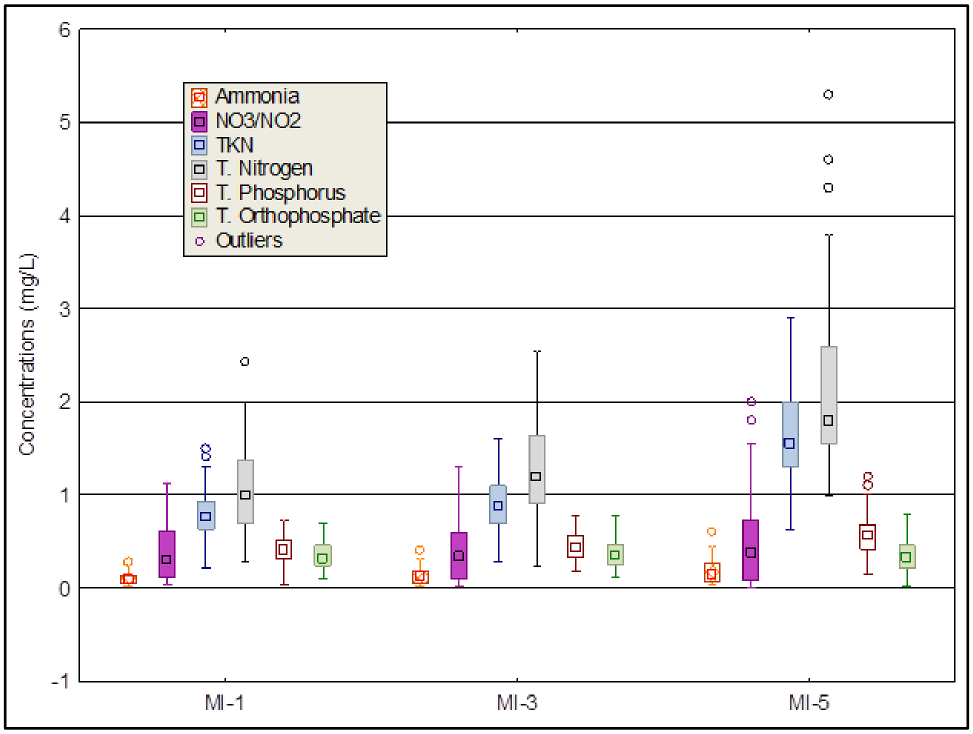


Figure 3-28. Milford Lake nutrient concentrations 2010-2019.

Nutrient concentration measured from surface samples collected at Milford Lake USACE water quality sample sites from 2010-2019.

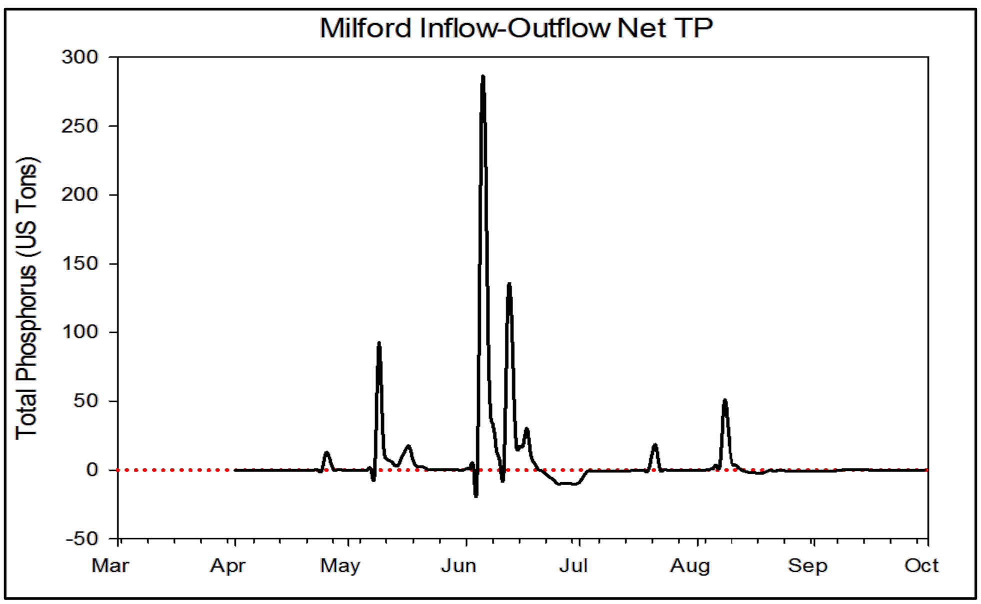


Figure 3-29. Milford Lake total phosphorus budget from March-December 2018.

Influences on light availability or water clarity include, but not limited to, inorganic sediment, organic carbon, turbidity, and phytoplankton (i.e., chlorophyll-a) (Testa et al., 2019). Light availability is a critical metric which influences biological productivity through light limitation of photosynthesis. Median total suspended solids, turbidity, and chlorophyll *a* concentrations were significantly higher and more variable at the upper lake site than mid and lower lake sites (Figure 3-30). Turbidity and TSS were an order of magnitude higher at the upper lake site. Consequently, Secchi depth was significantly different between all three sites as interquartile ranges do not overlap at any of the three sample locations with an order of magnitude difference observed between upper and lower lake sites (Figure 3-30). Organic carbon was slightly higher in samples from the upper lake site as expected from larger phytoplankton densities and influence from HABS.

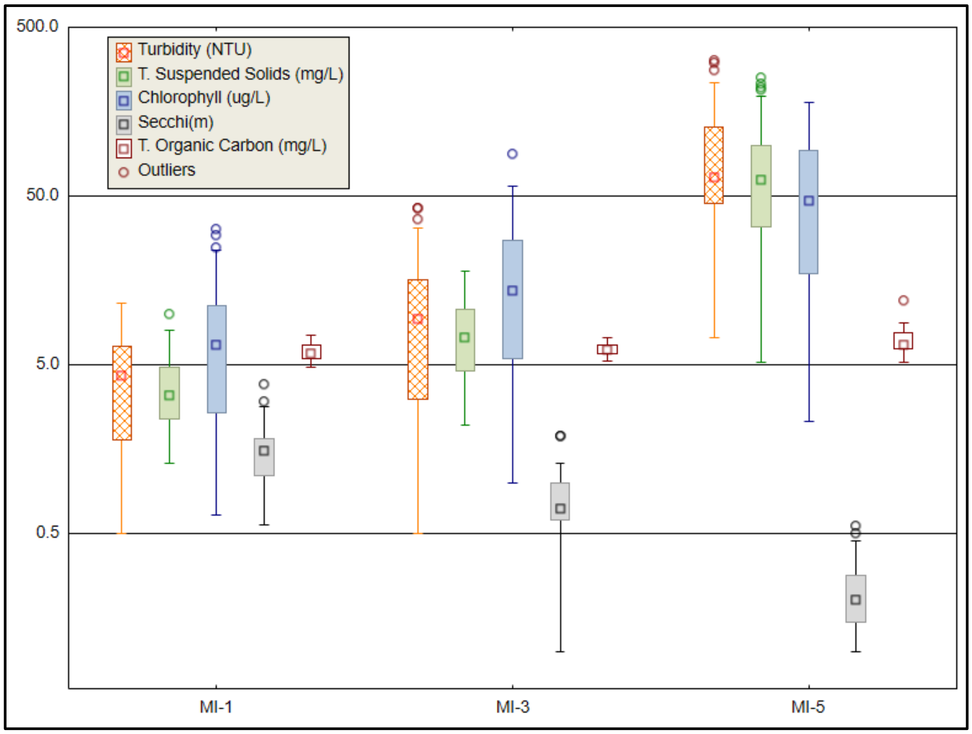


Figure 3-30. Milford Lake Water Clarity Metrics from 2010-2019.
Water clarity metrics measured at Milford Lake USACE water quality sample sites from 2010-2019.

Total metals concentration from surface samples from Milford Lake sites are represented Figure 3-31. Small sample size due to limited sampling effort and in several metals reporting as below minimum detection level have limited the utility of data. Ranked in order of relative abundance, iron, manganese, arsenic and lead were present at all at Milford Lake USACE water quality sample sites from 2010-2019. Differences between total metals between lake sites are not able to be determined. Seven additional metals were included in total metals analysis from 2010-2019 with results reported as below the minimum detection level.

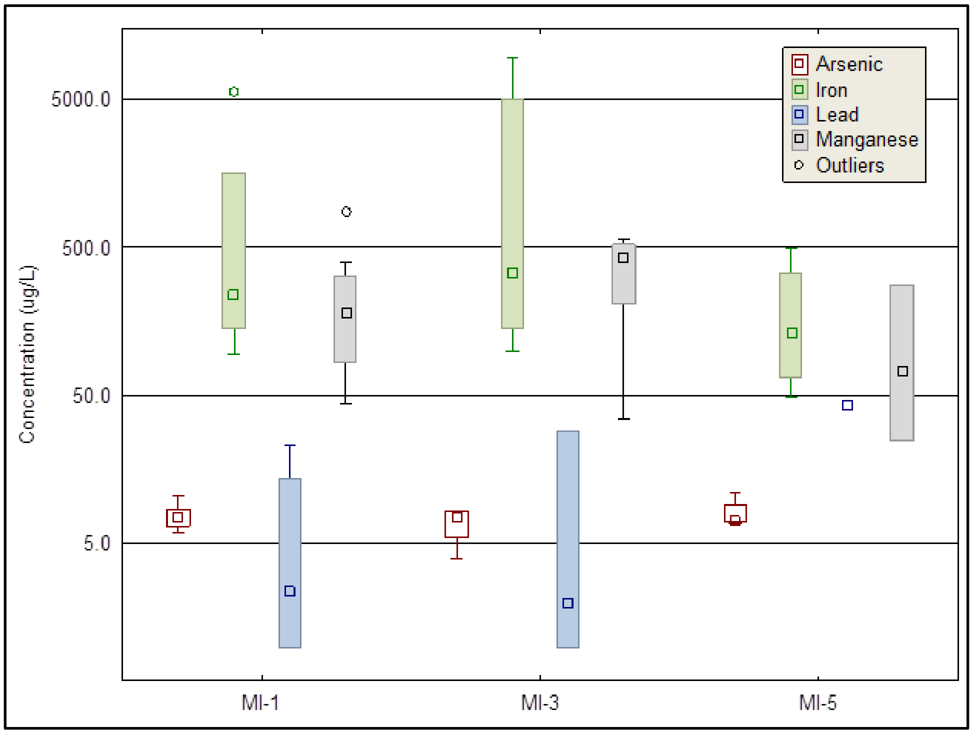


Figure 3-31. Milford Lake Total Metal Concentration from 2010-2019.

Total metal concentration measured from surface samples collected at Milford Lake USACE water quality sample sites from 2010-2019.

A summary of descriptive statistics of chemical analysis results at the site nearest the dam is found in Table 3-4. Bottom samples are typically collected from Kansas City District lakes every third year with total metals collected during the peak stratified month of August when stratified conditions are most likely. Seasonal periods when the lake is mixed (not stratified), bottom sample results are nearly identical to surface sample results for most analytes. Anaerobic conditions allow for oxidation/reduction reactions to release chemical compounds, including metals, which we are trying to quantify with bottom samples. Non-detection or result below minimum detection level occur on occasion and have been included in sample results (Table 3-4) as the value of half of the reported minimum detection limit to reduce bias based on the assumption that the analyte is present at a concentration below laboratory quantification (EPA, 1991). Sample size for bottom total metals samples was not sufficient for inclusion in the Table 3-4. All nutrient results, including orthophosphate, do not appear to differ between top and bottom samples in Table 3-4. Metals, orthophosphate, and suspended solids are typically more concentrate in the bottom samples during stratified months. However, total suspended solids was the only laboratory analyte with significant differences (Wilcoxon Signed-Rank Test; p=0.018) detected between surface and bottom samples at Milford Lake from April 2010 through September 2019 (Table 3-4).

Kansas City District nutrient results in Table 3-4 are indicative of impairment at the site near the dam as median total nitrogen (TN; 1.01 mg/L) and total phosphorus (TP; 0.39 mg/L) fall within the hypereutrophic range (Carlson, 1977) and exceed Central Great Plains median and statewide benchmark (KDHE, 2012). Chlorophyll *a* values at the dam were not in the eutrophic or impaired range as median chlorophyll *a* at the lower lake site was 6.6 ug/L while mean was 8.4 ug/L for the period April 2010 through September 2019. The use of summer chlorophyll values are applicable for trophic state index calculations due to increased seasonal variability during the Spring months (Carlson, 1977). KDHE reported long-term chlorophyll a average for 1996-2012 as 21.4 ug/L at KDHE sample site near the dam while Kansas City District average for the same period was 16.32 ug/L. KDHE chlorophyll *a* sample average is much higher than long-term averages from two different periods reported by USACE collections. This can be explained by seasonal variability as KDHE samples are typically collected in summer months while Kansas City District Water Quality Program statistics include 6 samples per year which include the months of April, May, and September when chlorophyll values are lower. Leiker et al. (2021) report chlorophyll a, phycocyanin (i.e., blue-green algal pigment) and algal toxin microcystin concentrations can vary greatly at Milford Lake during the months of July-October as phytoplankton community and relative abundance change.

Table 3-4. Milford Lake Chemical Water Quality Parameters and Chlorophyll *a* Summary Statistics.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.09	0.01	0.10	0.68	0.06	0.01	57
Ammonia (mg/L)	Bottom	0.12	0.04	0.14	0.46	0.06	0.01	16
NO_3/NO_2 (mg/L)	Surface	0.33	0.04	0.33	1.13	0.21	0.01	59
NO_3/NO_2 (mg/L)	Bottom	0.25	0.07	0.28	0.79	0.15	0.01	16
TKN (mg/L)	Surface	0.75	0.04	0.28	1.50	0.74	0.15	60
TKN (mg/L)	Bottom	0.71	0.07	0.26	1.40	0.69	0.29	16
Total Nitrogen (mg/L)	Surface	1.09	0.06	0.48	2.43	1.00	0.29	59
Total Nitrogen (mg/L)	Bottom	0.96	0.09	0.36	1.51	0.93	0.32	16
Total Phosphorus (mg/L)	Surface	0.40	0.02	0.14	0.73	0.40	0.04	60
Total Phosphorus (mg/L)	Bottom	0.45	0.04	0.17	0.79	0.41	0.20	16
Total Orthophosphate (mg/L)	Surface	0.33	0.02	0.15	0.70	0.32	0.003	60
Total Orthophosphate (mg/L)	Bottom	0.33	0.05	0.19	0.63	0.29	0.003	16
Total Suspended Solids (mg/L)	Surface	3.34	0.31	2.38	14.00	2.75	1.00	60
Total Suspended Solids (mg/L)	Bottom	12.99	6.94	27.77	116.00	4.90	1.00	16
Total Organic Carbon (mg/L)	Surface	6.90	0.55	2.67	17.00	6.10	4.80	23
Total Organic Carbon (mg/L)	Bottom	5.41	0.45	1.75	10.80	5.20	3.20	16
Chlorophyll *a* (ug/L)	Photic Zone	8.44	1.41	9.76	51.70	4.80	0.50	48

Note: *SE = Standard Error; ** SD = Standard Deviation
[1/]Summary statistics for chemical water quality parameters and chlorophyll *a* from Milford Lake site near the dam (MI-1), April 2010 through September 2019.

Surface and bottom physical water quality results selected from water quality profiles to compile descriptive statistics summary are in Table 3-5. Temperature and dissolved oxygen sensors are present on all data sondes used by Kansas City District Water Quality Program while pH, conductivity, and turbidity sensors may not be available each month. Calibration issues or sensor failure also account for a reduced number of sample results presented in Table 3-5. Turbidity differences between surface and bottom samples is attributed to settling of solids and metals throughout months and at locations with or without stratification. Temperature and dissolved oxygen concentration of are typically ideal for coolwater fish and native aquatic species. Periods of low D.O. below Kansas Water quality standards for dissolved oxygen (5 mg/L) are relative short lived and usually related to turnover events or short period of oxygen sag from periods of cloudy weather or rain when biochemical oxygen demand.

Table 3-5. Milford Lake Physical Water Quality Parameters for 2010 - 2019.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	7.9	0.15	1.9	12.23	7.8	3.1	163
Oxygen, Dissolved (mg/l)	Bottom	5.7	5.8	5.9	11.7	5.9	0.12	148
pH (Standard Unites)	Surface	8.3	0.03	0.4	9.1	8.4	7.4	153
pH (Standard Unites)	Bottom	8.3	0.03	0.4	8.8	8.2	7.3	144
Secchi Depth (m)	Surface	0.9	0.06	0.7	3.8	0.8	0.1	130
Specific Conductance (µS/cm)	Surface	670.2	11.1	137.9	1058.0	684.7	164.4	153
Specific Conductance (µS/cm)	Bottom	677.5	11.6	139.5	1060.0	687.3	164.8	144
Turbidity, Field (NTU)	Surface	34.1	4.4	54.6	315.5	9.6	<1	153
Turbidity, Field (NTU)	Bottom	149.9	30.8	360.9	2337.0	23.4	<1	137
Water Temperature (°C)	Surface	21.1	0.5	6.3	30.1	23.5	5.2	163
Water Temperature (°C)	Bottom	19.8	0.5	6.0	29.1	21.5	5.1	153

Notes *SE = Standard Error; ** SD = Standard Deviation
[1/]Summary statistics for physical water quality parameters, from all sites and dates, Milford Lake, April 2010 through September 2019.

The lower half of Milford Lake typically undergoes thermal stratification in July and August, while upper lake sites are generally too shallow to stratify or mixed by wind and/or flow throughout the summer (USACE, 2019). Water density from differences in temperature and salinity, distribution of heat, in-lake currents, reservoir releases, and wind action play a role in this process (Wetzel, 2001). Physical changes in water composition during stratified conditions from water temperature and density differences lead to chemical and biological changes in the absence of oxygen (anaerobic conditions). A representative compilation of stratified conditions at lower (MI-1) and mid-lake (MI-3) Kansas City District Water Quality Sites from ten years of temperature and dissolved oxygen profiles is shown in Figure 3-32. In August of 2013, strong stratification occurred at MI-1 as temperature and dissolved oxygen rapidly declined with depth at the thermocline located at 10 meters deep with minimum dissolved oxygen concentration of less than 1 mg/L at the bottom. In 2013, weak stratification was observed at the mid-lake site (MI-3) with moderate decline in dissolved oxygen and relatively little decline in temperature. When weak stratification occurs, fish and aquatic organisms have suitable habitat with adequate temperature and oxygen conditions while chemical composition resembles mixed conditions with a relatively small volume of water under anoxic conditions. Temperature and D.O. profiles in 2018 illustrate stratified conditions when fish and aquatic life were forced to adapt and move to shallower water to maintain oxygen preferences and tolerate much warmer water. This temperature/dissolved oxygen “crunch” can stress aquatic life and is part of the basis for the dissolved oxygen TMDL for Milford when KDHE documented dissolved oxygen deficiencies (i.e., concentrations less than 5 mg/L) (KDHE 2014).

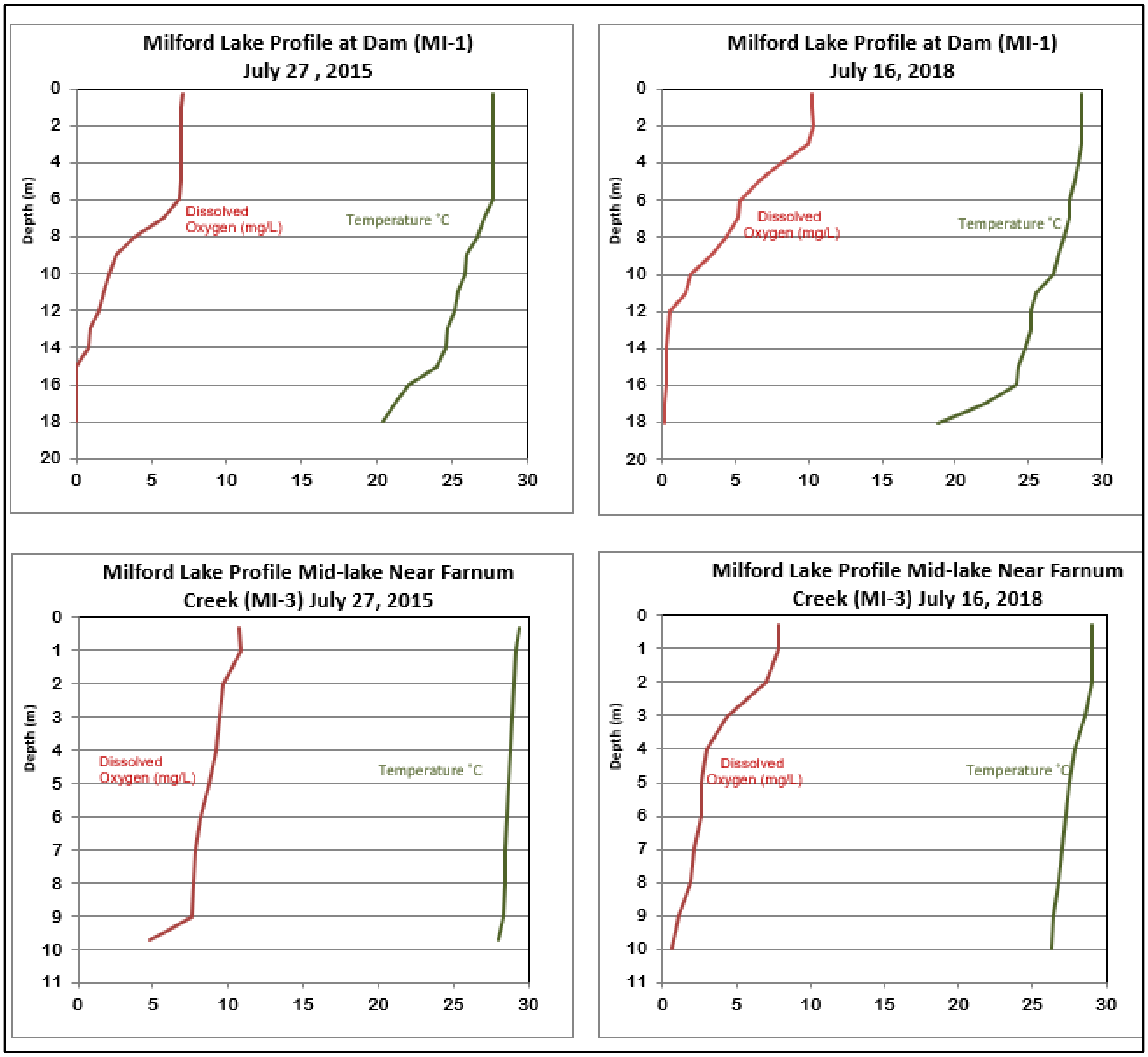


Figure 3-32. Milford Lake temperature and dissolve oxygen profiles.
Representative temperature and dissolved oxygen profiles from lower (MI-1) and middle (MI-3) Milford Lake USACE water quality sample sites from 2013 and 2018.

The hypereutrophic conditions at Milford Lake produce ideal physical and chemical conditions for production of HABs. An abundance of plant nutrients like orthophosphate and a low (i.e., <12) TN:TP ratio are two frequent water quality conditions associated with proliferation of blue-green algae which could produce toxins in freshwater (Downing, J. A., and E. McCauley. 1992; Xiaofeng et al. 2012). Ideal nutrient conditions combine with exceptional water clarity have led to an increase in HAB frequency, magnitude, and duration since 2010 (USACE, 2019) (KDHE, 2022). A summary of negative impacts include, but not limited to, serious illness to recreational users after HAB contact and verified dog fatalities from contacting HAB toxins (Trevino-Garrison et al., 2015), economic decline from reduced recreation and tourism (Pearce 2020; Terrill 2015), cyanobacterial toxin and taste-and-odor metabolites presence at drinking water intakes on the Kansas River (Graham et al., 2012) and has been associated with decline in local realty market from bad smell and negative media coverage from HABs (Groves, personal communication 2017).

KDHE CyanoHAB monitoring program started in 2010 (KDHE, 2022). Infrequent algal blooms without quantified toxins were observed and discussed by Kansas City District and KDHE water quality staff prior to 2010 and included one public complaint leading to a tentative HAB announcement in 2006 (USACE 2012). A marked increase in monitoring effort and increase in public reporting of HABs increases public awareness to the benefit of public safety but increased monitoring efforts has been blamed for inflating HAB reporting associated with media trends. This sudden increase in public monitoring and public awareness from state and federal agencies coincided with, and was directly linked to, a noticeable increase in HAB frequency that cannot be accurately quantified due to lack of monitoring data prior to 2010 when USACE categorized HAB toxins associated with infrequent and unpublicized blooms as “emerging issues” (USACE 2010).

Since 2010, Milford Lake HABs are most frequent and most concentrated in the upper end or Zone C (Figure 3-33) as cyanobacteria and resulting toxin follow a gradient related to orthophosphate from the upper lake to the lower lake. Prevailing winds during prime HAB conditions in the summer months tend to blow from the south/southwest which help concentrate buoyant cyanobacteria cells in the north end of Milford (Zone C) (Figure 3-33), which often creates a situation with dangerous toxin concentrations in the upper lake and while lower lake (Zone A) cell count and toxin concentrations are considered safe (i.e., “no action”). Nine instances (e.g. weeks) of extreme HABS consisting of 2,000 ug/L of microcystin and/or 10 million cells/mL when closure/hazard status was recommended by KDHE occurred in Zone C.

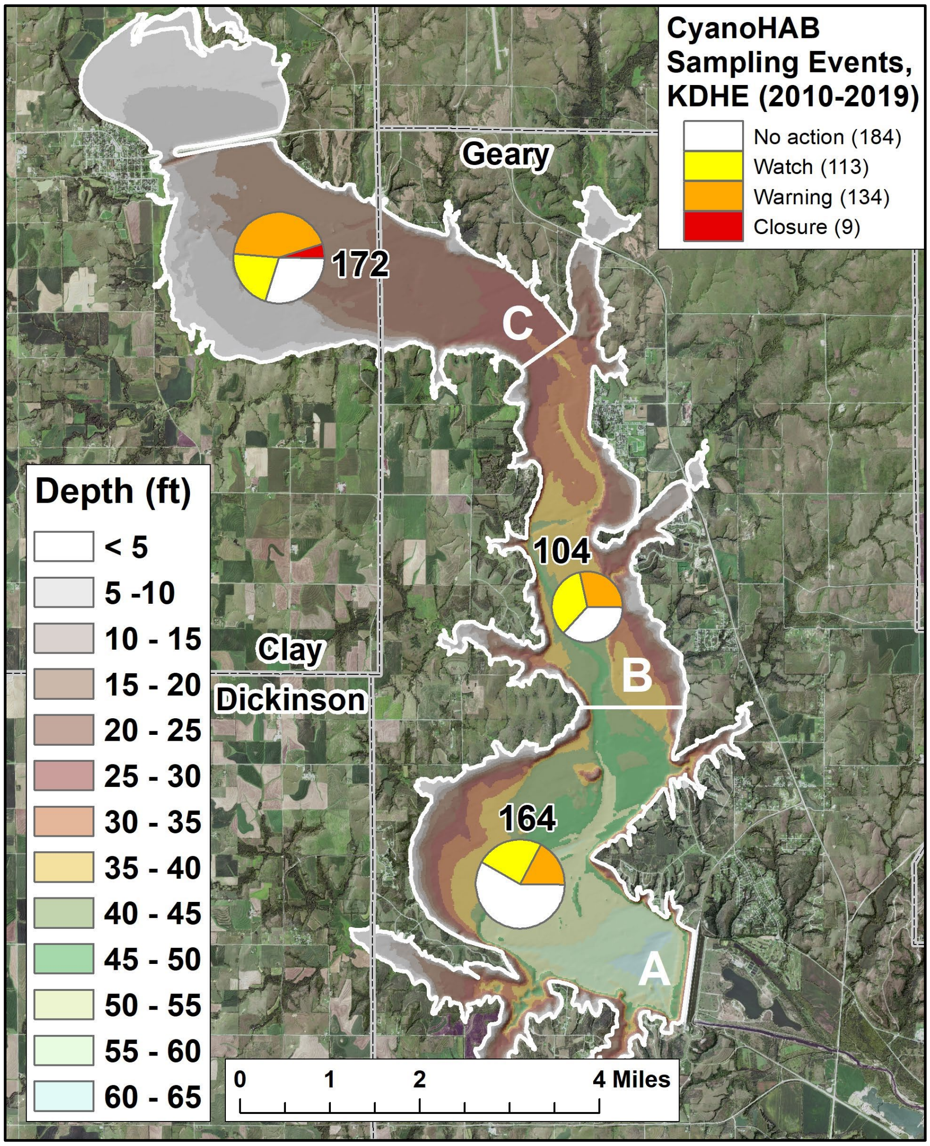


Figure 3-33. Milford Lake CyanoHAB sampling events from 2010-2019. Lake bed Sediment Quality
CyanoHAB sampling events in Milford by the KDHE CyanoHAB response program from 2010-2019, grouped Zones A, B, and C, with county names and lines (gray). Image courtesy of Ted Harris (2020)*, Kansas Biological Survey Report No.197.*

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or "recycle" nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984. A unified approach for sediment quality assessment based on freshwater ecosystem effects (MacDonald et al., 2000) allows lake owners, management agencies, and regulatory agencies to make informed decisions based on consensus-based concentration thresholds derived from aquatic toxicology data and EPA recommendations for common metals found in USACE Kansas City District lakes. Kansas City District Water Quality Program initiated collection of baseline lake sediment data in 2016 (Table 3-6) to gather baseline sediment nutrient and trace metal contamination data at standardized lake water quality sites. Based on long-term monitoring water quality sample results, less likely contaminants like polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), and chlorinated pesticides have not been included in recent lake bed sediment samples.

2016 (Table 3-6).

Nitrogen and phosphorus concentrations from Milford Lake sediment samples were moderate when compared to results from a diverse sample of North American Lakes (Barko, J.W. and R.M Smart. 1986). Metal concentrations from Kansas City District sample results (Table 3-6) did not exceed the “probable effect concentration” (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000). Similarly, Christensen and Juracek (2000) reported exceedance of “threshold effect level” (TEL) of four metals from lake bed sediment core samples, but concentrations were less than PEC values. In this study, it was surmised that increasing trends of As, Sr, and Se in the Republican and Solomon River basins may be related to natural conditions and increased irrigation.

Table 3-6. Milford Lake bed sediment chemical concentration from 2016-2017.

Site Station	Date mm/dd/yyyy	Time hhmm	Ammonia MG/KG	TKN MG/KG	T. Phosphorus MG/KG	Arsenic MG/KG	Copper MG/KG	Iron MG/KG	Lead MG/KG	Manganese MG/KG	Nickel MG/KG	Zinc MG/KG	Cadmium MG/KG	Chromium MG/KG	Total Solids %
MI-1	9/6/2016	1130	49.8	1460.0	581.0	5.4	9.1	14800	14.6	531.0	17.7	59.4	0.69	17.5	
MI-3	9/6/2016	1230	57.0	1380.0	554.0	8.1	13.4	19100	16.7	403.0	21.5	74.5	0.64	20.6	
MI-5	9/6/2016	1300	303.0	1820.0	771.0	8.6	14.7	18900	19.4	630.0	19.5	78.2	0.76	20.3	
Site Median			**57.0**	**1460.0**	**581.0**	**8.1**	**13.4**	**18900**	**16.7**	**531.0**	**19.5**	**74.5**	**0.7**	**20.3**	
Mean			**136.6**	**1553.3**	**635.3**	**7.4**	**12.4**	**17600**	**16.9**	**521.3**	**19.6**	**70.7**	**0.7**	**19.5**	
MI-1	9/11/2017	1115	120	2200	955	8.0	17.2	24700	18.7	1100	28.5	81.6	0.60	31.0	26.4
MI-3	9/11/2017	1145	232	2750	780	8.6	22.1	34300	25.4	829	33.2	122	0.77	36.1	21.4
MI-5	9/11/2017	1215	153	2750	983	8.5	23.9	31800	24.1	858	31.7	125	0.89	33.9	30.5
Site Median			**153.0**	**2750.0**	**955.0**	**8.5**	**22.1**	**31800**	**24.1**	**858.0**	**31.7**	**122.0**	**0.8**	**33.9**	**26.4**
Mean			**168.3**	**2566.7**	**906.0**	**8.4**	**21.1**	**30267**	**22.7**	**929.0**	**31.1**	**109.5**	**0.8**	**33.7**	**26.1**

Milford Lake Wetlands Habitat Restoration Project

The Milford Lake Wetlands Restoration Project was a Kansas City District, U.S. Army Corps of Engineers Section 1135, (Continuing Authorities Program) project sponsored by the Kansas Department of Wildlife and Parks (KDWP) with additional support and funding from the Kansas Wildscape Foundation (Figure 3-34). The organization raising funds for beneficial projects in Kansas involved construction of ten wetland sites on property located adjacent to the Republican River and Milford Lake near Junction City, Kansas.

The low berm wetland sites range in size from 60 to over 400 acres affecting approximately 2,100 acres of the 23,000 acres of the Milford Lake Project lands licensed to and managed by KDWP. The project was completed in phases, with final completion in 2005. The wetland project was a showcase of local, State and Federal cooperation to provide wetland habitat for fish and wildlife.

Water quality benefits to the Republican River and Milford Lake were anticipated as a secondary benefit of the wetland habitat project. The wetland would provide a limited function as a sediment and nutrient trap for flood waters with some potential to reduce nutrients from inflow water trapping by burial/storage of sediment bound nutrients, vegetation uptake, biogeochemical transformations including denitrification, and microbial degradation (Fisher and Acreman 2004; O’Geen et al. 2010).

Figure 3-34. Milford Lake Wetlands Restoration Project.

Milford Lake Wetlands Restoration Project wetland adjacent to Republican River upstream of Milford Lake.

In 2017, Milford Lake Wetlands were added as water quality sites to the Kansas City District Water Quality Program to describe nutrient concentrations at the lower terminus of the wetland complex (MI-7) relative to the adjacent Republican River (MI-6), standardized lake sites (MI-1, MI-3, MI-5), and the outflow site (MI-1a).

Depending on the form of phosphorus a variety of physical, chemical, and biological processes will occur resulting in a wetland acting as a sink, source, or transformer. Long-term removal or a net reduction of phosphorus from a lake or wetland ecosystem can only occur through active management when vegetation is harvested or when sediment bound phosphorus is removed from the system. Extreme concentrations of total phosphorus were reported in 2017 samples of shallow wetland site MI-7 (Figure 3-35). Median total phosphorus concentrations were eight times higher than the hypereutrophic threshold indicative of waters prone to excessive aquatic plant and algae growth. Peak total phosphorus concentrations occurred in June and July as evapotranspiration reduced water volume while it is assumed that internal loading mechanisms described by Søndergaard et al. (2003) including release from lake bed sediments via chemical diffusion and bioturbation from fish and invertebrates increased soluble phosphorus present in samples. Phosphorus is apparently stored in the wetland cells when compared to the adjacent Republican River site (MI-6) during most months. High flow periods when significant flows leave the wetland invariably led to phosphorus loads transferred downstream to Milford Lake. USACE water quality sampling protocol limits sampling during high flow periods when possible. Consequently, much of the phosphorus transfer downstream from the wetland was not captured. Peak total phosphorus measured at MI-6 in May 2017 was related to increased flow but may not be directly attributed to loss from wetland.

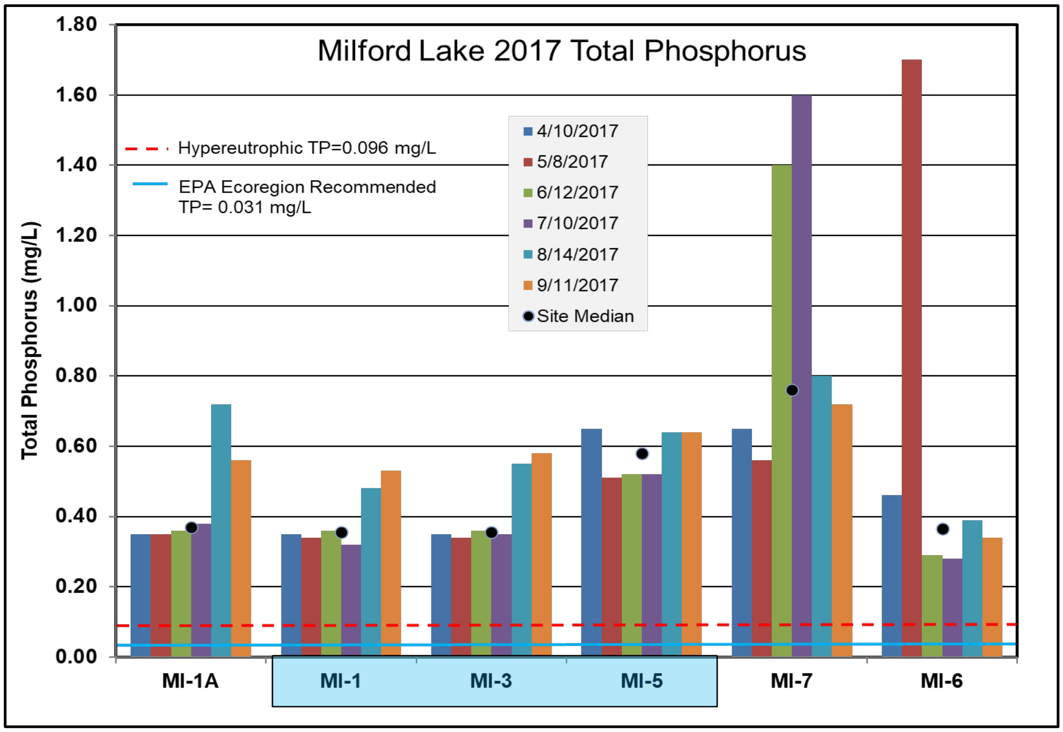


Figure 3-35. Milford Lake Monthly Total Phosphorus Outflow Concentrations April – September 2017.

Samples taken from Milford Lake Outflow (MI-1a), lake sites (MI-1, MI-3, and MI-5), lower terminus of Smith Bottom Wetland (MI-7) and adjacent Republican River site (MI-6) located upstream of Milford Lake. (Presented to Milford Lake Stakeholders Meeting 18-January 2018. Kansas City District Corps Water Quality Program Update).

Nitrogen enters wetlands in organic and inorganic forms. Three main processes responsible for nitrogen retention and removal in a wetland are denitrification, sedimentation, and uptake by vegetation (Mitsch and Gosselink 2000; Reddy and D'Angelo 1994; Saunders and Kalff 2001). The gaseous phase of nitrogen in the wetland nitrogen cycle can be permanently removed from soil and water column through the denitrification process. The pattern of denitrification is apparent at lake sites from July-September, but not evident at the wetland site MI-7 in 2017 (Figure 3-36). Uptake of plant available forms or nitrogen by vegetation at MI-7 was apparent from June-September when ammonia and nitrate decreased to non-detectable levels during this period while organic nitrogen measures increased proportionally (Kansas City District Water Quality Program, unpublished data).

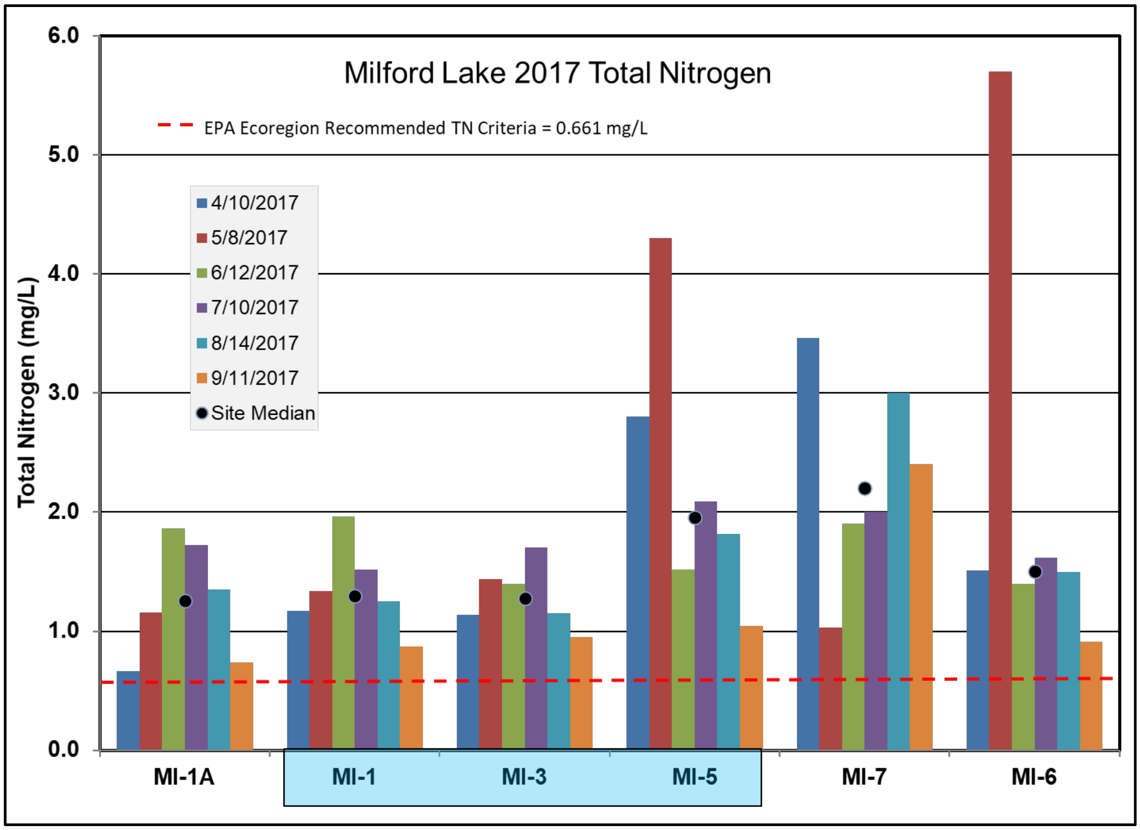


Figure 3-36. Milford Lake Monthly total nitrogen outflow concentrations 2017. *Monthly total nitrogen concentrations from Milford Lake outflow (MI-1a), lake sites (MI-1, MI-3, and MI-5), lower terminus of Smith Bottom Wetland (MI-7) and adjacent Republican River (MI-6) site located upstream of Milford Lake. (Presented to Milford Lake Stakeholders Meeting 18-January 2018. Kansas City District Corps Water Quality Program Update)*

3.1.3 Wilson Lake

Wilson Lake (9,045 acre) has been named the clearest lake in Kansas, built on the Saline River in 1964. Wilson Lake is operated for flood control, downstream water quality, fish and wildlife, and recreation. The primary water quality threats are best described by current KDHE TMDL for chloride and sulfate originating from natural sources in the Dakota Aquifer and with relatively small amount of augmentation by oil-field brine (KDHE 2004). Natural background chloride levels in the Saline River above Wilson Lake consistently exceed water quality criteria of 250 mg/L.

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics related to flow (i.e., volume, load, and concentration), water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological response. Figure 3-37 illustrates Wilson Lake hydrologic data with overlay of water quality samplings events.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September). Low inflow and lake level below conservation pool was observed at the end of 2012 with surface elevation falling below 1,506 ft while recovery period is apparent in spring of 2016. Significant flooding and corresponding high-water period was observed in 2019 with inflows exceeding 6,500 cfs. Surface elevation of Wilson Lake peaked at 11 ft above conservation-pool elevation (CPE) and exceeded CPE for 159 days in 2019.

Average water residence time for Wilson Lake of 23.6 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Wilson Lake average water residence time was second longest of Kansas River Watershed lakes in this study. Extended residence time allows for longer dilution and settling time as well as biological attenuation of agricultural runoff which improves water quality downstream of Wilson Lake. Accumulation of sediments and storage of sediment bound contaminants have negative implications for water quality as extended water residence time is a contributor to eutrophication including negative impacts to temperature and oxygen profiles from algal growth and potential increase in harmful algae blooms, increase potential of internal nutrient loading and loss of pool volume. Wilson Lake frequent mixing and relatively short thermal stratification reduces many of potential negative impacts.

Figure 3-37. Wilson Lake Time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Water Quality Sample Locations

To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow. Saline River sample locations for inflow samples are at site WI-1 while outflow samples are collected below Wilson Lake dam from site WI-16 (Figure 3-38). Lake sample locations on main lake and Hell’s Creek tributary arm in river channel at each sample location.

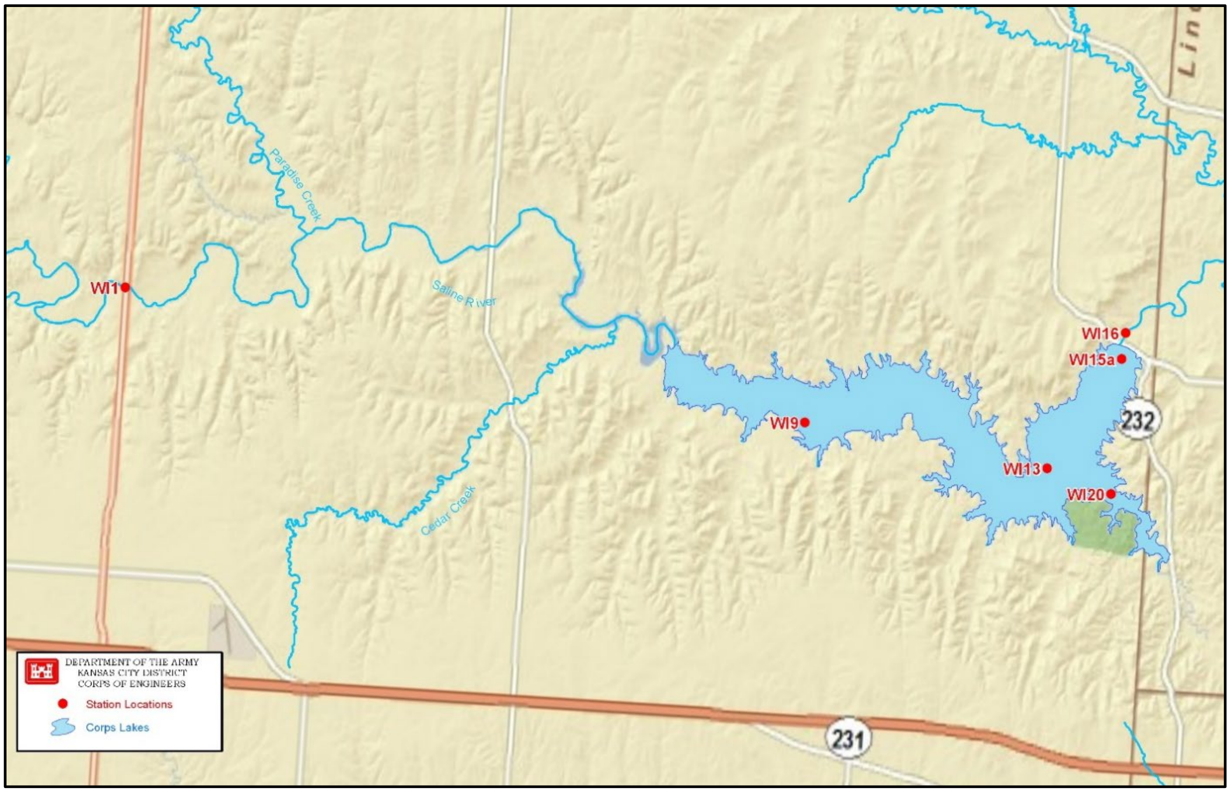


Figure 3-38. Wilson Lake Historic USACE Water Quality sample sites**.** *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow.*

Impairments

Wilson Lake and inflow impairments including TMDLs at Wilson Lake for chloride and sulfate are caused by naturally occurring salt compounds from the Dakota Aquifer entering the Saline River via groundwaters additions to inflow streams (Figure 3-39). Natural background chloride and sulfate levels on Saline River above Wilson Lake consistently exceed water quality criteria of 250 mg/L which prevents achievement of KDHE state water quality criteria of 250 mg/L. When the source of naturally occurring substances …"due to intrusion of mineralized groundwater, the existing water quality shall be maintained, and the newly established numeric criteria for domestic water supply shall be the background concentration" (KDHE 2018). Dilution from freshwater from rain events reduces the concentration of compounds. Water quality related to salt ions and TMDL attainment at Wilson Lake generally degrades with reduced inflow and water levels below multi-purpose pool elevation associated with drier weather periods.

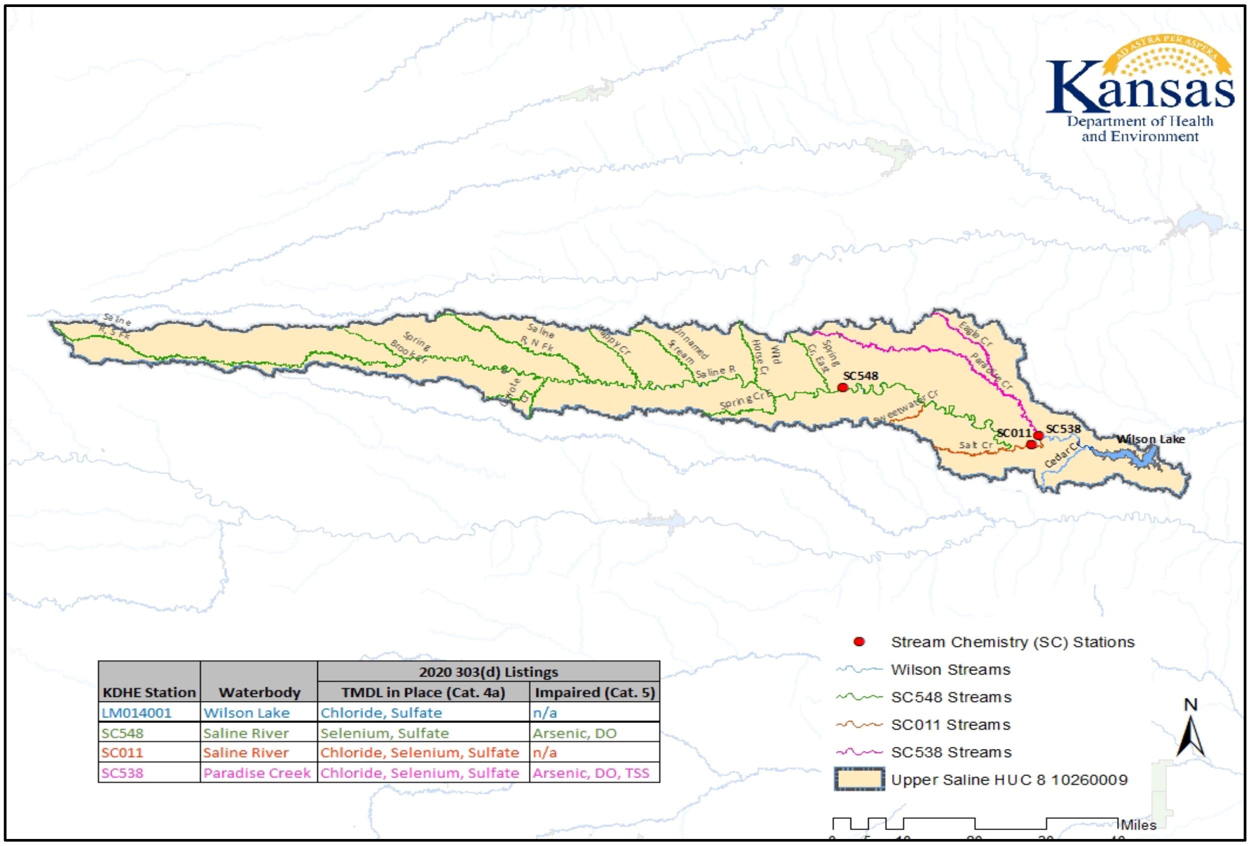


Figure 3-39. Wilson Lake and Watershed Impaired Waters and TMDLs. *Impaired waters and TMDLs of Wilson Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Inflow/Outflow

Row crop agriculture in Wilson Lake watershed is a relatively low percentage of land use compared to other USACE District Lakes in Kansas. Consequently, herbicide and fertilizer runoff influence water quality less than most Kansas lakes. While most herbicide results are below minimum reporting limit, common corn herbicide atrazine and metolachlor were detected in Wilson inflow and outflow (Figure 3-40). Atrazine results were more variable from inflow samples (WI-1) while median and maxima at both locations were less than 50% of EPA drinking water criteria of 3 ug/L.

Nutrient concentrations above and below Wilson Lake (Figure 3-41) show a great deal of attenuation resulting from settling and biological process. Sample means of all nutrient analytes in Figure 3-41, except ammonia, are significantly ($P<0.05$) lower at the outflow than in Saline River samples above Wilson Lake. Soluble or plant available nutrients (e.g. orthophosphate and nitrate) results were below minimum detection limit in many outlet samples due in large part to biological conversion in the lake environment.

Water clarity measures of turbidity and total suspended solids demonstrate similar decreases in concentration from settling of sediment and reduced algal cell influence (Figure 3-42). Sample means of turbidity and total suspended solids are significantly less ($P<0.05$) in the outflow compared to Saline River samples. Total organic carbon results in Figure 3-42 are similar above and below Wilson Lake with median and sample mean values separated by less than 10% difference or 1 mg/L in concentration.

Chloride and sulfate ion concentration at inflow and outflow sites are illustrated in Figure 3-43. Median values for these salt compounds are similar at inflow and outflow sites. Changes in measured concentration of these ions due to dilution from local rain events as well as proximity to high salinity groundwater during drier periods is the primary cause of increase variability at Saline River site (WI-1).

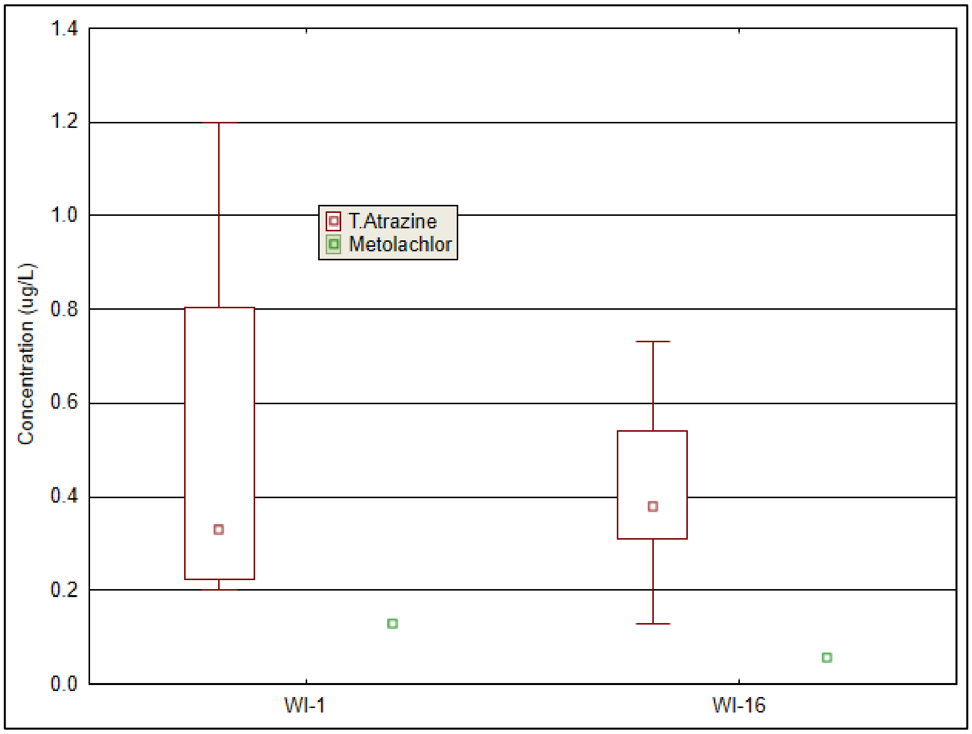


Figure 3-40. Herbicide Concentrations upstream and downstream of Wilson Lake from 2010—2019. *Herbicide Concentration measured from surface samples collected at Wilson Lake inflow (WI-1) and outflow (WI-16) USACE water quality sample sites from 2010-2019.*

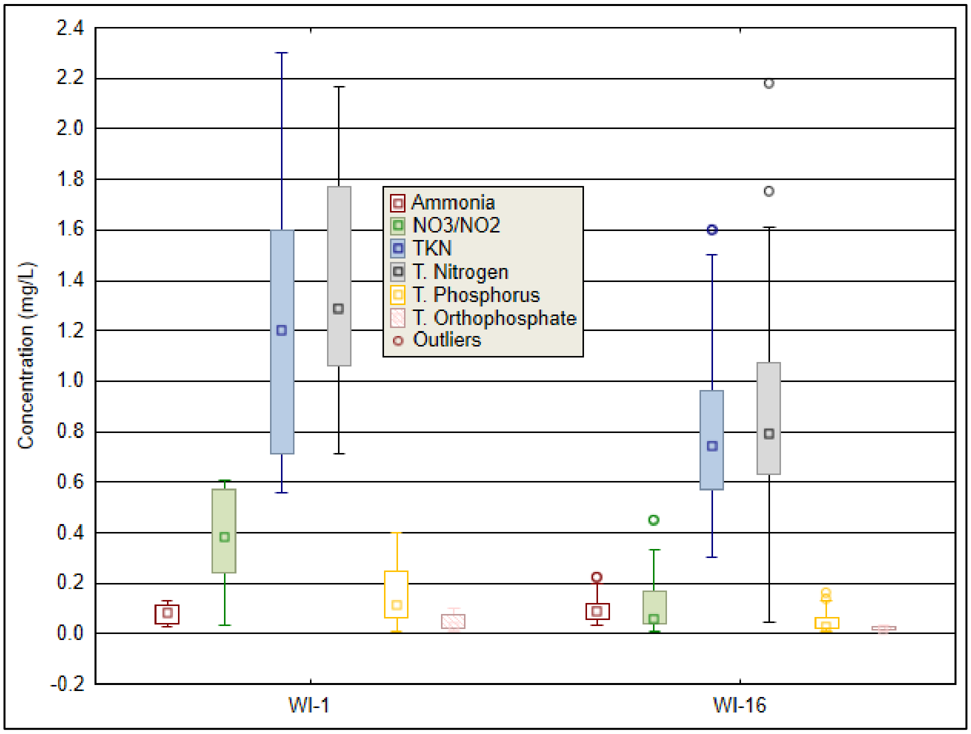


Figure 3-41. Nutrient concentrations upstream and downstream of Wilson Lake from 2010-2019. *Nutrient concentration measured from surface samples collected at Wilson Lake inflow (WI-1) and outflow (WI-16) USACE water quality sample sites from 2010-2019.*

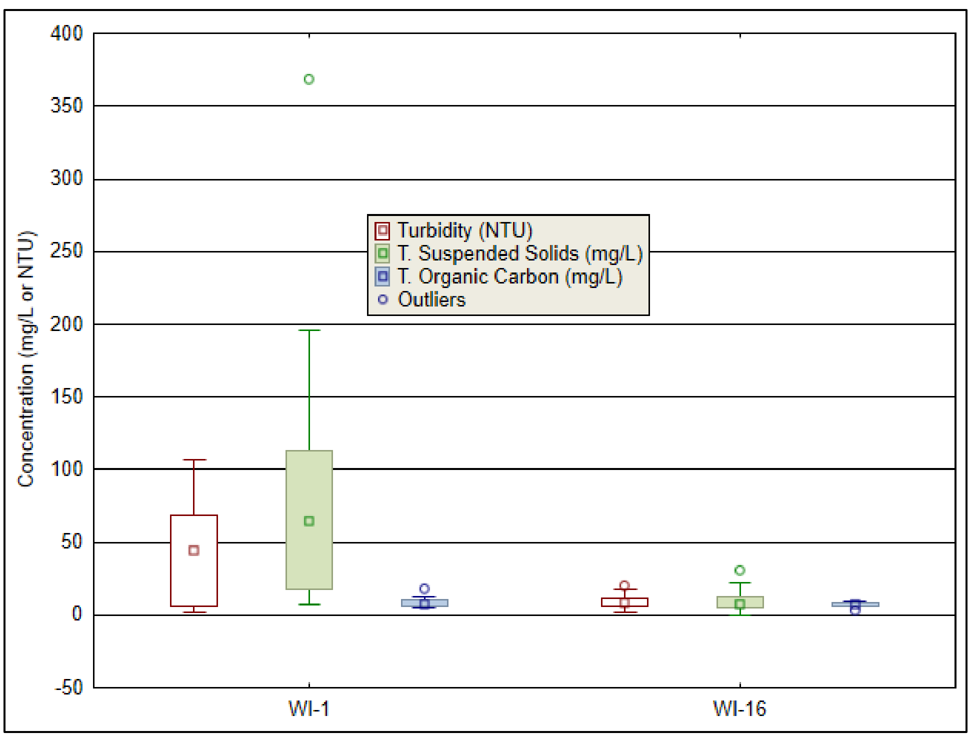


Figure 3-42. Water clarity influences upstream and downstream of Wilson Lake from 2010-2019. *Water clarity influences measured from Wilson Lake inflow (WI-1) and outflow (WI-16) USACE water quality sample sites from 2010-2019.*

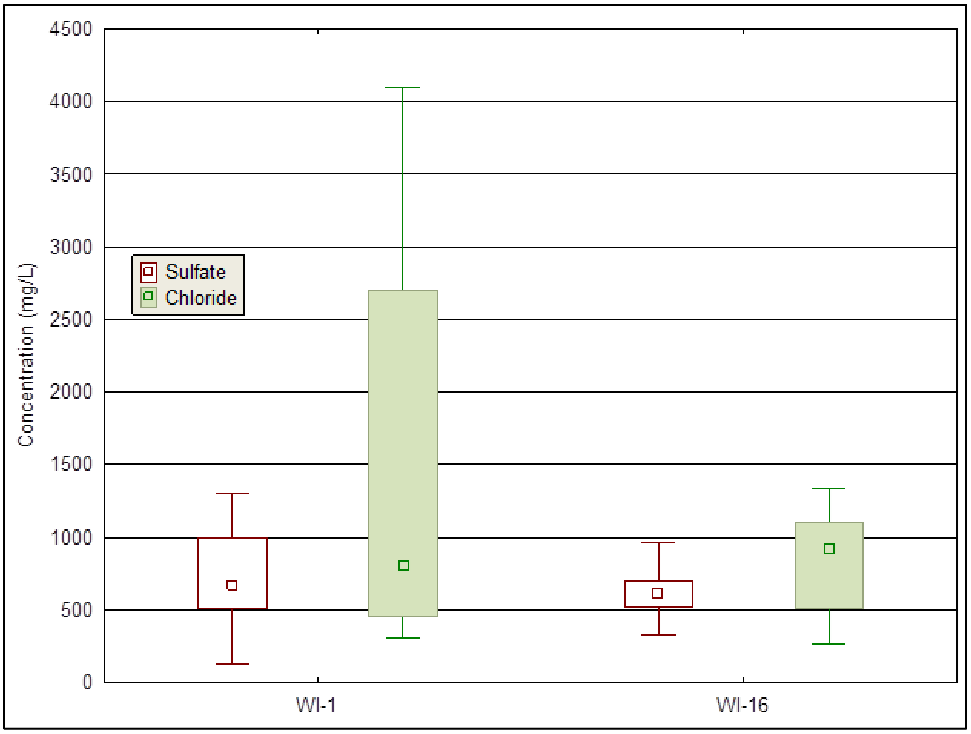


Figure 3-43. Naturally occurring salts upstream and downstream of Wilson Lake from 2010-2019. *Naturally occurring salts measured from Wilson Lake inflow (WI-1) and outflow (WI-16) USACE water quality sample sites from 2010-2019.*

Lake Water Quality

Naturally occurring salts in the watershed are the main cause of water quality concerns at Wilson Lake and linked to numerous chloride and sulfate TMDLs for Domestic Water Supply and Acute Aquatic Life Support in Smoky Hill/Saline River Basin streams described by KDHE (2004). Wilson Lake watershed has considerably less row crop agriculture, sediment runoff, fertilizer and pesticide runoff than other lakes in the Kansas River Basin. Water quality can degrade during extended wet periods or flood conditions as observed in 2019. During this time, the degraded conditions are less extreme than those experienced in other watersheds.

Physical and chemical attenuation (e.g., dilution, dispersion, chemical changes, and uptake by organisms) of compounds and settling of suspended matter leads to a general decrease in concentration of many constituents of water quality, often interpreted as improved water quality, as water moves through a reservoir system (Bosch et al., 2009). This process will be evident with many analytes in graphic representations in lake water quality sections. The following section is an overview of chemical and physical data from surface samples from 4 lake sites, describes chemical and physical differences between surface and bottom strata at the site near the dam and stratification, and briefly describes available phytoplankton and cyanobacteria data related to public health advisories.

Herbicide are detected in relatively low concentrations in Wilson Lake samples (Figure 3-44). Two common herbicides detected in samples include atrazine which did not exceed EPA recommendations for maximum exposure of 3 ppb in samples collected from 2010-2019. One sample with low concentration of metolachlor was also detected from the upstream lake site. Higher concentrations of herbicides in inflow and upper lake sites degrade from sunlight and microorganisms to the low levels near the Wilson Dam.

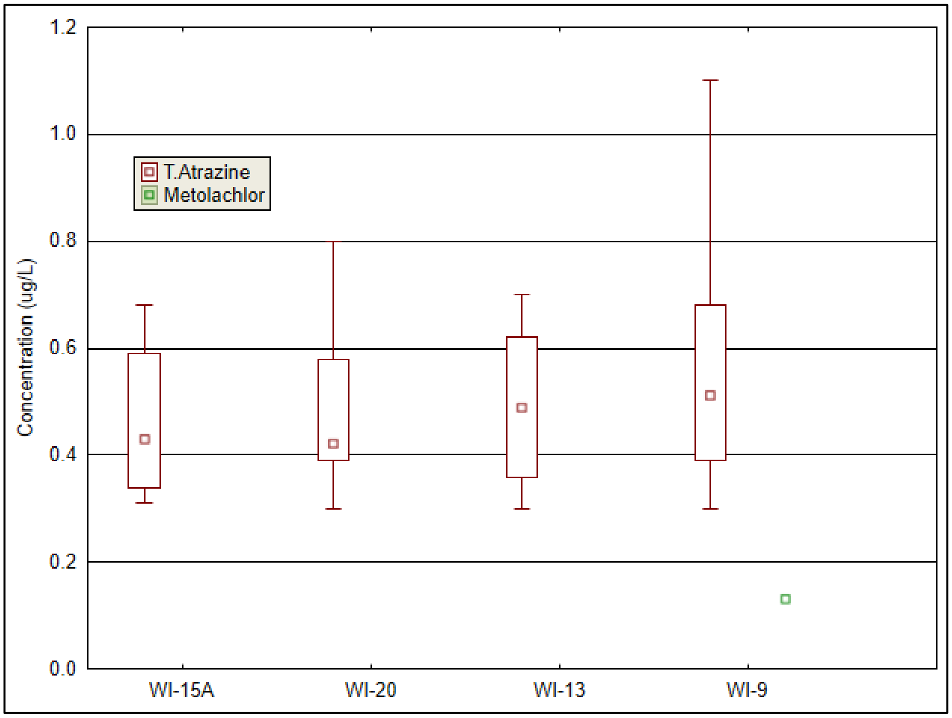


Figure 3-44. Wilson Lake Herbicide concentration from 2010-2019. *Herbicide concentration measured from surface samples collected at Wilson Lake USACE water quality sample sites from 2010-2019.*

Wilson Lake nutrient data is illustrated in Figure 3-45. Ammonia, nitrate/nitrite, and both phosphorus measures were below minimum reporting limit in many samples which is also apparent in Table 3-7. Total nitrogen concentration decreases slightly from the upper lake site to the lower three sites while median values of other nitrogen analytes measures are similar at upper and lower sites. Attenuation and denitrification occurs on a smaller scale than many of the larger reservoirs in the District. Median bioavailable forms of nitrate/nitrite and ammonia were similar between sample sites but more variable at the upper lake site (WI-9). Median total phosphorus and soluble orthophosphate concentrations were slightly lower at the sample location near the dam (WI-15a). Large inflows and high water above normal high-water line resulted in record high nutrient concentrations in Wilson Lake and are responsible for most of the outliers at the upper end of the distribution. Wilson Lake total phosphorus values meet EPA Ecoregion recommendations (Figure 3-1) while all the other District lakes far exceed Ecoregion recommendations and most watershed conservation milestones.

Water quality measures affecting water clarity in the “clearest lake in Kansas” are presented Figure 3-46. Median Secchi measures indicate water transparency increases from 0.55 meters at the upstream site (WI-9) to 1.75 meters at the dam with maximum Secchi depth of 4 meters. Median turbidity, total suspended solids, and chlorophyll *a* exceed the 75th percentile (Q3) of respective measures at three lower lakes sites and median turbidity at WI-9 exceeds all turbidity records at the dam (WI-15a). Median total organic carbon was similar at all sites but more variable at Hell’s Creek arm site (WI-20).

Sulfate and Chloride concentrations typically exceed EPA drinking water criteria (250 mg/L) at all Wilson Lake sites (Figure 3-47). Proximity to inflows with proportionally more fresh water following rain events increases variability and reduces concentrations during wetter periods. Median and interquartile range of sulfate and chloride were nearly identical between lower lake sites WI-15a, WI-13, and WI-9.

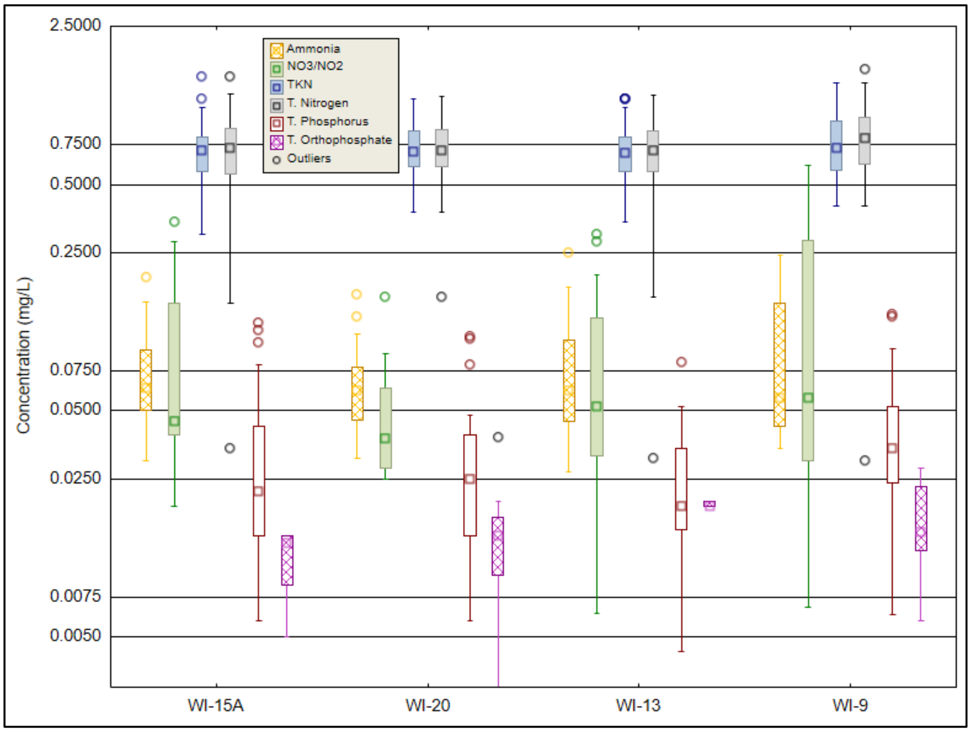


Figure 3-45. Wilson Lake Nutrient concentrations from 2010-2019. *Nutrient concentration from surface samples taken from Wilson Lake USACE water quality sample sites from 2010-2019.*

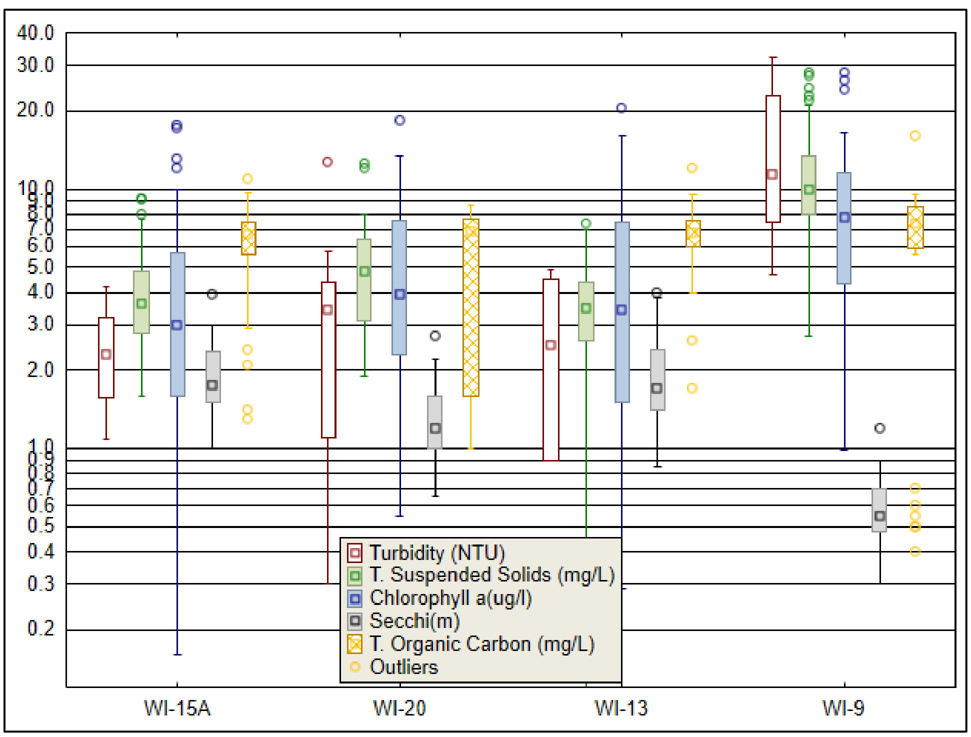


Figure 3-46. Wilson Lake water clarity influences from 2010-2019. *Water clarity influences measured from Wilson Lake USACE water quality sample sites from 2010-2019.*

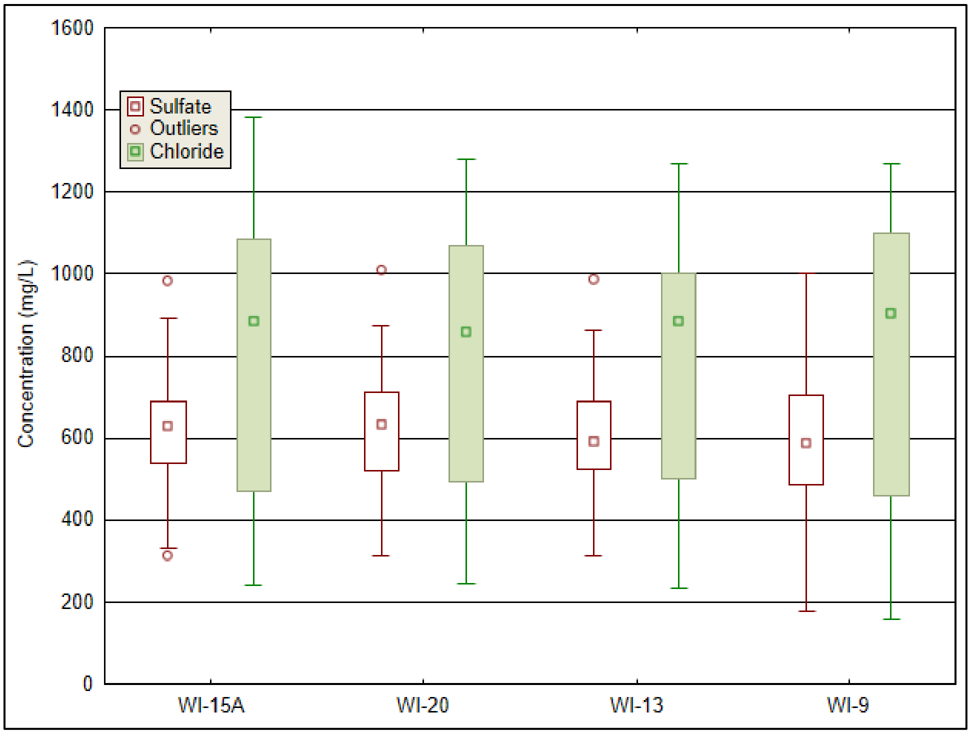


Figure 3-47. Wilson Lake naturally occurring salts from 2010-2019. *Naturally occurring salts measured from Wilson Lake USACE water quality sample sites from 2010-2019.*

Water quality chemistry differences between surface and bottom samples at Wilson Lake site nearest the dam (WI-15a) are described in statistical summary Table 3-7. Non-detection or result below minimum detection level are frequent and have been included in sample results as the value of half of the reported minimum detection limit to reduce bias based on the assumption that the analyte is present at a concentration below laboratory quantification (EPA, 1991). USACE collects bottom samples routinely from Kansas City District lakes every third year with total metals collected during the month of August when stratified conditions are most likely to show increased metal solubility due to anoxic conditions near the bottom. Wilson Lake stratifies for short periods in the summer months. When not stratified, frequent mixing homogenizes chemical and physical conditions and sample results are similar from top to bottom excepting unfiltered analytes sediment or heavier particles involved (e.g. TSS, turbidity). If all sample results were below minimum reporting limit or sample size was less than 3, NA was recorded in Table 3-7.

Physical water quality data from profiles collected at Wilson Lake are presented in Table 3-8. Thermal mixing is apparent as temperature and dissolved oxygen results are similar at surface and bottom sites. Frequent mixing or lack of a thermocline is also apparent in representative summer profiles from Wilson Lake (Figure 3-48). Profiles from upper and lower lake sites in July 2015 are typical with no signs of thermal stratification. The second set of profiles collected in August 2017 represent the most stratified conditions observed during the 10-year analysis period. The presence of oxygen in bottom layers increases available habitat for aquatic species and decreases the rate of enrichment of hypolimnetic waters with phosphorus and metals released at lower rates from lake sediments in the presence of oxygen (Jensen et al. 1992).

Table 3-7. Wilson Lake Summary statistics for chemical water quality parameters 2010-2019.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.05	0.01	0.05	0.19	0.02	0.01	60
Ammonia (mg/L)	Bottom	0.02	0.01	0.02	0.08	0.02	0.01	13
NO3/NO2 (mg/L)	Surface	0.06	0.02	0.13	0.66	0.01	0.01	60
NO3/NO2 (mg/L)	Bottom	0.23	0.07	0.25	0.60	0.09	0.01	13
TKN (mg/L)	Surface	0.70	0.03	0.22	1.50	0.69	0.30	60
TKN (mg/L)	Bottom	0.70	0.12	0.43	1.40	0.64	0.14	13
Total Nitrogen (mg/L)	Surface	0.72	0.03	0.27	1.51	0.71	0.01	60
Total Nitrogen (mg/L)	Bottom	0.89	0.11	0.41	1.49	1.06	0.15	13
Total Phosphorus (mg/L)	Surface	0.04	0.01	0.05	0.29	0.02	0.01	60
Total Phosphorus (mg/L)	Bottom	0.02	0.01	0.02	0.06	0.02	0.001	13
Total Orthophosphate (mg/L)	Surface	0.01	0.00	0.00	0.01	0.01	0.01	60
Total Orthophosphate (mg/L)	Bottom	0.01	0.001	0.001	0.02	0.001	0.001	13
Total Suspended Solids (mg/L)	Surface	3.94	0.24	1.82	9.20	3.60	1.60	60
Total Suspended Solids (mg/L)	Bottom	14.25	3.59	15.25	68.00	9.50	2.20	13
Total Organic Carbon (mg/L)	Surface	6.18	0.45	2.42	11.00	6.70	1.30	29
Total Organic Carbon (mg/L)	Bottom	7.62	0.35	1.46	11.00	7.20	6.20	17
Chlorophyll a (ug/L)	Photic Zone	3.89	0.52	4.16	17.60	2.80	0.16	60
Total Chloride (mg/L)	Surface	734.51	52.25	350.49	1380.00	700.00	243.00	45
Total Chloride (mg/L)	Bottom	962.29	61.86	163.67	1120.00	969.00	627.00	7
Total Sulfate (mg/L)	Surface	605.46	18.93	150.27	983.00	626.00	313.00	60
Total Sulfate (mg/L)	Bottom	634.11	25.59	108.57	822.00	650.00	468.00	18
Total Iron (ug/L)	Surface							NA
Total Iron (ug/L)	Bottom	249.5	27.21	54.41	330.00	229.00	210.00	4
Total Manganese (ug/L)	Surface							NA
Total Manganese (ug/L)	Bottom	146.75	45.45	90.90	263.00	127.00	70.00	4

Notes: *SE = Standard Error; ** SD = Standard Deviation

[1/]Summary statistics for chemical water quality parameters from Wilson Lake site near the dam (WI-15A), April 2010 through September 2019.

Table 3-8. Wilson Lake Summary Statistics for Physical Water Quality Parameters 2010-2019.

Parameter	Sample Depth	Mean	SE*	SD*	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	8.4	0.07	1.3	12.3	8.1	5.8	252
Oxygen, Dissolved (mg/l)	Bottom	7.0	0.2	2.4	11.9	7.0	0.1	197
pH (Standard Unites)	Surface	8.2	0.03	0.3	9.0	9.3	6.7	83
pH (Standard Unites)	Bottom	8.1	0.03	0.3	8.8	8.1	7.1	68
Salinity (‰)	Surface	2.4	0.1	0.5	2.9	2.4	1.2	34
Salinity (‰)	Bottom	2.5	0.1	0.4	2.9	2.7	1.6	34
Secchi Depth (m)	Surface	1.5	0.1	0.8	4.0	1.4	0.3	113
Specific Conductance (µS/cm)	Surface	3814.0	85.9	782.5	5058.0	3478.0	1751.0	83
Specific Conductance (µS/cm)	Bottom	3561.0	103.3	851.7	5056	3270.0	1590.0	68
Turbidity, Field (NTU)	Surface	8.2	0.03	0.3	34.9	1.6	0.5	81
Turbidity, Field (NTU)	Bottom	16.9	3.2	26.3	146.3	7.5	0.5	68
Water Temperature (ºC)	Surface	21.6	0.4	5.9	29.6	24.0	6.7	252
Water Temperature (ºC)	Bottom	20.2	0.4	5.9	28.35	25.5	6.2	197

Notes: *SE = Standard Error; ** SD = Standard Deviation
[1/]Summary statistics for physical water quality parameters, from all sites and dates, Wilson Lake, April 2010 through September 2019.

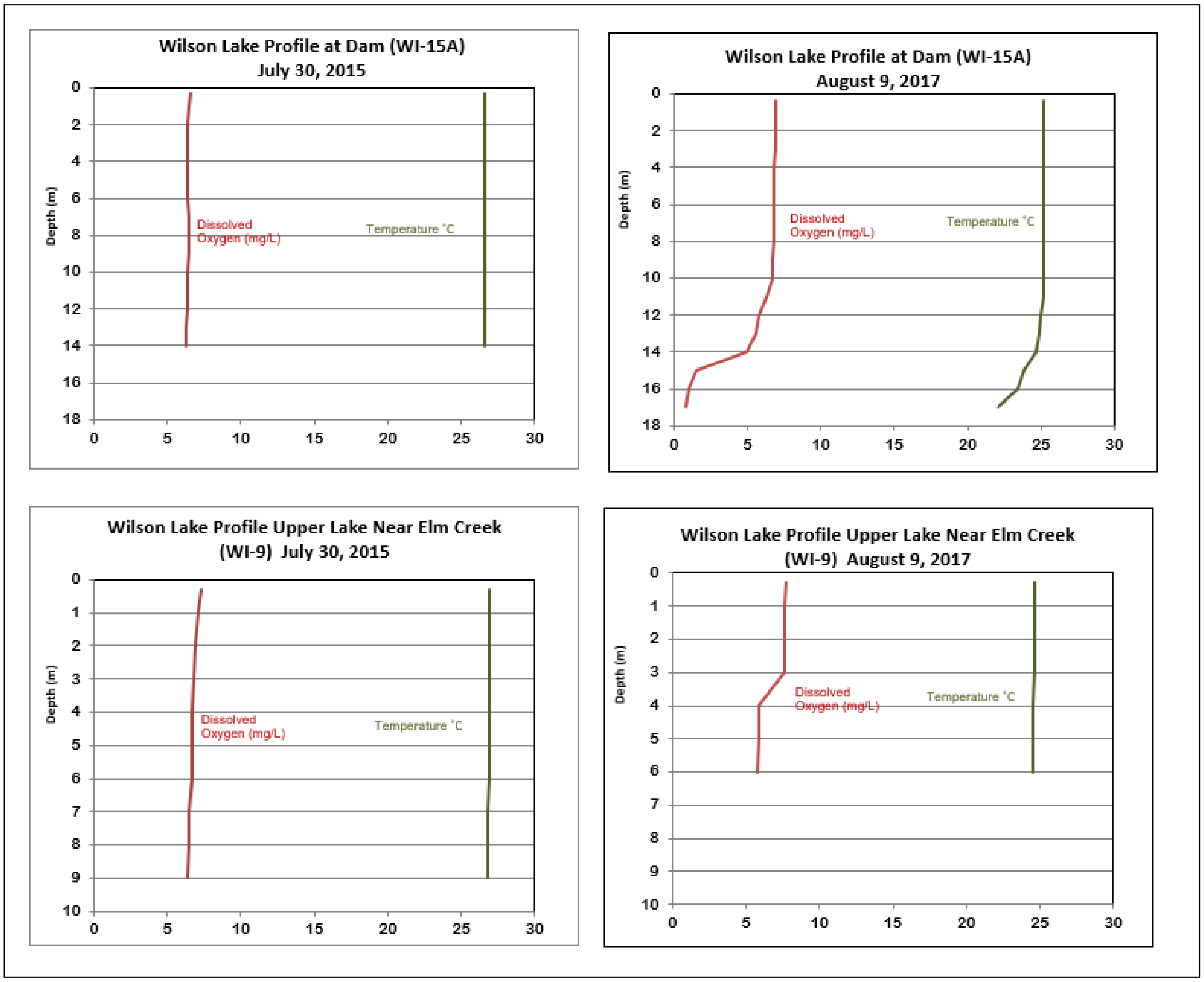


Figure 3-48. Wilson Lake Representative Temperature and Dissolved Oxygen Profiles.
Representative temperature and dissolved oxygen profiles from lower and upper Wilson Lake USACE water quality sample sites from 2015 and 2017.

Phytoplankton community at Wilson Lake has not been sampled at regular intervals and cyanobacteria have not led to public health advisories as of 2022. KDHE results from 2006 and 2009 show species dominance shift as 77% green algae (Chlorophyta) was dominant single sample in 2006 (KDHE 2007) while cyanobacteria accounted for 77% of phytoplankton in single sample from 2009 (KDHE 2010). USACE samples show similar results with cyanobacteria and diatoms comprising the highest percent composition from intensive surveys of 2014 and 2017 (Figure 3-49) with low cell densities typically less than 50,000 cells/mL (USACE unpublished data 2014, 2017). Cell count and biovolume units of measure were both reported in 2014 samples highlighting the differences in the percent composition by biovolume (i.e. volume of a sample occupied by cells of one genera) and cell count (number of cells/mL) estimated from counts from subsamples. The August 2014 sample in figure 3-49 illustrates that higher cell counts of smaller cells (e.g. blue-green algae) may not be what is visually dominant in a sample (i.e. biovolume). While cell count for sum of all cyanobacteria (56,179 cell/mL) in August sample below is nearly ten times diatom cell count (5,765 cell/mL), the larger diatoms in the sample are visually dominant due to biovolume they occupy. Algal toxins microcystin, cylindrospermopsin, and anatoxin-a were not detected above minimum reporting limit (<0.15 ug/L) in 2014 and 2017 samples.

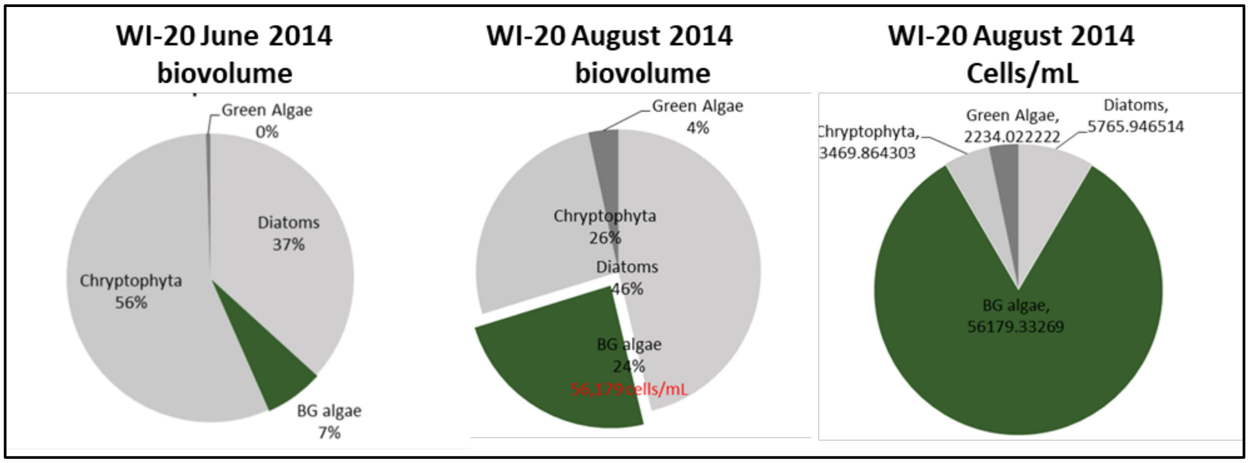


Figure 3-49. Wilson Lake Select phytoplankton composition graphs. *Select phytoplankton composition graphs from lower and upper Wilson Lake USACE water quality sample sites from 2014 intensive survey.*

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or "recycle" nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). A unified approach for sediment quality assessment based on freshwater ecosystem effects (MacDonald et al., 2000) allows lake owners, management agencies, and regulatory agencies to make informed decisions based on consensus-based concentration thresholds derived from aquatic toxicology data and EPA recommendations for common metals found in USACE Kansas City District lakes.

Median concentrations of nitrogen, phosphorus, manganese, and iron from Wilson Lake bed samples ranked lowest of seven Kansas City District Lakes in the Kansas River watershed (Figure 3-15). Wilson Lake sediment concentrations (Table 3-9) of arsenic, cadmium, and nickel exceeded the respective threshold-effects guidelines (MacDonald et al., 2000) in which toxic biological effects occasionally occur. This is typical for reservoirs in eastern Kansas (Juracek, 2003, 2004; Juracek and Mau, 2002). Metal and trace element concentrations reported in Kansas City District bed sediment results (Table 3-9) did not exceed the "probable effect concentration" (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000).

Table 3-9 Wilson Lake bed sediment chemical concentration in sediment 2010-2019.

Station	Date mm/dd/yyyy	Time hhmm	Ammonia MG/KG	Nitrate-Nitrite Nitrogen MG/KG	Total Kjeldahl Nitrogen MG/KG	Phosphorus MG/KG	Arsenic MG/KG	Copper MG/KG	Iron MG/KG	Lead MG/KG	Manganese MG/KG	Nickel MG/KG	Zinc MG/KG	Cadmium MG/KG	Chromium MG/KG	Total Solids %
WI-20	9/14/2017	1300	8.0	<2.5	413	216	4.6	4.8	10500	6.3	194	9.8	24.8	0.22	6.9	67.2
WI-9	9/14/2017	1200	37.0	<2.5	1760	547	9.6	20.3	21000	20.4	410	31.7	99.3	1.2	23.0	36.2
WI-13	9/14/2017	1130	117	<7.2	1970	558	12.3	19.4	23800	20.8	614	31.5	111	0.83	23.7	25.9
WI-15A	9/14/2017	1100	36.4	<2.8	661	314	6.2	11.6	15800	10.6	205	17.5	34.2	0.34	14.6	55.7

3.1.4 Kanopolis Lake

Kanopolis Lake (3,406 acre) is the oldest USACE lake in Kansas, built on the Smoky Hill River in 1948. Located 141 miles downstream from Cedar Bluff Lake, Kanopolis Lake is operated for flood control, downstream water quality, and public water supply. The primary water quality threats are best described by current KDHE TMDL for eutrophication from non-point nutrient sources, failing onsite waste-water systems (KDHE 2011b), and chloride and sulfate originating from natural sources in the Dakota Aquifer with some augmentation by oil-field brine (KDHE 2004).

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics related to flow (i.e., volume, load, and concentration), water residence time, and lake mixing/stratification which in turn influence physical and chemical processes, frequently resulting in biological responses. Figure 3-50 illustrates Kanopolis Lake hydrologic data with overlay of water quality samplings events.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September). Low inflow and lake level below conservation pool was observed at the end of 2012 with surface elevation falling below 1,456 ft while recovery period is apparent in spring of 2013. Significant flooding and corresponding high-water period in 2019 followed inflows exceeding 13,000 cfs. Surface elevation of Kanopolis Lake peaked at 33 ft above conservation-pool elevation (CPE) and exceeded CPE for 268 days in 2019.

Kanopolis Lake average water residence time of 4.5 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Kanopolis Lake average water residence time is below average of 10.8 months for 7 USACE Kansas River Watershed lakes in this study. Short residence times can lead to pronounced seasonal shifts and dynamic water quality at Kanopolis Lake with less time allowed for dilution, settling, and biological attenuation of sediment, nutrients, and other contaminants.

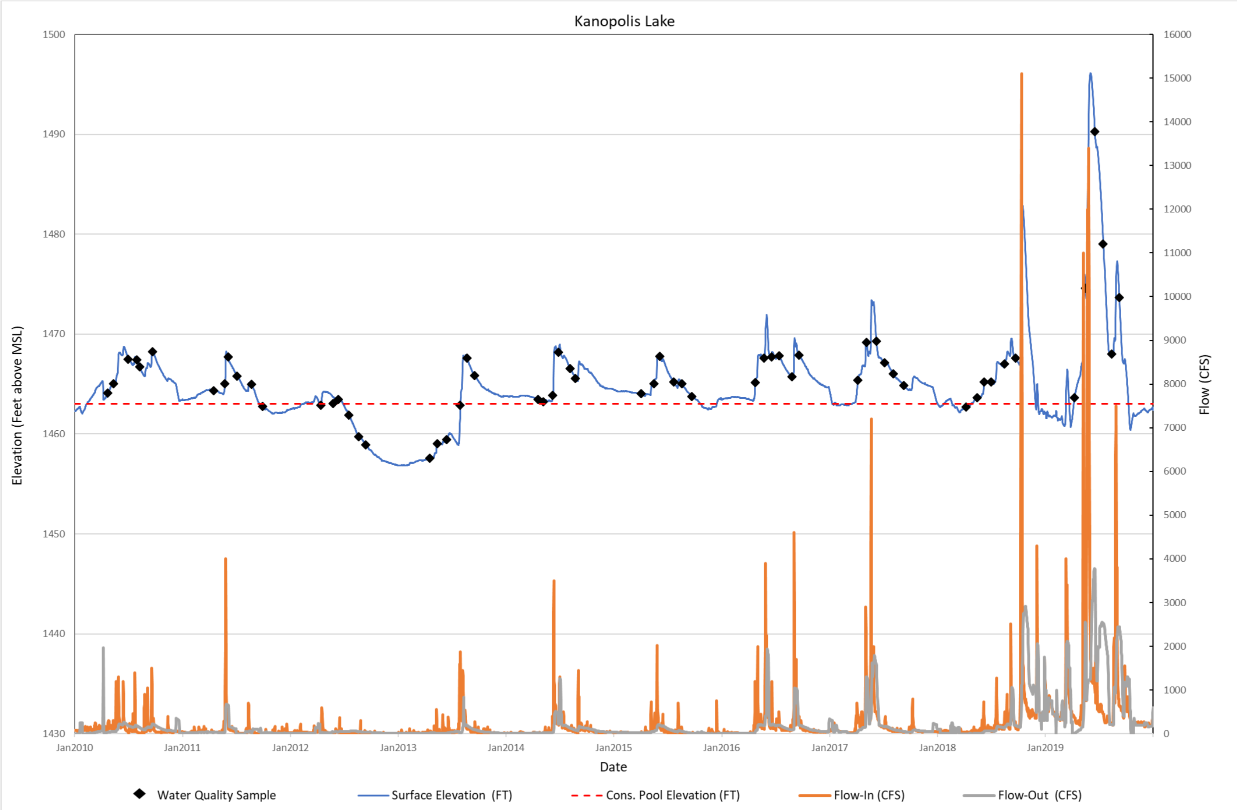


Figure 3-50. Kanopolis Lake Time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Water Quality Sample Locations

Historic water quality sample sites at Kansas City District lake projects are generally named in decreasing numeric order from inflow sites to the outflow site below the dam (Figure 3-51). Inflow sites KA-20 and KA-14 are both on Smoky Hill River. Inflow KA-20 was chosen to document influence from the city of Russel, KS on stream water quality and located approximately 64 miles upstream of the lake boundary. To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

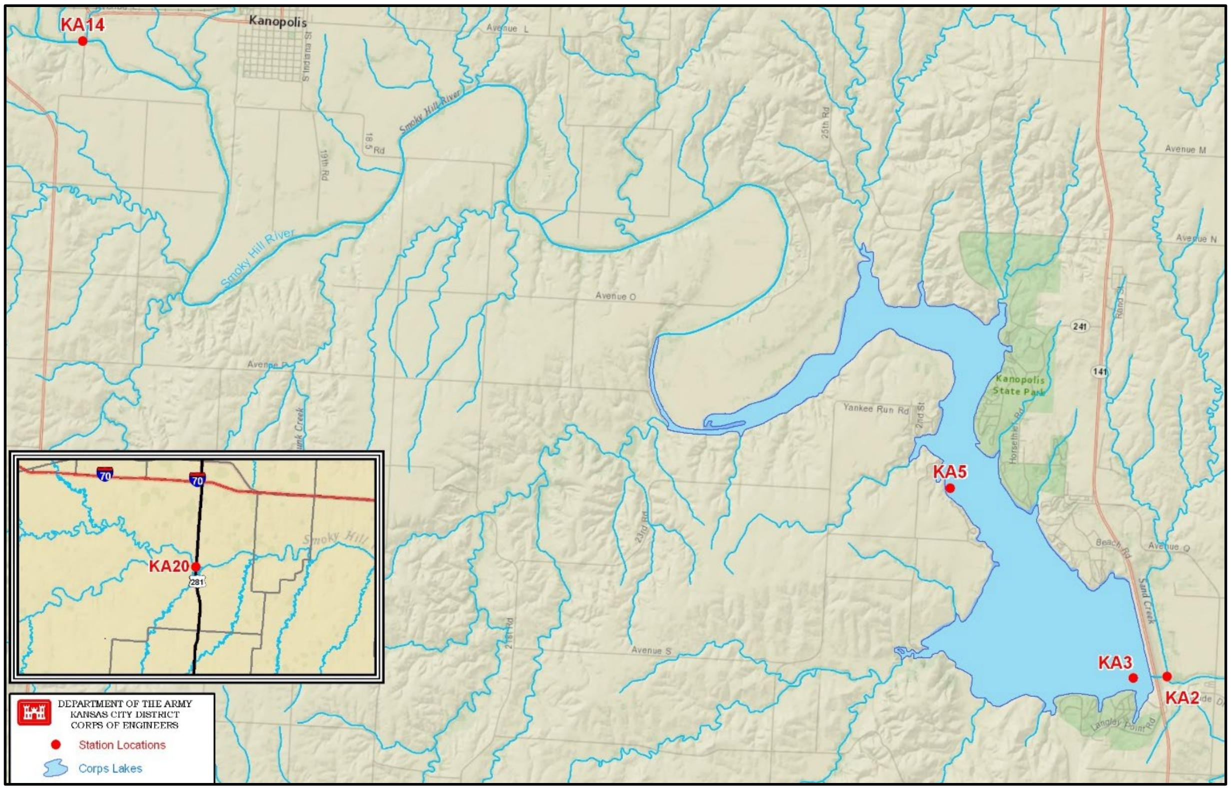
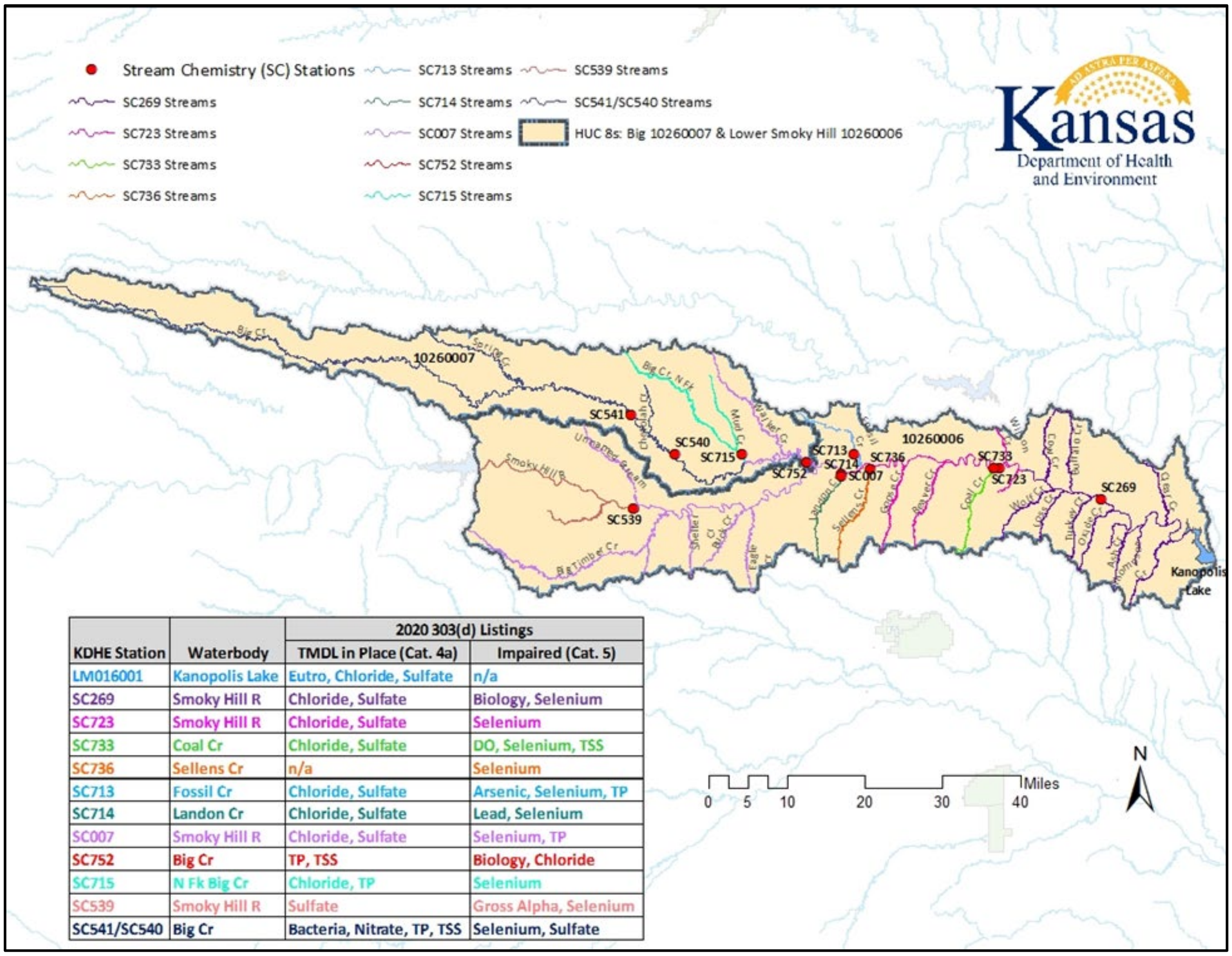


Figure 3-51. Kanopolis Lake USACE water quality sample sites. *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow*

Impairments

The Kanopolis Lake watershed includes eleven impaired stream segments listed on the 2020 303(d) list (Figure 3-52) mostly associated with discharge of saline groundwater from the Dakota aquifer and naturally occurring selenium (KDHE 2004). Elevated salinity and nutrients have led to established TMDLs for most of the Kanopolis Lake watershed (Figure 3-52). The ultimate endpoint for this TMDL will be to achieve the Kansas Water Quality Standards fully supporting Drinking Water Use according to current EPA standard of 250 mg/L of chloride used to establish the TMDL. The elevated background of chloride plus additional inputs from brine discharge in Russell County, consistently above 250 mg/L, makes achievement of the Standard unlikely at lower flow conditions at mainstem Smoky Hill River KDHE sample stations 007, 269, and 723 (Figure 3-52). The specific stream criteria to supplant the general standard low-flow standard is planned to be developed in subsequent phases of 303(d) process (KDHE, 2004). Impairments listed above do not extend below Kanopolis Lake.

The approved WRAPS plan for Big Creek and Middle Smoky Hill River Watersheds (BCMSHRW), which includes Kanopolis Reservoir, outlines a range of prioritized watershed issues providing opportunities and a functional mechanism for regional entities to improve water quality. The Kanopolis Lake eutrophication TMDL is targeted for nutrient and sediment reduction measures by the active WRAPS group.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM016001	Kanopolis Lake	Eutro, Chloride, Sulfate	n/a
SC269	Smoky Hill R	Chloride, Sulfate	Biology, Selenium
SC723	Smoky Hill R	Chloride, Sulfate	Selenium
SC733	Coal Cr	Chloride, Sulfate	DO, Selenium, TSS
SC736	Sellens Cr	n/a	Selenium
SC713	Fossil Cr	Chloride, Sulfate	Arsenic, Selenium, TP
SC714	Landon Cr	Chloride, Sulfate	Lead, Selenium
SC007	Smoky Hill R	Chloride, Sulfate	Selenium, TP
SC752	Big Cr	TP, TSS	Biology, Chloride
SC715	N Fk Big Cr	Chloride, TP	Selenium
SC539	Smoky Hill R	Sulfate	Gross Alpha, Selenium
SC541/SC540	Big Cr	Bacteria, Nitrate, TP, TSS	Selenium, Sulfate

Figure 3-52. Kanopolis Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Kanopolis Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Inflow/Outflow

Lakes and reservoirs store suspended particles and soluble chemicals enter reservoirs from runoff, groundwater, and inflow streams. Different sediment, nutrient, contaminant, and geological sources in the watershed and associated inflows influence lake water quality including water clarity, nutrient concentration, chemical contamination, and element ratio or nutrient balance in receiving waters. These factors also have implications for biological response in the streams and receiving waters including trophic state and which type of algae dominate the primary production in the system.

Water exiting through the dam or outlet works of Corps' lakes can be quite different than the inflows as large amounts of nutrients, pesticides, and metals are processed and/or stored in the lake causing a sink effect (Satoh et al., 2002). Chemical compounds solubilized under anoxic conditions when lakes are thermally stratified are seasonal exceptions to this trend. Low dissolved oxygen concentrations in outflows due to release of anoxic water during stratified periods and supersaturation during flood releases degrade water quality and can be stressful or lethal to aquatic life below dams.

Atrazine is the most common herbicide detected in Kanopolis Lake inflows and outflow. Herbicides are not currently listed as impairments for Kanopolis Lake by KDHE. The median of inflow sample results for total atrazine at the inflow sites are below the EPA drinking water criteria of 3 ug/L while no samples from the outflow exceed this criterion (Figure 3-53).

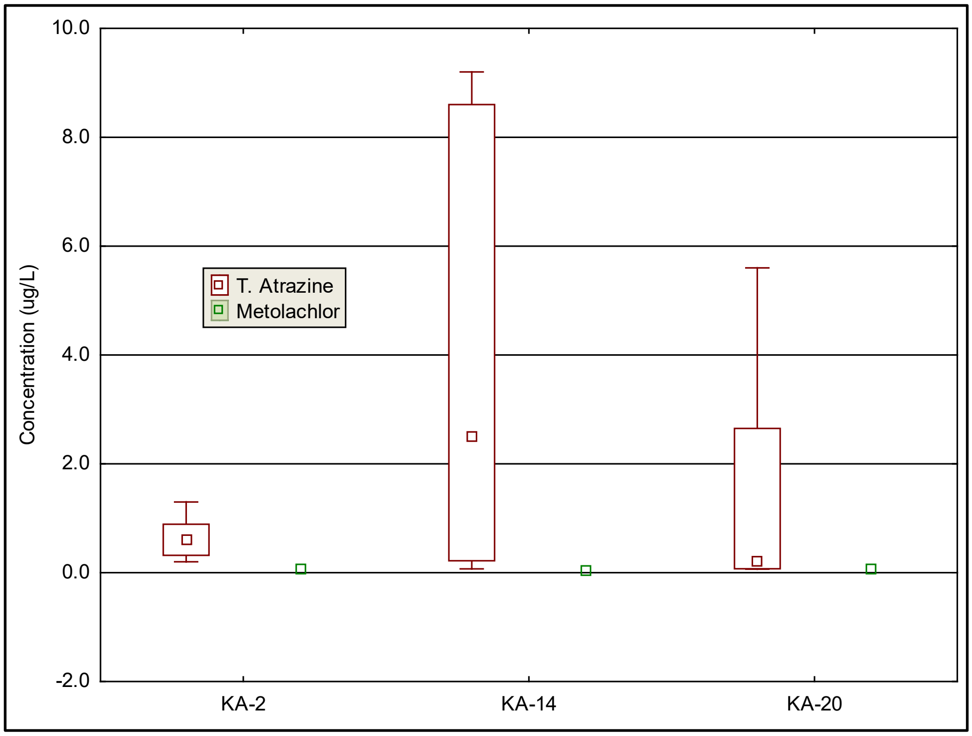


Figure 3-53. Herbicide concentration upstream and downstream of Kanopolis Lake from 2010-2019. *Herbicide concentration from surface samples taken from Kanopolis Lake outflow (KA-2) and inflows (KA-14 and KA-20) at USACE water quality sample sites collected from 2010-2019.*

Inflows into Kanopolis Lake carry high nutrient loads (Figure 3-53) associated with sediment and non-point source nutrients. Median total nitrogen and organic nitrogen (TKN) measured at inflow sites exceed the 75th percentile (Q3) found in the outflow which is indicative of significant biological attenuation and denitrification occurring in Kanopolis Lake. Ammonia and orthophosphate are two soluble nutrients where export exceeds input or where median values measured in export samples exceed respective median values in inflows. Three outliers observed in inflow nutrients (TP and NO_3) in Figure 3-54 are associated with sampling in proximity of runoff or rain events.

Water clarity is greatly improved from the duration residency in Kanopolis Lake. Median turbidity and total suspended solids are up to three times greater at inflow sites than the outflow (Figure 3-55). Suspended particles and sediment settle and accumulate in Kanopolis Lake improving water clarity metrics at the outflow site.

Ten-year median chloride and sulfate concentrations from USACE samples collected at the outflow site below Kanopolis Lake (Fig 3-54) do not exceed EPA drinking water standards and are diluted by numerous tributaries in the 64 river miles separating upper inflow sites and Kanopolis Lake. Smoky Hill River chloride sample medians are 2-3 times greater than the outflow site.

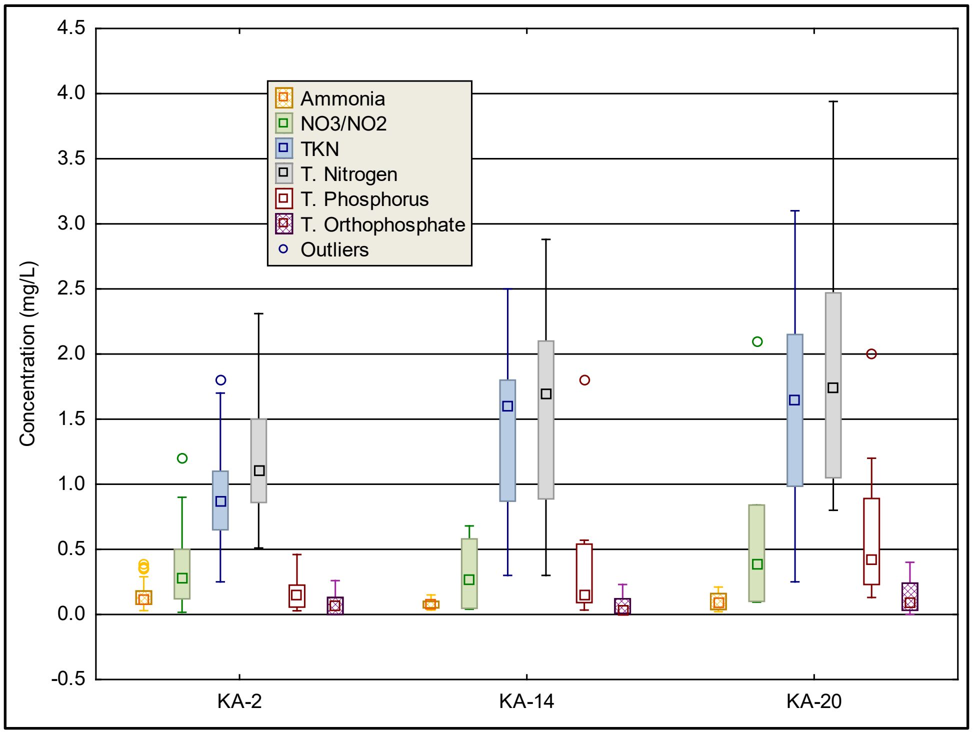


Figure 3-54. Nutrient Concentrations upstream and downstream of Kanopolis Lake from 2010-2019. *Nutrient concentration from surface samples taken from Kanopolis Lake outflow (KA-2) and inflows (KA-14 and KA-20) at USACE water quality sample sites collected from 2010-2019.*

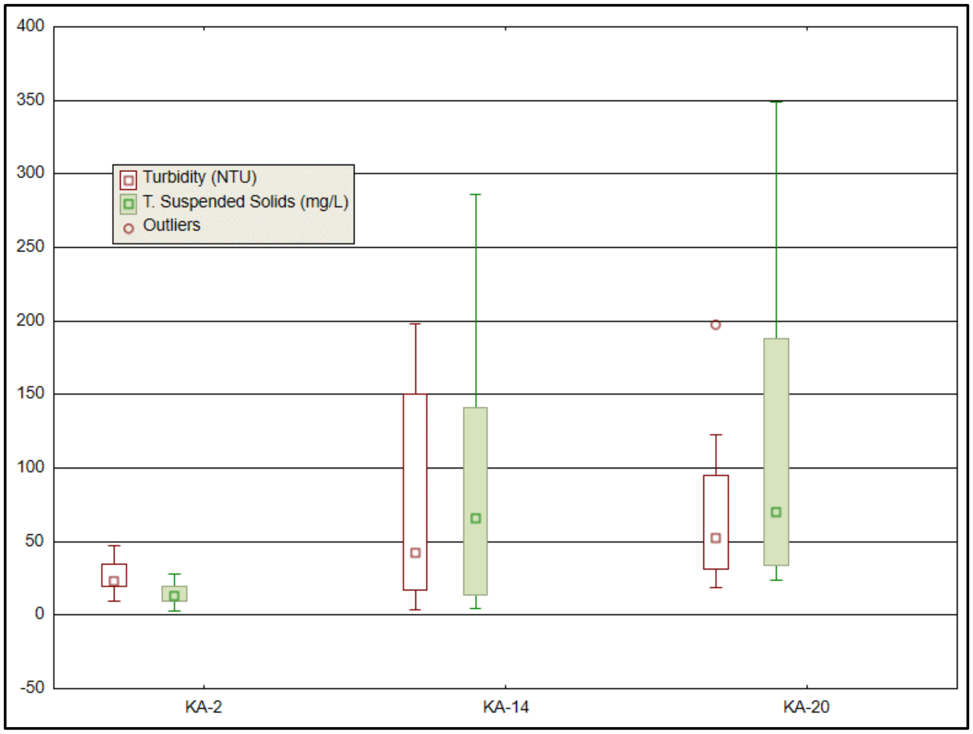


Figure 3-55. Water Clarity Influences upstream and downstream of Kanopolis Lake from 2010-2019. *Water clarity influences measured from Kanopolis Lake outflow (KA-2) and inflows (KA-14 and KA-20) at USACE water quality sample sites collected from 2010-2019.*

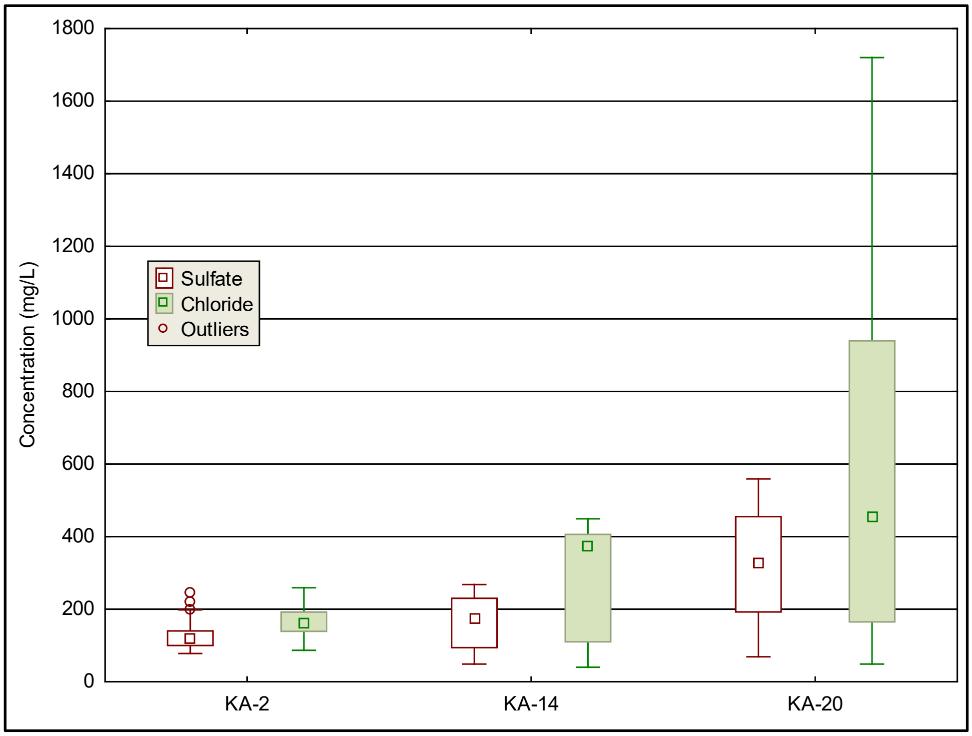


Figure 3-56. Naturally Occurring Salts upstream and downstream of Kanopolis Lake from 2010-2019. *Naturally occurring salts measured from Kanopolis Lake outflow (KA-2) and inflows (KA-14 and KA-20) at USACE water quality sample sites from 2010-2019.*

Lake Water Quality

Nutrient rich runoff and naturally occurring salts in the watershed lead to water quality problems at Kanopolis Lake linked to TMDLs for eutrophication and chloride/sulfate ions as described by 303d listing by KDHE. KDHE WRAPs have modeled phosphorus and nitrogen load reductions of 48% to 52% respectively, are needed in Big Creek Middle Smoky Hill River Watersheds to meet TMDL goals for Kanopolis Lake (Kanopolis Reservoir- Big Creek Middle Smoky Hill River Watersheds 9 Element Watershed Protection Plan, 2011b). Increased nutrients and sediment accumulating in Kanopolis Lake will lead to a decline in water quality and reduced storage capacity for water use. This age-related process makes older reservoirs more susceptible to contamination and internal loading of nutrients, metals and compounds stored in lake bed sediment (Juracek, 2014).

Physical and chemical attenuation (e.g., dilution, dispersion, chemical changes, and uptake by organisms) of compounds and settling of suspended matter leads to a general decrease in concentration of many constituents of water quality, often interpreted as improved water quality, as water moves through a reservoir system (Bosch et al., 2009). This process will be evident with many analytes in graphic representations in lake water quality sections. The following section is an overview of chemical and physical data from surface samples from 2 lake sites. Chemical and physical differences between surface and bottom strata at the site near the dam and stratification are described along with a brief description of available phytoplankton and cyanobacteria data related to public health advisories.

Herbicides are detected in relatively low concentrations in Kanopolis Lake samples. Two common herbicides detected in samples include atrazine which did not exceed EPA recommendations for maximum exposure of 3 ppb in samples collected from 2010-2019 (Figure 3-57) and low frequency and low concentration of metolachlor also detected at levels well below the few existing exposure guidelines (i.e., Canada limit 50 ppb of metolachlor).

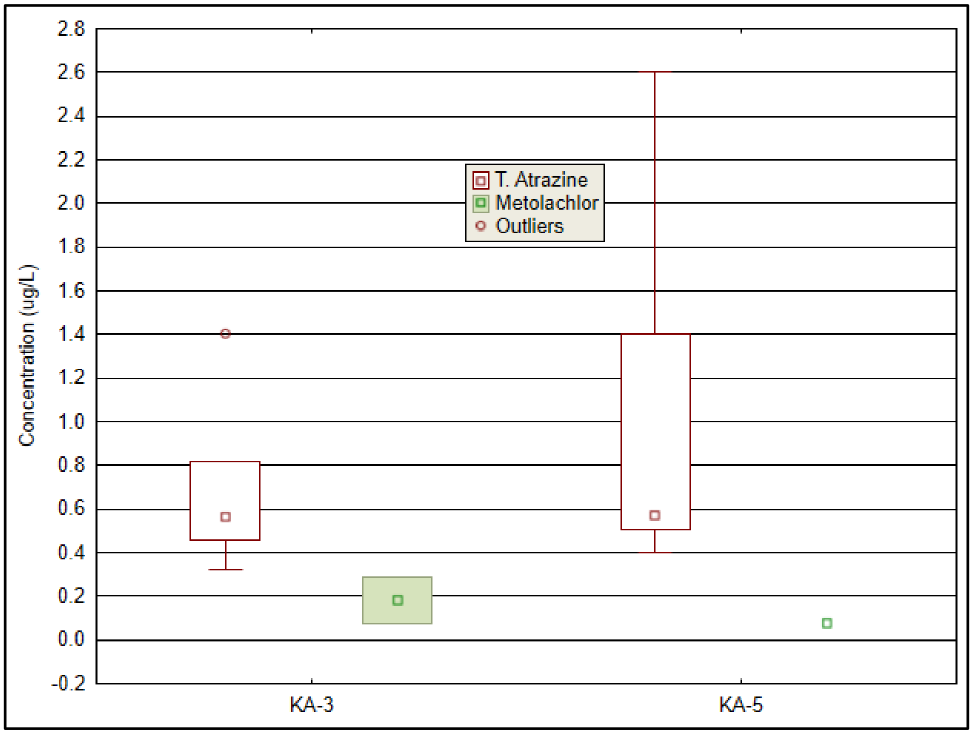


Figure 3-57. Kanopolis Lake Herbicide Concentration from 2010-2019. *Surface samples taken from Kanopolis Lake USACE water quality sample sites collected from 2010-2019.*

Excess nutrients are the primary impact to water quality at Kanopolis Lake as indicated by eutrophication TMDL targeted to reduce phosphorus loading associated with soil erosion and farming practices as well as permitted discharges. Phosphorus concentrations are typically in the top 5 of 18 Kansas City District lakes (Figure 3-1).

Total nitrogen and organic nitrogen (TKN) concentrations decreases slightly from the upper lake site to the dam (Figure 3-58). Kanopolis is relatively linear with less than 4 miles between standardized upper and lower lake sites. Attenuation and denitrification/biological uptake occur, but on a smaller scale than many of the larger reservoirs in the District. Median bioavailable forms of nitrate/nitrite and ammonia were similar between sample sites.

Total phosphorus and soluble orthophosphate concentrations (Figure 3-58) declined and were less variable at lower lake site KA-3 near the dam. However, mean and median total phosphorus from 10-year reporting period (Table 3-10) exceeded hypereutrophic threshold of 0.09 mg/L (Carlson, 1977) as well as EPA Ecoregion recommendations.

Sulfate and Chloride concentrations rarely exceeded EPA drinking water criteria (250 mg/L) as measured at both standardized Kanopolis Lake sites (Figure 3-59). Median and interquartile range of sulfate and chloride were nearly identical between sites. Some outliers likely due to proximity to inflows, were recorded at upper lake site KA-5.

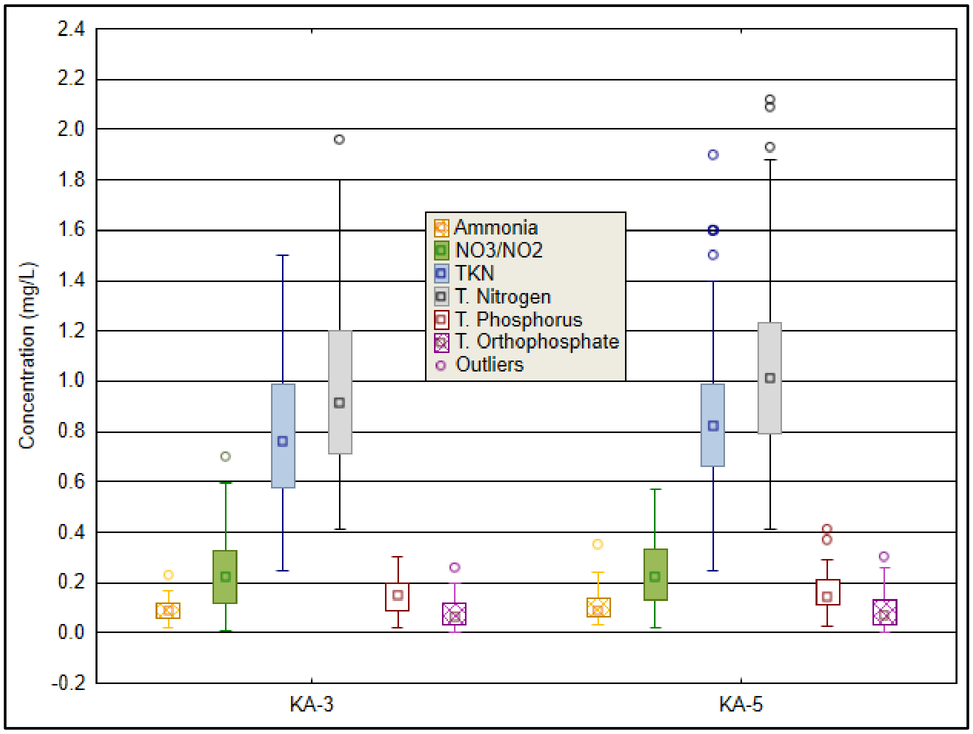


Figure 3-58. Kanopolis Lake Nutrient Concentrations from 2010-2019. *Nutrient concentration from surface samples taken from Kanopolis Lake USACE water quality sample sites collected from 2010-2019.*

Water clarity or transparency increases between upper and lower Kanopolis Lake sample locations (Figure 3-60). Median TSS and chlorophyll *a* are significantly lower at dam while median Secchi depth measurement is significantly greater than respective upper lake site values. Turbidity values are also typically lower at the lower lake site than upper lake site, but KA-3 median values do not fall below interquartile range of upper lake site turbidity.

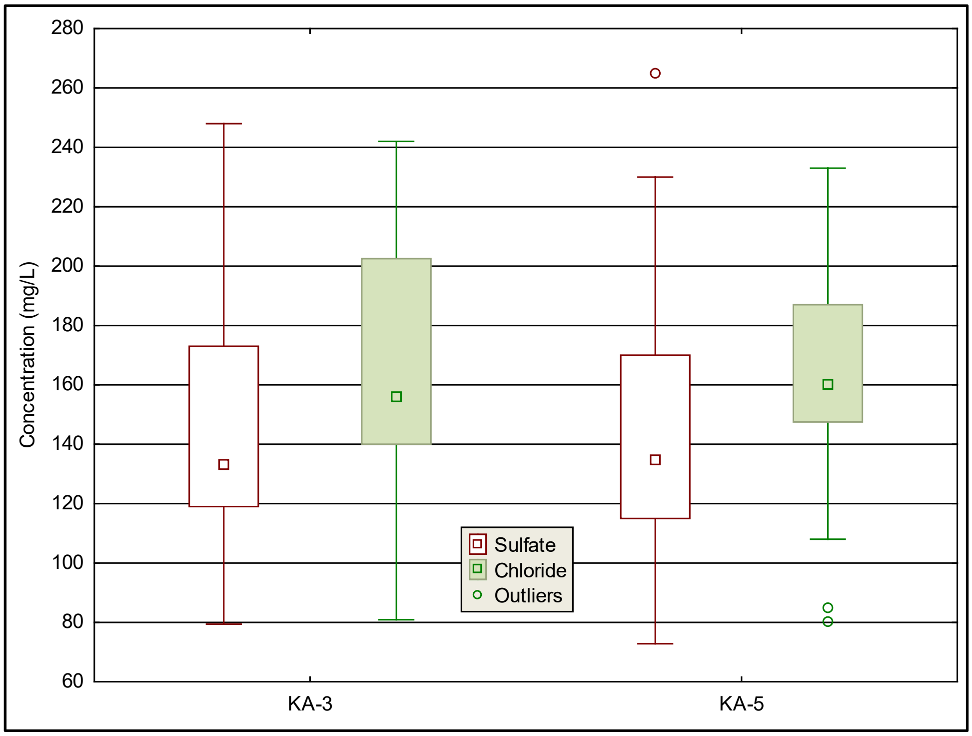


Figure 3-59. **Kanopolis Lake naturally occurring salts 2010-2019**. *Naturally occurring salts measured from Kanopolis Lake USACE water quality sample sites from 2010-2019.*

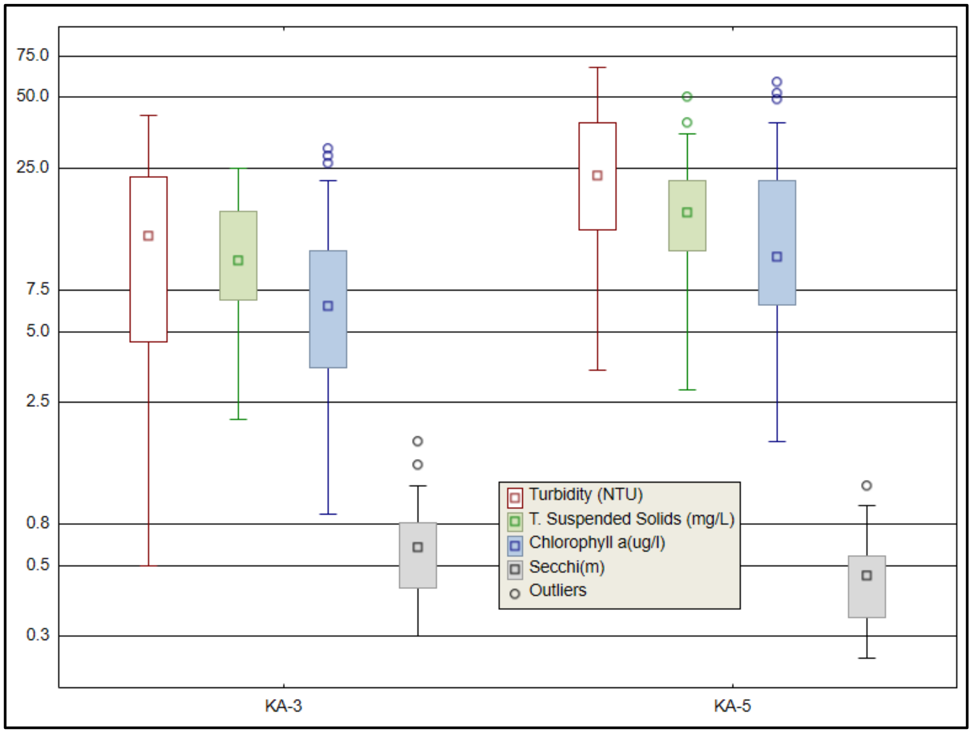


Figure 3-60. Kanopolis Lake Water Clarity Influences from 2010-2019. *Water clarity influences measured from Kanopolis Lake USACE water quality sample sites from 2010-2019.*

A summary of Kanopolis Lake descriptive statistics of chemical analysis results at site nearest the dam is found in Table 3-10. Bottom samples are typically collected from Kansas City District lakes every third year with total metals collected during peak stratified month of August when stratified conditions are most likely to influence metal solubility. During seasonal periods when the lake is mixed (not stratified), bottom sample results are nearly identical to surface sample results for most analytes. Anaerobic conditions allow for oxidation/reduction reactions to release chemical compounds, including metals, which can be elevated in bottom samples. Small sample size for metals results is related to three-year sample frequency for 10-year analysis period. Results below minimum detection level have been included in sample results as the value of half of the reported minimum detection limit to reduce bias based on the assumption that the analyte is present at a concentration below laboratory quantification (EPA, 1991).

Kanopolis water column is rarely stratified with obvious thermal and chemical mixing observed in surface to bottom results (Table 3-10). Significant differences ($p<0.05$) were detected between surface and bottom results for NO3/NO2, TSS, and total manganese.

Table 3-10. Kanopolis Lake Summary statistics for chemical water quality parameters 2010-2019.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.07	0.01	0.06	0.32	0.06	0.01	60
Ammonia (mg/L)	Bottom	0.10	0.02	0.06	0.21	0.08	0.02	12
NO3/NO2 (mg/L)	Surface	0.17	0.02	0.17	0.70	0.12	0.01	60
NO3/NO2 (mg/L)	Bottom	0.05	0.01	0.05	0.17	0.03	0.03	12
TKN (mg/L)	Surface	0.79	0.04	0.31	1.50	0.76	0.20	60
TKN (mg/L)	Bottom	0.75	0.09	0.29	1.10	0.88	0.15	12
Total Nitrogen (mg/L)	Surface	0.96	0.05	0.37	1.96	0.91	0.22	60
Total Nitrogen (mg/L)	Bottom	0.81	0.09	0.29	1.17	.090	0.20	12
Total Phosphorus (mg/L)	Surface	0.14	0.01	0.07	0.30	0.15	0.02	60
Total Phosphorus (mg/L)	Bottom	0.14	0.02	0.06	0.25	0.13	0.08	12
Total Orthophosphate (mg/L)	Surface	0.08	0.01	0.06	0.26	0.06	0.00	60
Total Orthophosphate (mg/L)	Bottom	0.07	0.02	0.07	0.20	0.05	0.003	12
Total Suspended Solids (mg/L)	Surface	11.88	1.29	10.03	76.00	9.40	1.00	60
Total Suspended Solids (mg/L)	Bottom	20.3	15.76	16.2	250.00	17.00	3.60	12
Total Organic Carbon (mg/L)	Surface	6.84	0.61	2.94	15.00	5.80	4.40	23
Total Organic Carbon (mg/L)	Bottom	5.25	0.33	1.06	7.70	5.15	3.70	10
Chlorophyll a (ug/L)	Photic Zone	9.47	1.34	9.60	53.10	6.40	0.83	51
Sulfate (mg/L)	Surface	145.86	5.15	39.25	248.00	133.00	79.41	58
Sulfate (mg/L)	Bottom	171.2	12.95	50.15	250.00	160.00	113.00	12
Chloride (mg/L)	Surface	164.44	10.07	45.02	242.00	156.00	70.90	20
Chloride (mg/L)	Bottom	164.60	7.85	17.56	184.00	173.00	141.00	5
Total Iron (ug/L)	Surface	523.00	93.95	162.72	696.00	500.00	373.00	3
Total Iron (ug/L)	Bottom	604.75	143.25	286.50	992.00	560.50	306.00	3
Total Manganese (ug/L)	Surface	559.20	485.59	841.07	1530.00	97.60	50.00	3
Total Manganese (ug/L)	Bottom							NA

Notes: *SE = Standard Error; ** SD = Standard Deviation
1/Summary statistics for chemical water quality parameters from Kanopolis Lake site near the dam (KA-3), April 2010 through September 2019.

Physical water quality data from profiles collected at Kanopolis Lake are presented in Table 3-11. Thermal mixing is apparent as temperature and dissolved oxygen results are similar at surface and bottom sites. Significant difference ($p<0.05$) between surface and bottom turbidity was detected as water quality profiles frequently found increased turbidity in the bottom meter of depth (Table 3-11) regardless of temperature and oxygen mixing. Frequent mixing or lack of a thermocline is apparent in a representative summer profile from Kanopolis Lake (Figure 3-61). The presence of oxygen in bottom layers increases available habitat for aquatic species and decreases the rate of enrichment of hypolimnetic waters with phosphorus and metals released at lower rates from lake sediments in the presence of oxygen (Jensen et al. 1992).

Table 3-11. Kanopolis Lake Summary statistics for physical water quality parameters 2010- 2019.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	8.0	0.1	1.4	11.7	7.8	4.5	115
Oxygen, Dissolved (mg/l)	Bottom	6.5	0.2	2.5	11.5	6.7	0.1	115
pH (Standard Units)	Surface	8.4	0.1	0.5	9.9	8.4	7.2	34
pH (Standard Units)	Bottom	8.4	0.1	0.7	10.0	8.3	7.7	33
Salinity (‰)	Surface	0.7	0.03	0.07	0.8	0.7	0.6	12
Salinity (‰)	Bottom	0.7	0.03	0.07	0.8	0.7	0.6	12
Secchi Depth (m)	Surface	0.5	0.02	0.05	1.3	0.5	0.2	102
Specific Conductance (µS/cm)	Surface	1146.0	46.0	268.3	1156.0	1208.0	709.7	34
Specific Conductance (µS/cm)	Bottom	1160.0	45.2	259.9	1555.0	1225.0	711.2	34
Turbidity, Field (NTU)	Surface	21.6	2.4	0.4	67	22.3	3.4	34
Turbidity, Field (NTU)	Bottom	139.3	58.1	328.6	1712.0	35.6	6.1	32
Water Temperature (°C)	Surface	20.6	0.6	6.9	31.2	22.8	5.8	115
Water Temperature (°C)	Bottom	21.9	0.5	5.4	29.8	23.4	7.5	115

Notes: *SE = Standard Error; ** SD = Standard Deviation
[1/]Summary statistics for physical water quality parameters, from all sites and dates, Kanopolis Lake, April 2010 through September 2019.

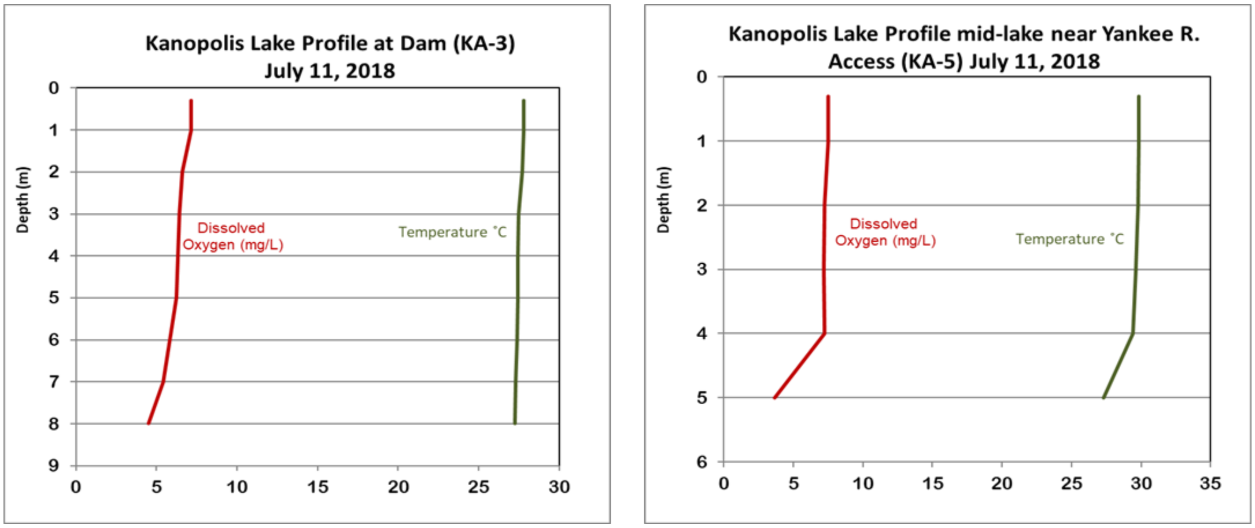


Figure 3-61. Kanopolis Lake Representative Temperature and Dissolved Oxygen Profiles. *Representative Temperature and Dissolved Oxygen Profiles measured at Kanopolis Lake USACE water quality sample locations on July 11, 2018***.**

Phytoplankton at Kanopolis Lake can historically be characterized as relatively low-density populations (<50,000 cells/mL) dominated seasonally by green algae (Chlorophyta), diatoms (Bacillariophyta) and infrequently by cyanobacteria from short lived blooms (KDHE 2007, KDHE 2010, USACE unpublished data 2014) (Figure 3-62). Kanopolis lake trophic state of is typically scores as eutrophic or slightly eutrophic based on algal chlorophyll TSI scores (KDHE 2010) but inorganic turbidity may impede algal growth (USACE unpublished data 2014).

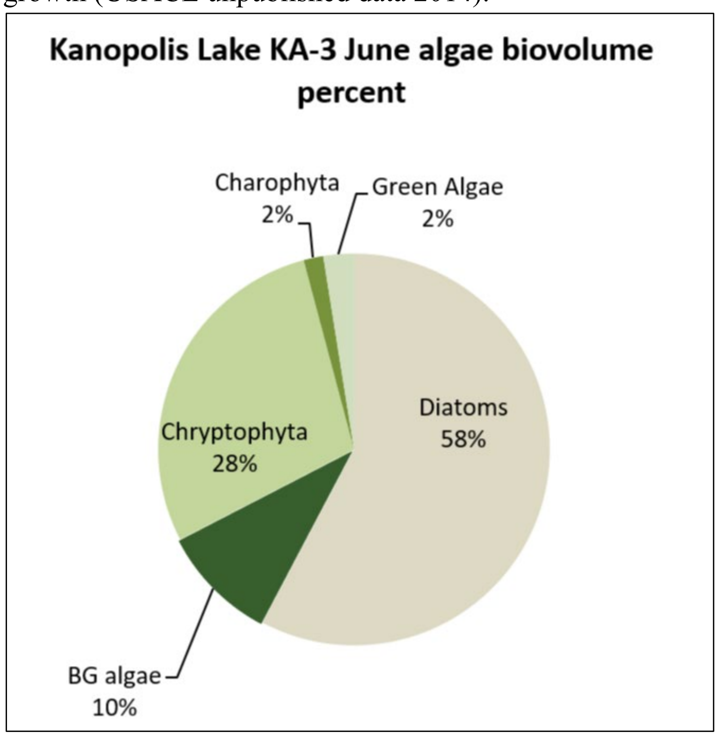


Figure 3-62. Kanopolis Lake KA-3 June 2014 Algae Biovolume Percentages.

Large inflows followed by an extended period of elevated lake level in 2019 (Figure 3-50) led to a nutrient pulse including high phosphorus levels up four times the 10-year median values (USACE. 2019). This nutrient pulse led to Kanopolis Lake experiencing the first HAB warnings since implementation of KDHE HAB Policy in 2011. The 2020 bloom was located near USACE managed public swim beaches and resulted in a 6-week beach closure during peak Covid-19 conditions with very high public use and limited sampling due to Covid policies. Results from USACE beach samples (Table 3-12) indicate that Veningo Beach (site name KA-V. Beach) exceeded KDHE warning threshold of 250,000 cells/mL.

Table 3-12. Kanopolis Lake Beach Cyanobacteria Samples Collected during 2020 HAB event.

STATION	SAMPLE DATE	GENUS	DIVISION	TALLY	DENSITY cells/L	TOTAL BV um^3/L	NOTES	cell/mL
KA SSSP Beach	6/8/2020	Aphanizomenon cf. flosaquae	Cyanobacteria	102	4.69E+07	2.82E+09		46917
KA SSSP Beach	6/8/2020	Microcystis sp.	Cyanobacteria	20	9.20E+06	4.39E+08		9199
		TOTAL		122	5.61E+07	3.26E+09		56116
KA-V.Beach	6/8/2020	Aphanizomenon sp.	Cyanobacteria	547	2.52E+08	1.42E+10		251603
		TOTAL		547	2.52E+08	1.42E+10		251603

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or "recycle" nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). Kansas City District Water Quality Program initiated collection of baseline lake sediment data at all District lakes in 2016 with 2018 the first opportunity to collect Kanopolis Lake samples (Table 3-13) in the standard 3-year intensive sampling rotation.

Nitrogen and phosphorus concentrations from Kanopolis Lake sediment samples were low to moderate when compared to results from a group of lakes from Southeast and Northern United States (Barko, J.W. and R.M Smart. 1986). Metal concentrations reported in Kansas City District lake bed sediment results (Table 3-13) did not exceed the "probable effect concentration" (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000).

Table 3-13. Kanopolis Lake bed sediment chemical concentrations 2018.

				Ammonia MG/KG	Nitrate-Nitrite MG/KG	Total Kjeldahl Nitrogen MG/KG	Phosphorus MG/KG	Arsenic MG/KG	Copper MG/KG	Iron MG/KG	Lead MG/KG	Manganese MG/KG	Nickel MG/KG	Zinc MG/KG	Cadmium MG/KG	Chromium MG/KG
KA-3	0.1	9/13/2018	1115	41.5	<4.1	<49.8	753	12.4	15.1	24300.0	17	935.0	22	74.1	0.3	20.60
KA-5	0.1	9/13/2018	1130	83.6	9.0	1380	920	11.4	24.3	31500	20.5	825	30.9	115	0.91	32.8

3.1.5 Perry Lake

Perry Lake is an 11,146 acre lake built on the Delaware River in Kansas reaching full pool in 1970. The primary water quality threats to Perry Lake are summarized by current Total Maximum Daily Load (TMDL) for eutrophication are nutrients enrichment with occasional dissolved oxygen problems due to infrequent algal blooms.

The Watershed Restoration and Protection Strategy (WRAPS) program is a KDHE planning and management tool used to identify watershed restoration and protection needs, establish management goals, establish plans (e.g., EPA approved 9-Element Watershed Plans) and implement goals to address water resource concerns (https://www.kdheks.gov/nps/wraps/). Most priority goals/targets of the WRAPS

Plans for subbasins in the Kanas River Watershed align with strategies and measures included in this study. The WRAPS process is in the implementation and monitoring phase of their process to administer programs using BMPs to reduce phosphorus loads originating in Kansas by 617,204 lbs/yr., nitrogen loads originating in Kansas by 2,341,263 lbs/yr and sediment load reduction goal of 32,999 tons/year.

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics like flow, water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological response.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September) (Figure 3-63). Dry/drought periods were observed at the end of 2012 and 2018 with surface elevation falling below 897 ft in spring of 2013. High water conditions when pool elevation exceeds conservation pool were evident nearly every summer at Perry Lake as outflows were managed to maintain conservation pool elevation. Significant flooding and corresponding high-water period were observed for most of 2019 as several inflow events measured at or above 20,000 cfs contributed to record pool elevations across the Midwest. Perry Lake peaked at 28 feet above conservation pool elevation in 2019.

Perry Lake average water residence time of 5.6 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Perry Lake average water residence time is below average of 10.8 months for 7 USACE Kansas River Watershed lakes in this study. Short residence times can lead to pronounced seasonal shifts and dynamic water quality at Perry Lake with less time allowed for dilution, settling, and biological attenuation of sediment, nutrients, and other contaminants.

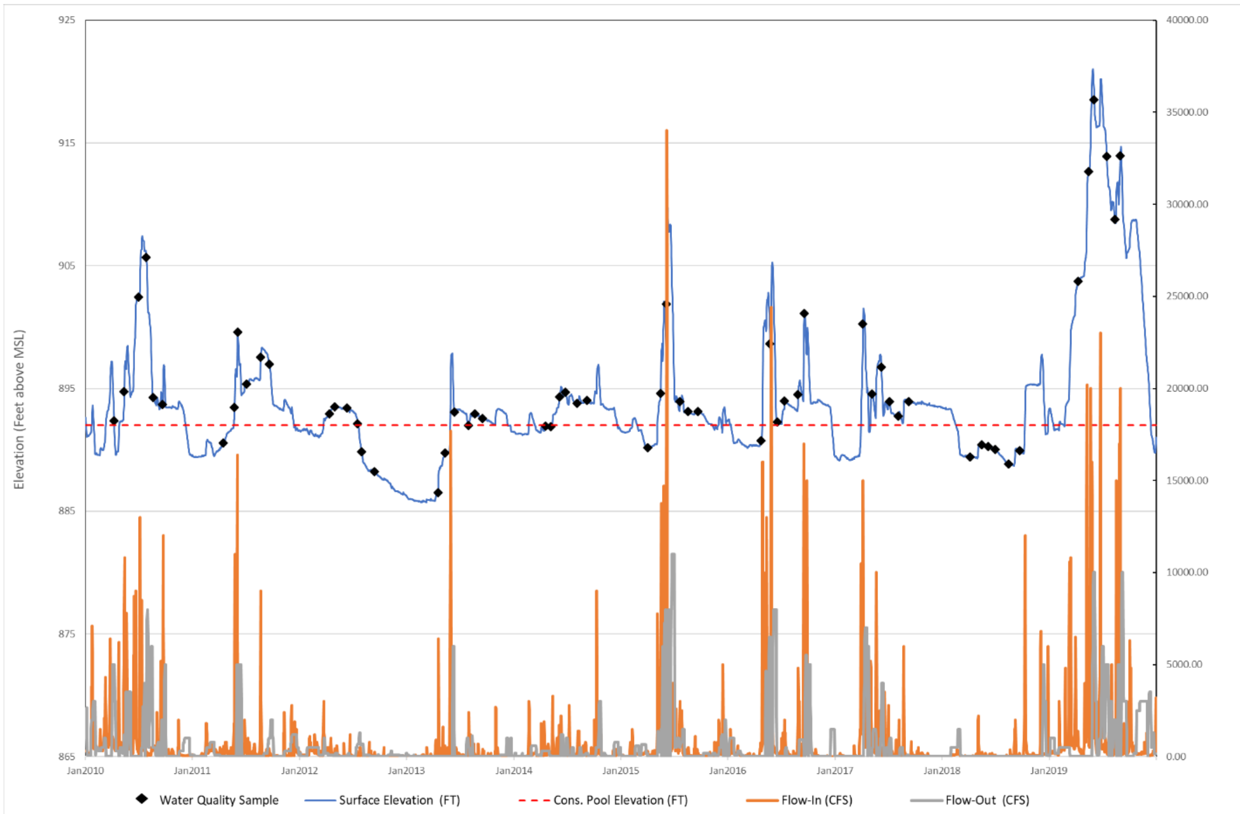


Figure 3-63. Perry Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Water Quality Sample Locations.

Historic water quality sample sites at Kansas City District Kansas City District lake projects are generally named in decreasing numeric order from inflow sites to the outflow site below the dam (Figure 3-64). Perry Lake has 3 extra inflow sites which were monitored to provide additional data for KDHE WRAPS planning efforts during development of EPA 9-Element Watershed Plan and provide additional support of impaired waters monitoring in the upper watershed. KDHE HAB management zones are included in Figure 3-64 for reference. To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

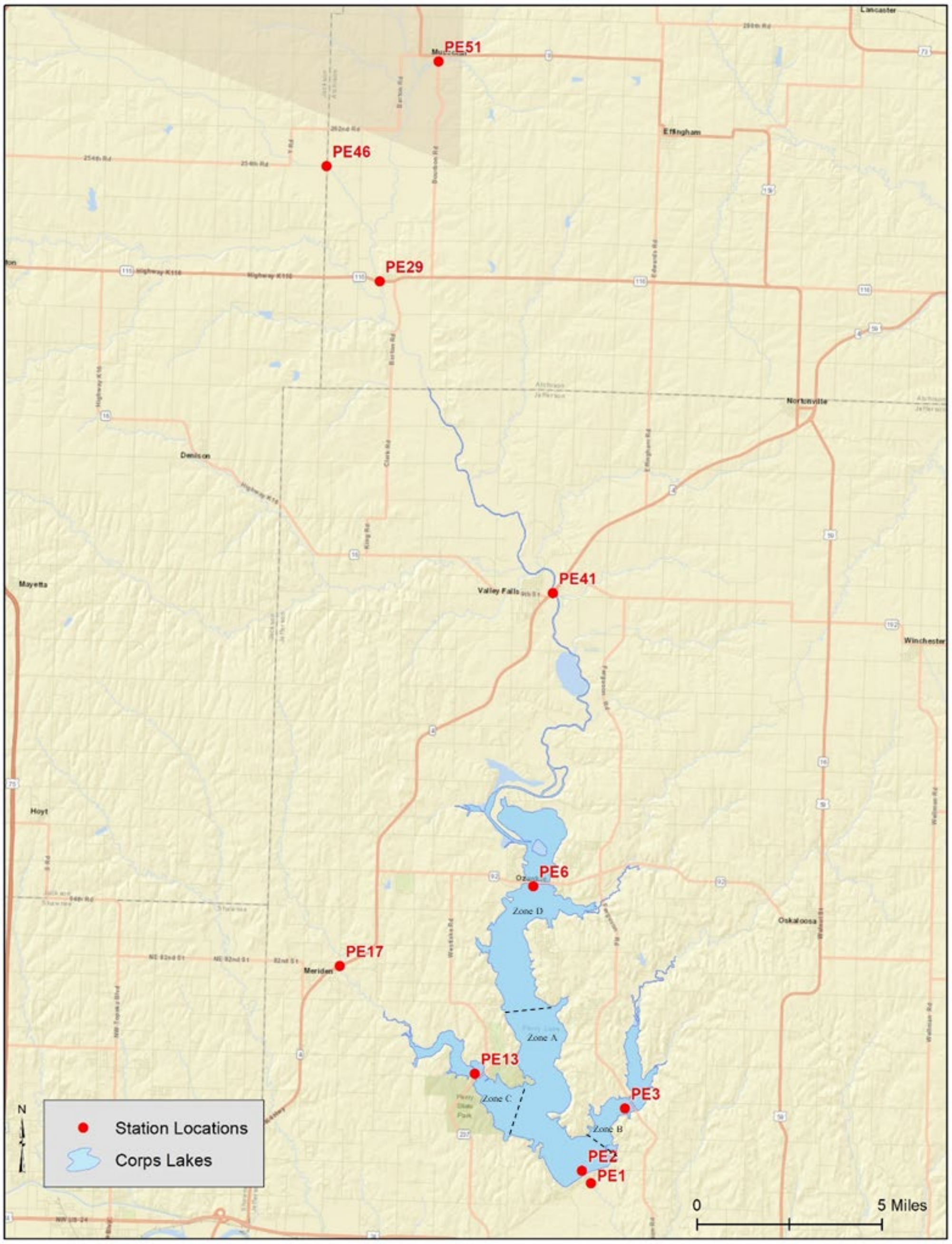
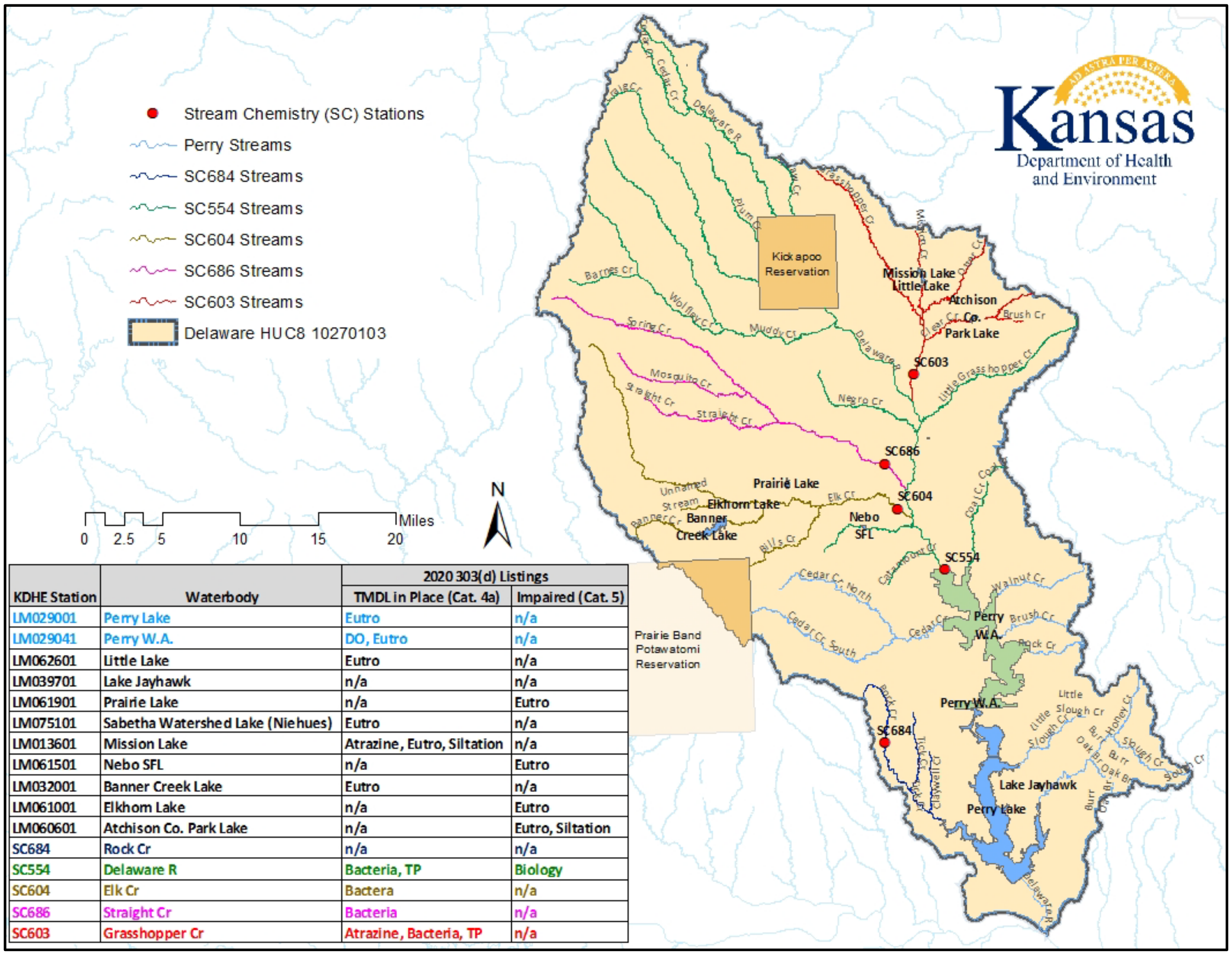


Figure 3-64. Perry Lake historic USACE water quality sample sites. *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow.*

Impairments

Section 303(d) of the Clean Water Act requires that states develop a list of "impaired" water bodies that do not sufficiently meet water quality standards to support specific designated use(s). These impaired streams and lakes require additional protection (e.g., TMDLs) and restoration work (e.g., conservation planning, best management practices, in-stream and corridor improvements) in order to achieve water quality standards and restore designated uses of the waters.

The Perry Lake watershed includes four impaired stream segments listed on the 2020 303(d) list (Figure 3-65) impacted generally by bacteria, nutrients, and herbicide. Inflow streams appear to attenuate much of the bacteria and herbicide to levels below state water quality standards before they enter Perry Lake. Nutrient and sediment impacts, directly related to HABs and low dissolved oxygen, persist in Perry Lake as Eutrophication TMDL supports.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM029001	Perry Lake	Eutro	n/a
LM029041	Perry W.A.	DO, Eutro	n/a
LM062601	Little Lake	Eutro	n/a
LM039701	Lake Jayhawk	n/a	n/a
LM061901	Prairie Lake	n/a	Eutro
LM075101	Sabetha Watershed Lake (Niehues)	Eutro	n/a
LM013601	Mission Lake	Atrazine, Eutro, Siltation	n/a
LM061501	Nebo SFL	n/a	Eutro
LM032001	Banner Creek Lake	Eutro	n/a
LM061001	Elkhorn Lake	n/a	Eutro
LM060601	Atchison Co. Park Lake	n/a	Eutro, Siltation
SC684	Rock Cr	n/a	n/a
SC554	Delaware R	Bacteria, TP	Biology
SC604	Elk Cr	Bactera	n/a
SC686	Straight Cr	Bacteria	n/a
SC603	Grasshopper Cr	Atrazine, Bacteria, TP	n/a

Figure 3-65. Perry Lake and Watershed Impaired Waters and TMDLs. *Impaired waters and TMDLs of Perry Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Inflow/Outflow

Lakes and reservoirs store sediment and associated chemical compounds carried by inflows and runoff. Sediment, nutrient, contaminant, and geological sources in the watershed and associated inflows influence lake water quality including water clarity, nutrient concentration, chemical contamination, and nutrient balance in receiving waters. These factors also have implications for biological response in the streams and receiving waters including trophic state and which type of plants and algae dominate the primary production in the system.

Nutrients sources, geology, and land-use are primary influence on water quality in inflow streams in the watershed which influence Perry Lake. Water exiting through the dam or outlet works of Corps' lakes can be quite different than the inflows as large amounts of nutrients, pesticides, and metals are processed and/or stored in the lake causing a sink effect (Satoh, Y., Ura, H., Kimura, T. et al. 2002). Chemical and nutrient compounds solubilized under anoxic conditions when lakes are thermally stratified are seasonal exceptions to the sink effect as they are released into lower strata and occasionally to the river below. Similarly, low dissolved oxygen concentration in outflows related to release of anoxic water during stratified periods and supersaturation during flood releases are problematic physical water quality conditions exhibited below dams.

Herbicides have been monitored at Perry Lake by Kansas City District Water Quality personnel since 1996. The list of herbicides detected have included mostly chlorinated species and chemical constituents of atrazine, alachlor, metolachlor, cyanazine, metribuzin, simazine, acetochlor as well as 2, 4-D and glyphosate. EPA regulation of herbicide licensing to reduce chemical persistence and mobility in the environment have reduced the number and concentration of chemicals detected in Kansas City District Water Quality samples. Total atrazine and alachlor concentrations peak in the spring and are associated with runoff events as herbicides mobilize and enter the Delaware River in concentrations typically much higher than those exiting through the outlet. Median concentrations of monitored herbicides in the outflow are lower than corresponding medians from inflow (Figure 3-66). Concentrations of atrazine and detectable levels of alachlor in the outflow persist at levels below EPA drinking water standards 3 ug/L and 2 ug/L, respectively. Instances of total atrazine exceeding EPA drinking water standards of 3 ug/L were documented on Delaware River above Perry Lake between 2010-2019 according to USACE Water Quality Program Data (unpublished data 1996-2019).

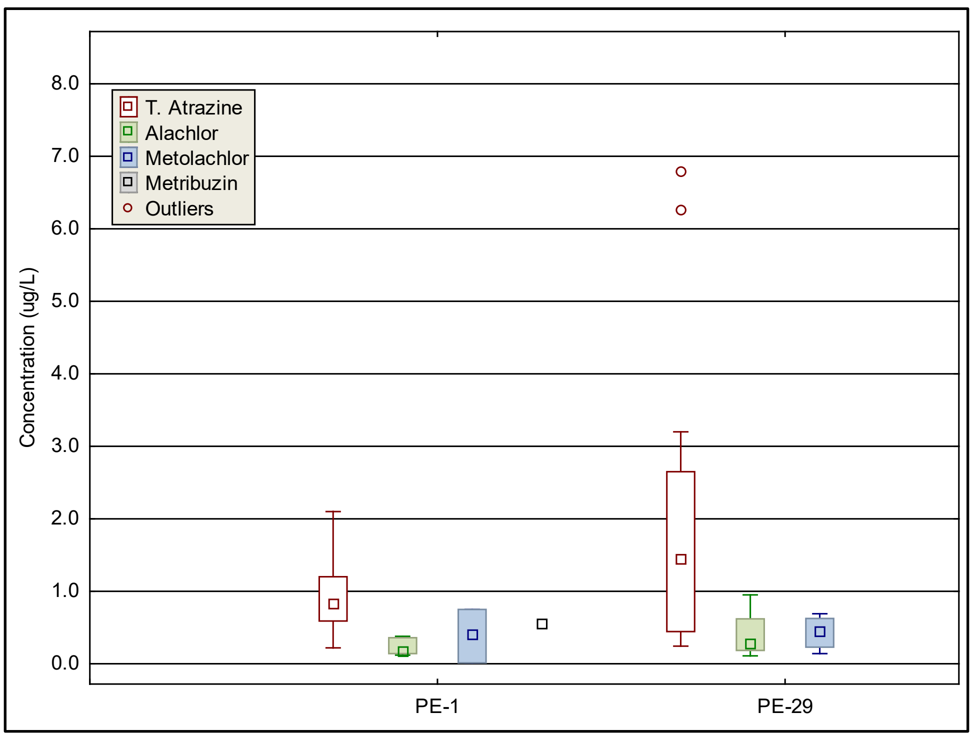


Figure 3-66. Herbicide Concentrations upstream and downstream of Perry Lake 2010-2019. *Herbicide concentration measured from surface samples collected at Perry Lake Outflow (PE-1) and inflow (PE-29) USACE water quality sample sites from 2010-2019.*

Inflows into Perry Lake carry high nutrient loads (Figure 3-67) associated with sediment and non-point source nutrients. Median total nitrogen and soluble form nitrate (NO3) measured at the Delaware River site both exceed the 75th percentile (Q3) found in the outflow indicative of significant biological attenuation and denitrification in Perry Lake. Ammonia-N concentrations were higher in the outflow as release from deep water near the dam frequently have high ammonia concentration under stratified conditions. TKN median and distribution are similar between inflow and outflow sites during our study period. Both phosphorus and orthophosphate medians were 1.5 times higher at the inflow site than respective median values measured at the outflow.

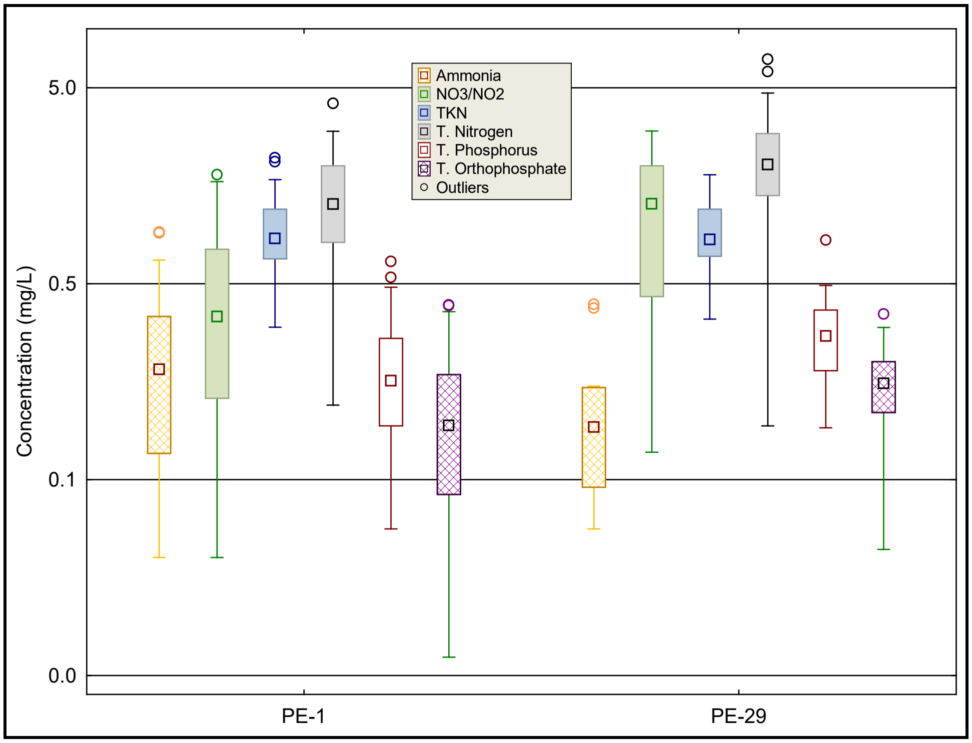


Figure 3-67. Nutrient Concentrations upstream and downstream of Perry Lake from 2010-2019. *Nutrient concentration measured from surface samples collected at Perry Lake Outflow (PE-1) and inflow (PE-29) USACE water quality sample sites from 2010-2019.*

Perry Lake inflows carry inorganic sediment and well as suspended organic matter which influence water clarity. Attenuation of sediment through Perry reservoir is apparent as median TSS at the inflow exceeds over 99% of TSS records from the outflow (Figure 3-68). There was not significant change of total organic carbon detected in Perry Lake inflow and outflow sample data. Median turbidity values were also similar between inflow and outflow data with more than 50% increase in variation in the upper quartile as effects from runoff events and mobile sediment load are more likely influence water quality above the reservoir.

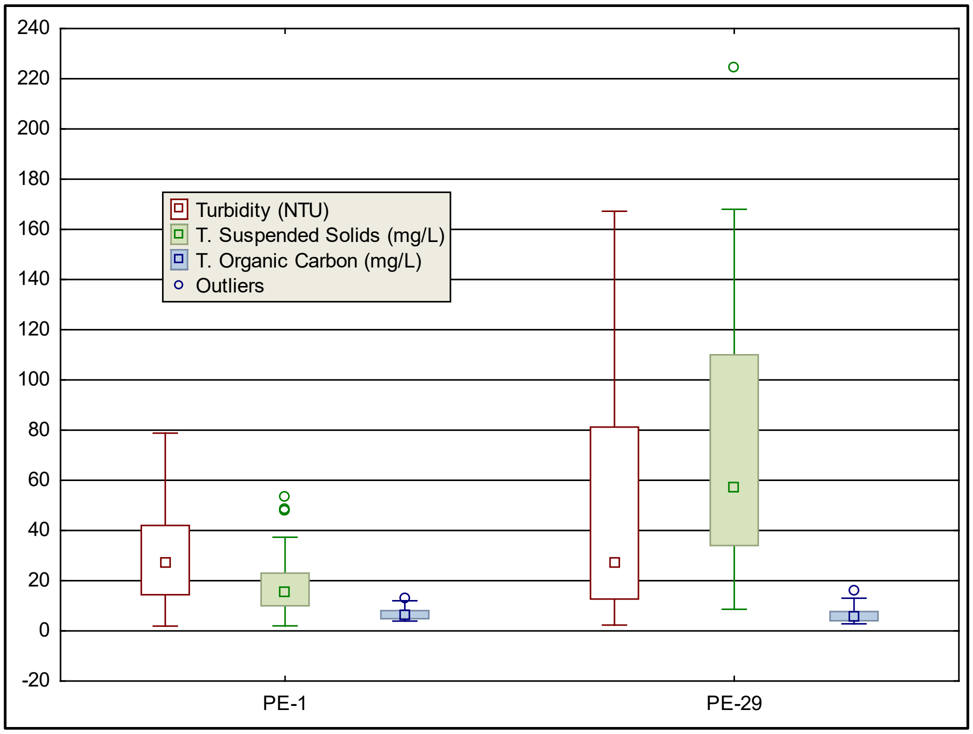


Figure 3-68. Water Clarity metrics upstream and downstream of Perry Lake from 2010-2019. *Water clarity metrics measured from Perry Lake Outflow (PE-1) and inflow (PE-29) USACE water quality sample sites from 2010-2019.*

Types of trace elements reported as total metals (e.g. dissolved+particulate) in water quality samples were similar in Perry Lake inflow and outflow (Figure 3-69). Summer conditions at the site near the dam of Perry Lake is strongly stratified in summer months (Figure 3-74) creating an anoxic layer in the bottom strata. The lack of oxygen creates conditions allowing for mobilization or "desorbtion" of certain sediment bound elements and nutrients due to chemical reduction or electron exchange in the absence of oxygen which is often assisted by anerobic bacteria (Kimborough 1999). Elevated concentrations of solubilized metals iron, lead, and manganese are common during summer months in the outflow releases of stratified reservoirs including Perry Lake. Kimborough (1999) describes how removal of anoxic hypolimnetic water in reservoir releases could be a tool for managing certain redox sensitive elements where drinking water sources are impacted.

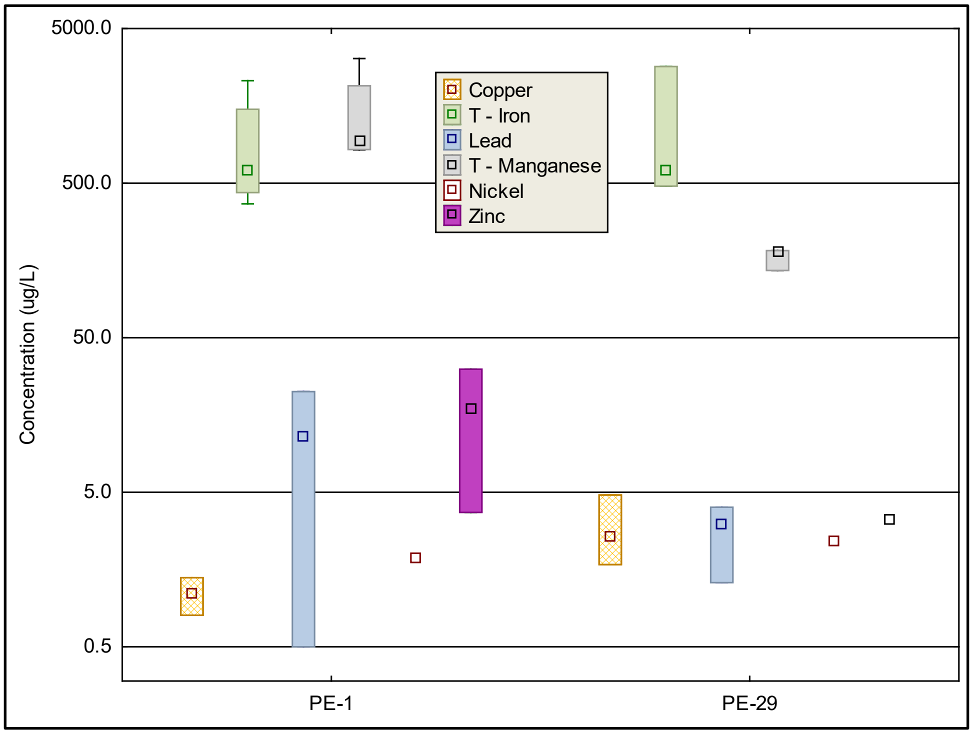


Figure 3-69. Total metal concentration upstream and downstream of Perry Lake from 2010-2019. *Total metal concentration measured from surface samples collected at Perry Lake Outflow (PE-1) and inflow (PE-29) USACE water quality sample sites from 2010-2019.*

Lake Water Quality

Nutrient rich runoff and soil loss from fields and stream banks work in tandem to compound water quality problems linked to the most frequent Kansas City District lake impairment summarized as eutrophication. Sedimentation and eutrophication problems associated with non-point source pollution are top priority with watershed conservations efforts. Although the dominate land use in the Perry Lake watershed is hay/pasture with row crop agriculture representing only 27% of the watershed, increased row crop production is anticipated due in part to increased demand for biofuels. Yasarer et al. (2016) demonstrate via SWAT modeling of Perry Lake watershed that sediment and nutrient loads show the greatest increase when pasture and Conservation Reserve Program (CRP) acres are converted to row crop agriculture. Increased nutrients and sediment accumulating in Perry Lake will lead to decline in water quality and reduced storage capacity for water use. This age-related process makes older reservoirs more susceptible to contamination and internal loading of nutrients, metals and compounds stored in lake bed sediment (Juracek, 2014).

Physical and chemical attenuation (e.g., dilution, dispersion, chemical changes, and uptake by organisms) of compounds and settling of suspended matter leads to a general decrease in concentration of many constituents of water quality, often interpreted as improved water quality, as water moves through a reservoir system (Bosch et al., 2009). This process will be evident with many analytes in graphic representations in lake water quality sections. The following section is an overview of chemical and physical data from surface samples at 4 lake sites, describes chemical and physical differences between surface and bottom strata at the site near the dam and stratification, and briefly describes available phytoplankton and cyanobacteria data related to public health advisories.

USACE and KDHE pesticide sample results indicate that three common herbicides were detected in Perry Lake but are found in higher concentrations in the Delaware River and diminish as water moves through the lake. Concentrations of atrazine exceeding EPA drinking water criteria of 3 ug/L were reported only at the upstream most site near Old Town (PE-6) (Figure 3-70). Concentrations of atrazine and three other herbicides were found at low concentration at lower lake sites (Figure 3-70). KDHE Lake and Wetland Monitoring Program Reports (KDHE 2007, 2010) report detection of pesticides in Perry Lake below state water quality standards.

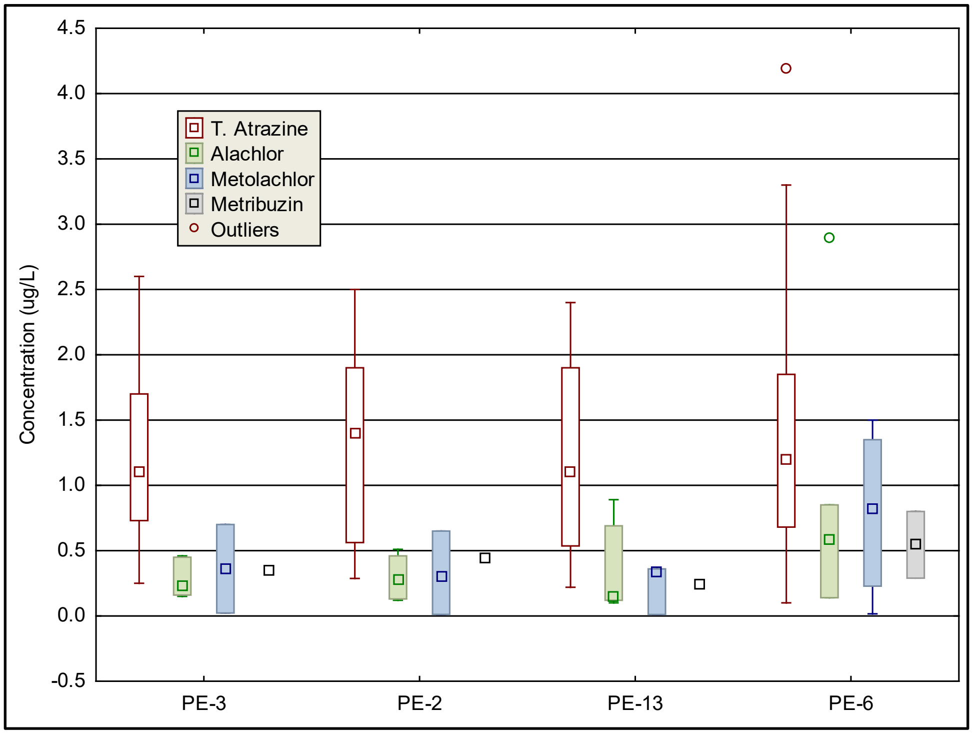


Figure 3-70. Perry Lake herbicide concentrations. *Herbicide concentration measured from surface samples collected at Perry Lake USACE water quality sample sites from 2010-2019.*

Ten-year nutrient data (Figure 3-71) indicate nitrate/nitrite and ammonia nitrogen available for aquatic plant and phytoplankton growth were similar between three lower lake sites but more abundant at upper lake site (PE-6). Both TKN and total nitrogen showed minor attenuation from upstream sites to lower lake sites. Median TKN at the PE-6 exceeded the interquartile range of the lower lake (PE-2) site at the dam, likely due to presence of organic matter and algae present in higher concentration in upper lake samples. Median and maximum total phosphorus and soluble orthophosphate were greatest at upper site (PE-6) with significant decrease in both measures of phosphorus at lower lake sites indicating biological uptake of orthophosphate by phytoplankton and settling of sediment-bound phosphorus.

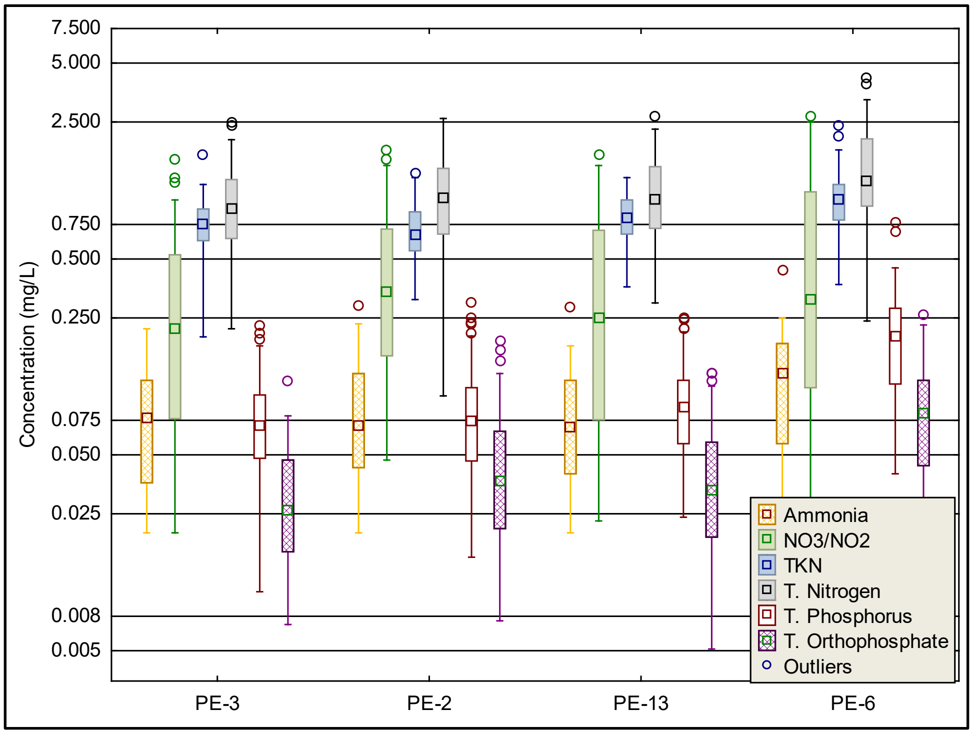


Figure 3-71. Perry Lake nutrient concentrations. *Nutrient concentration measured from surface samples collected at Perry Lake USACE water quality sample sites from 2010-2019.*

Influences on light availability or water clarity including inorganic sediment, organic carbon, turbidity, and phytoplankton (Testa et al., 2019). Light availability is a critical metric which influences biological productivity through light limitation of photosynthesis. Median total suspended solids, turbidity, and chlorophyll *a* concentrations were higher at the upper lake site than mid and lower lake sites (Figure 3-72). Similarly, median turbidity and TSS exceeded all recorded data, including outliers, at lower lake sites PE-2 and PE-3. Consequently, Secchi depth was significantly less at upper lake site than all three lower lakes sites. Median Secchi values from 0.7-0.9 meters at lower Perry Lake sites are less than ideal (1-3 meters) for rooted aquatic plant growth, but emergent aquatic vegation is present at low density in coves and low energy shoreline areas in the upper reaches of Perry Lake. Chlorophyll *a* values exceeding 12 ug/L indicate that phytoplankton is thriving as the basis of primary productivity to support aquatic life including occasional harmful algal blooms (Figure 3-72).

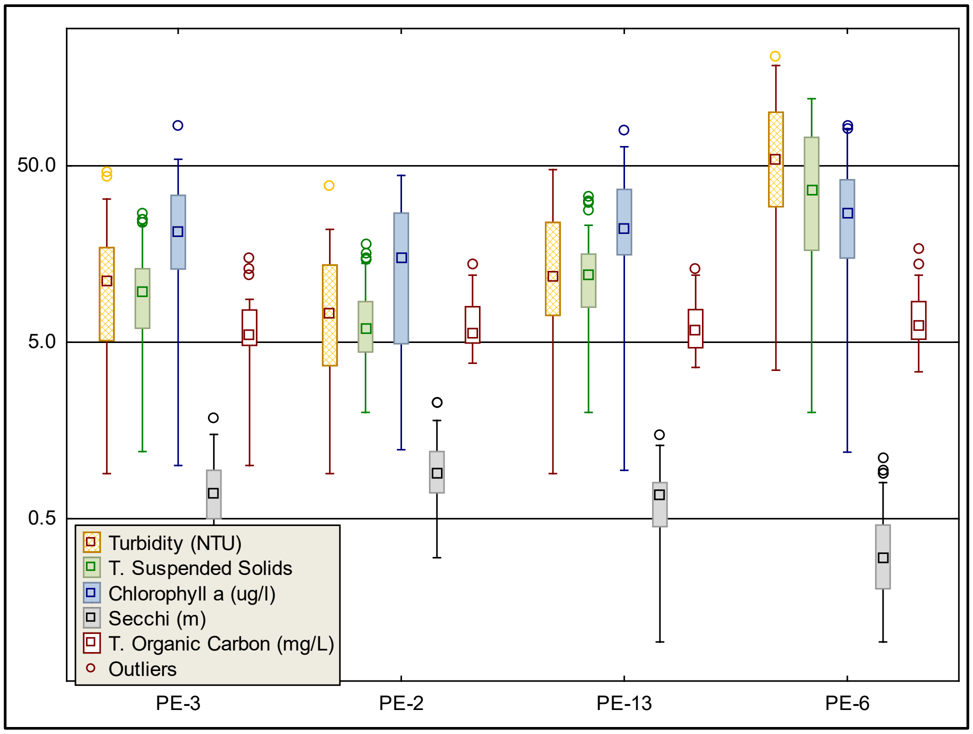


Figure 3-72. Perry Lake water clarity metrics. *Water clarity metrics measured from surface samples collected at Perry Lake USACE water quality sample sites from 2010-2019.*

Median total iron, manganese, zinc, and copper were significantly higher at upper lake sites than three lower lake sites (Figure 3-73). Lead and nickel were detected in low concentration in single samples from 2010-2019 as indicated by single data points with limited representation of data distribution and quartile range in box-whisker plot.

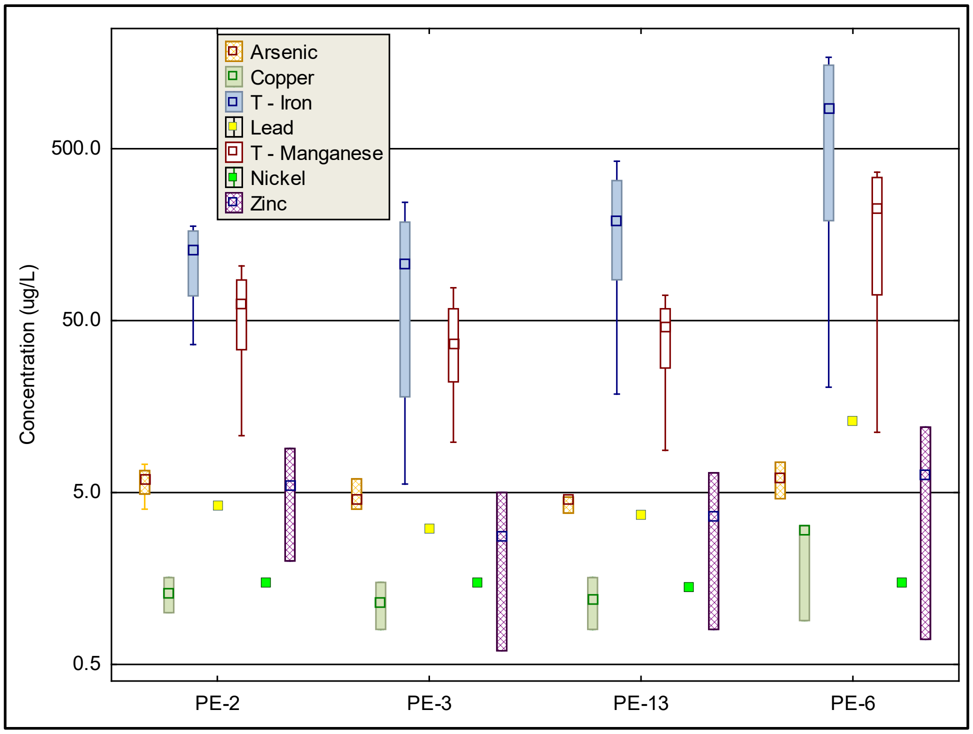


Figure 3-73. Perry Lake total metal concentrations. *Total metal concentration measured from surface samples collected at Perry Lake USACE water quality sample sites from 2010-2019.*

A summary of descriptive statistics for chemical analysis results at the site nearest the dam (PE-2) is found in Table 3-14. Bottom samples are typically collected from Kansas City District lakes every third year with total metals collected during the month of August when stratified conditions are most likely. When the lake is mixed or not stratified, bottom sample results are nearly identical to surface sample results for most analytes. Anaerobic conditions allow for oxidation/reduction reactions to release chemical compounds, including metals, which we are trying to quantify with bottom samples. Results less than minimum detection level are frequent and have been included in sample results as the value of half of the reported minimum detection limit to reduce bias based on the assumption that the analyte is present at a concentration below laboratory quantification (EPA, 1991)(Table 3.14) Sample size, sampling effort, and normality distribution constraints are best addressed with the use of descriptive statistics to describe and summarize sample results. Perry Lake chemical results were significantly different between top and bottom sample groups for TSS (Wilcoxon Signed-Rank Test; p=0.005) and total manganese (P=0.008) had significantly different sample means between surface to bottom samples.

Table 3-14. Perry Lake chemical water quality summary statistics 2010-2019.[1]

Parameter	Sample Depth	Mean	SE*	SD**	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.05	0.01	0.06	0.29	0.03	0.01	60
Ammonia (mg/L)	Bottom	0.17	0.04	0.21	0.62	0.07	0.00	22
NO3/NO2 (mg/L)	Surface	0.42	0.06	0.43	1.80	0.27	0.01	60
NO3/NO2 (mg/L)	Bottom	0.43	0.08	0.36	1.30	0.32	0.02	22
TKN (mg/L)	Surface	0.66	0.03	0.27	1.36	0.65	0.15	60
TKN (mg/L)	Bottom	0.75	0.09	0.43	1.70	0.67	0.15	22
Total Nitrogen (mg/L)	Surface	1.08	0.07	0.55	2.61	1.02	0.21	60
Total Nitrogen (mg/L)	Bottom	1.17	0.10	0.46	2.08	1.18	0.22	22
Total Phosphorus (mg/L)	Surface	0.09	0.01	0.06	0.30	0.07	0.02	60
Total Phosphorus (mg/L)	Bottom	0.15	0.02	0.09	0.39	0.12	0.02	22
Total Orthophosphate (mg/L)	Surface	0.04	0.01	0.05	0.24	0.03	0.04	60
Total Orthophosphate (mg/L)	Bottom	0.08	0.01	0.07	0.25	0.06	0.00	22
Total Suspended Solids (mg/L)	Surface	7.36	0.61	4.76	24.40	5.95	2.00	60
Total Suspended Solids (mg/L)	Bottom	21.07	4.31	20.20	98.00	19.47	3.20	22
Total Organic Carbon (mg/L)	Surface	6.69	0.50	2.66	14.00	5.65	3.80	28
Total Organic Carbon (mg/L)	Bottom	5.58	0.42	1.88	11.00	5.00	3.60	20
Total Iron (ug/L)	Surface	117.83	32.29	62.58	177.00	129.00	36.30	4
Total Iron (ug/L)	Bottom	1953.00	1064.17	2128.35	4680.00	1536.00	60.00	4
Total Manganese (ug/L)	Surface	60.03	19.25	38.50	104.00	62.70	10.70	4
Total Manganese (ug/L)	Bottom	2147.50	602.17	1204.33	3550.00	1985.00	1070.00	4

Notes: [1/] Summary statistics for chemical water quality parameters from Perry Lake site near the dam (PE-2), April 2010 through September 2019.
*SE = Standard Error; ** SD = Standard Deviation

Table 3-15. Perry Lake physical water quality summary statistics.[1]

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	8.8	0.1	2.2	16.7	8.5	2.9	223
Oxygen, Dissolved (mg/l)	Bottom	4.6	0.2	3.4	12.9	4.5	0.1	223
pH (Standard Units)	Surface	8.2	0.1	0.4	9.4	8.2	7.0	170
pH (Standard Units)	Bottom	7.8	0.04	0.5	9.7	7.8	6.9	170
Secchi Depth (m)	Surface	0.6	0.02	0.4	2.3	0.9	0.3	47
Chlorophyll a (ug/L)	Photic Zone	16.22	1.78	12.86	44.10	14.00	1.00	52
Specific Conductance (µS/cm)	Surface	329.1	3.6	46.8	537.0	332.0	207.4	173
Specific Conductance (µS/cm)	Bottom	337.6	3.8	51.6	545.5	340.9	196.2	173
Turbidity, Field (NTU)	Surface	27.4	4.0	53.1	451.0	12.2	1	173
Turbidity, Field (NTU)	Bottom	86.7	11.9	159.4	1605.0	54.7	1.5	178
Water Temperature (°C)	Surface	22.9	0.4	5.9	32.0	25.1	6.4	223
Water Temperature (°C)	Bottom	21.2	0.3	5.6	32.0	22.8	6.1	223

Note: [1/] Summary statistics for physical water quality parameters, from all sites and dates, Perry Lake, April 2010 through September 2019.
*SE = Standard Error; ** SD = Standard Deviation

The lower lake site PE-2 typically experiences strong thermal stratification in July and August, while upper lake sites may experience weak stratification or are mixed throughout the summer (USACE, 2019). Differences in water density from differences in temperature and salinity, distribution of heat, in-lake currents, reservoir releases, and wind action play a role in the stratification process (Wetzel, 2001). Physical changes in water composition during stratified conditions from water temperature and density differences lead to chemical and biological changes in the absence of oxygen (anaerobic conditions). A representative compilation of water profiles from Perry Lake sites (Figure 3-74) illustrates the typical summer conditions including strong stratification with apparent thermocline at 8 meters of depth at lower lake (PE-2) and mild stratification with no apparent thermocline at mid-lake at Rock Creek Arm (PE-13), and no stratification nor thermocline at upper lake on Delaware River Arm (PE-6). Temperature and D.O. profiles in 2018 illustrate differences in stratified conditions when fish and aquatic life habitat is partially limited to shallower and much warmer water. This temperature/dissolved oxygen "crunch" can stress aquatic life. Currently the TMDLs in Perry Watershed for dissolved oxygen deficiencies do not include Perry Lake (Figure 3-66) (KDHE 2014).

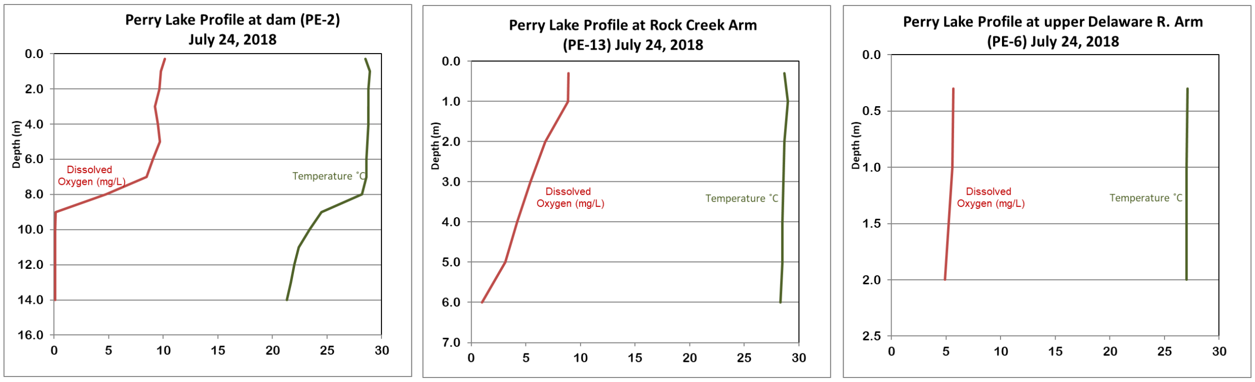


Figure 3-74. Perry Lake temperature and dissolved oxygen profiles. *Representative temperature and dissolved oxygen profiles measured at Perry Lake USACE water quality sample locations on July 24, 2018.*

Hypereutrophic conditions at Perry Lake produce ideal chemical conditions for production of HABs. An abundance of plant nutrients nitrate and orthophosphate and a low (i.e., <12) TN:TP ratio are two frequent water quality conditions associated with proliferation of blue-green algae which could produce toxins in freshwater (Downing, J. A., and E. McCauley. 1992; Xiaofeng et.al. 2012; Havens et al., 2003). The presence of a healthy zebra mussel population at Perry Lake has also been associated with increased risk of the common HAB producing cyanobacterium *Microcystis aeruginosa* (Raikow et al., 2004; Knoll et al., 2008; Sarnelle et al., 2005). Less than optimal sunlight penetration in the photic zone due to high turbidity (Havens et al., 2003) is the most likely factor limiting relatively low-density cyanobacteria blooms at Perry Lake.

KDHE CyanoHAB monitoring program started in 2010 (KDHE, 2022) and has evolved with scientific knowledge of cyanobacteria and understanding of Kansas HABs. Perry Lake is one of three large lakes in Kansas with "zoned" management allowing for more precise recreational health advisories for four distinct areas (Harmful Algal Bloom | KDHE, KS.)

HAB advisories, based on EPA recommendations, to manage risk to recreational (whole-body contact) lake users currently designates three recommendations for lake managers based on algae cell count density and/or algal toxin concentration thresholds in order of increasing severity from Watch-Warning-Hazard.

Perry Lake HABs have occurred infrequently and have been based on high cell count exceeding KDHE health public health thresholds (KDHE unpublished weekly HAB reports 2010-2021) with low concentration of algal toxins. Perry Lake experienced the most significant algal bloom conditions in July, 2011. This lake-wide bloom was most intense in the Old Town region on the Delaware River and the Rock Creek Arm on the west side of the lake. KDHE issued a Public Health Warning which impacted the entire lake including two-week closure of swim beaches and reduced recreational traffic at the lake. Cyanobacteria cell counts also exceeded warning status in Perry Lake in all zones for one week in 2017 and two weeks in Zone B during 2018 and (KDHE unpublished weekly HAB reports 2017, 2018). The most recent KDHE health advisory at Perry Lake was eight weeks of watch status due to cell count and visual observations by USACE Rangers and USGS scientist(s) in 2020 (Figure 3-75). Swim beaches at Perry Lake have been closed due to flooding, bacteria safety concerns, and up to two weeks due to HAB warning in 2011 and 2017.

Figure 3-75. Perry Lake during 2020 KDHE issued HAB Watch. *USACE photo.*

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or “recycle” nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). Kansas City District Water Quality Program initiated collection of baseline lake sediment data in 2016 (Table 3-16).

Nitrogen and phosphorus concentrations from Perry Lake sediment samples were low to moderate when compared to results from a group of lakes from Southeast and Northern United States (Barko, J.W. and R.M Smart. 1986). Metal concentrations reported in Kansas City District lake bed sediment results (Table 3-16) did not exceed the “probable effect concentration” (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000).

Table 3-16. Perry Lake bed sediment chemical concentration from 2016 and 2019.

Station	Date	Ammonia Nitrogen	Nitrate-Nitrite Nitrogen	Phosphorus	Total Kjeldahl Nitrogen	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Total Solids	Mercury
	mm/dd/yy	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	%	MG/KG
PE-2	9/7/2016	24.7	<2.6	<296	512.0	5.2	0.3980	9.2	6.4	8740	9.1	511.0	10.2	71.8	
PE-3	9/7/2016	93.7	<5.2	748.0	1650.0	10.8	0.9450	28.4	20.8	27100	21.0	747.0	31.4	36.3	
PE-13	9/7/2016	14.3	4.3	338.0	820.0	8.4	0.2460	15.7	8.7	15000	11.3	407.0	17.3	73.7	
PE-6	9/7/2016	76.6	<2.8	534.0	1140.0	7.8	0.4720	17.8	12.2	16500	14.8	504.0	20.2	58.6	
PE-7	9/7/2016	92.4	<2.9	462.0	1100.0	8.3	0.5210	19.9	13.2	17800	15.6	552.0	21.7	55.5	
ite Median		**76.6**	**4.3**	**498.0**	**1100.0**	**8.3**	**0.4720**	**17.8**	**12.2**	**16500.0**	**14.8**	**511.0**	**20.2**	**58.6**	
Mean		**60.3**	**4.3**	**520.5**	**1044.4**	**8.1**	**0.5164**	**18.2**	**12.3**	**17028.0**	**14.4**	**544.2**	**20.2**	**59.2**	
PE-2	8/6/2019	15.3	3.4	590.0	275.0	5.9	0.3040	10.8	12.1	27300	13.6	483.0	24.9		0.0272
PE-3	8/6/2019	13.2	1.1	1100.0	519.0	11.7	0.5470	11.8	17.3	31700	18.5	427.0	28.9		0.0372
PE-13	8/6/2019	18.3	<2.8	973.0	268.0	9.6	0.3460	11.6	17.2	33000	17.5	355.0	29.3		0.0339
PE-6	8/6/2019	37.3	3.6	508.0	412.0	3.9	0.2130	8.2	8.0	14300	10.8	253.0	15.0		0.0162
ite Median		**16.8**	**3.4**	**781.5**	**343.5**	**7.8**	**0.3**	**11.2**	**14.7**	**29500.0**	**15.6**	**391.0**	**26.9**		**0.0306**
Mean		**21.0**	**2.7**	**792.8**	**368.5**	**7.8**	**0.4**	**10.6**	**13.7**	**26575.0**	**15.1**	**379.5**	**24.5**		**0.0286**

3.1.6 Tuttle Creek Lake

Tuttle Creek Lake is a 10,900 acre impoundment built on the Big Blue River reaching full pool in 1963. Sedimentation at Tuttle Creek Lake has reduced the surface area by 4900 acres from 1957-2010 according to USACE engineers. Blue River watershed drains roughly equal area of row crop and grassland in Nebraska and Kansas before entering Tuttle Creek Lake and then the Kansas River. Sediment runoff is at the root of primary water quality threats to Tuttle Creek Lake and smaller impoundments in the watershed summarized by current Total Maximum Daily Load (TMDL) for siltation and eutrophication. TMDLs for atrazine, E. coli bacteria and excessive phosphorus have been defined for most streams in the watershed above Tuttle Creek Lake.

During Tuttle Creek Lake construction, Kansas and Nebraska entered an interstate compact (https://agriculture.ks.gov/divisions-programs/dwr/interstate-rivers-and-compacts/big-blue-river-compact), finalized in 1971, to promote interstate comity with equitable water apportionment while continuing active pollution abatement programs in each of the two states. The current administration of the Blue River Compact provides stream flow targets for Big Blue and Little Blue Rivers during summer months.

Watershed conservation efforts have increased in priority for state and local rankings to address sedimentation and water quality in Tuttle Creek Lake. The Watershed Restoration and Protection Strategy (WRAPS) program is a KDHE planning and management tool used to identify watershed restoration and protection needs, establish management goals, establish plans (e.g., EPA approved 9-Element Watershed Plans) and implement goals to address water resource concerns (https://www.kdheks.gov/nps/wraps/). Most priority goals/targets of the approved WRAPS Plans for subbasins in the Kanas River Watershed align with strategies and measures included in this study. The WRAPS process is in the implementation and monitoring phase of their process to administer programs using BMPs in Tuttle Creek Lake watershed to meet TMDLs and reduce phosphorus loads originating in Kansas by 3.6 million lbs/yr., sediment load reduction goal of 3 million tons/year, and atrazine reduction of 55.9 thousand lbs/yr (KDHE 2018).

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics with related to flow (i.e., volume, load, and concentration), water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological responses. Figure 3-76 illustrates reservoir hydrologic data with overlay of water quality sampling events.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September). Low inflow periods were observed at the end of 2012 with lake surface elevation falling to 1,062 ft while recovery period is apparent beginning late spring of 2013. Significant flooding with a corresponding high-water period was observed in 2019 as inflows peaked at 54,200 cfs with three events exceeding 48,000 cfs from March through August. Surface elevation of Tuttle Creek Lake peaked at 60.7 ft above CPE and exceeded CPE for 306 days in 2019.

Tuttle Creek Lake average water residence time of 2.5 months was calculated from historic water management records for the period 1990-2022 using HEC-ResSim software. Tuttle Creek Lake average water residence time is below average of 10.8 months for 7 USACE Kansas River Watershed lakes in this study. Short residence times can lead to pronounced seasonal shifts and dynamic water quality at Tuttle

Creek Lake with less time allowed for dilution, settling, and biological attenuation of sediment, nutrients, and other contaminants.

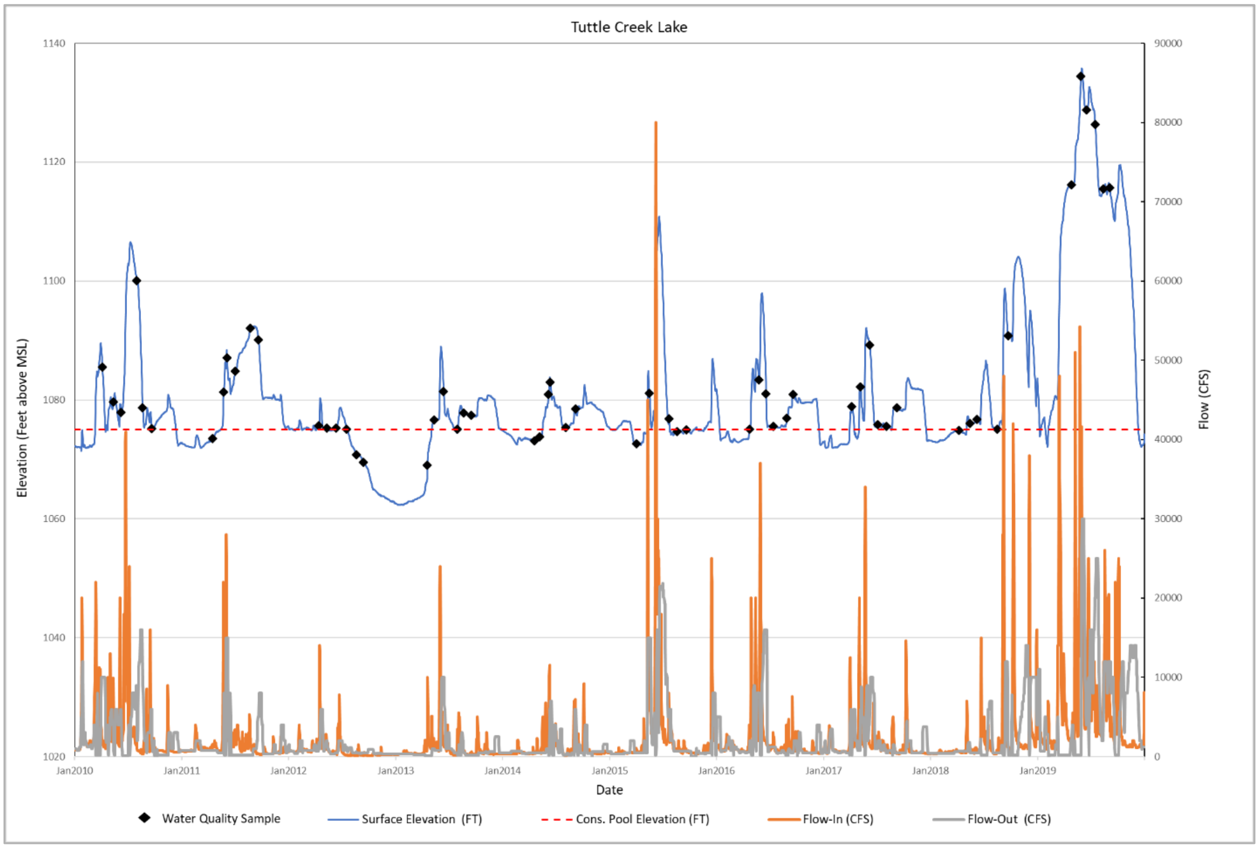


Figure 3-76. Tuttle Creek Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Water Quality Sample Locations

Historic water quality sample sites at Kansas City District lake projects are named in decreasing numeric order from inflow sites to the outflow site below the dam with exceptions at Tuttle Creek Lake outlet and inflow (Figure 3-77). To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

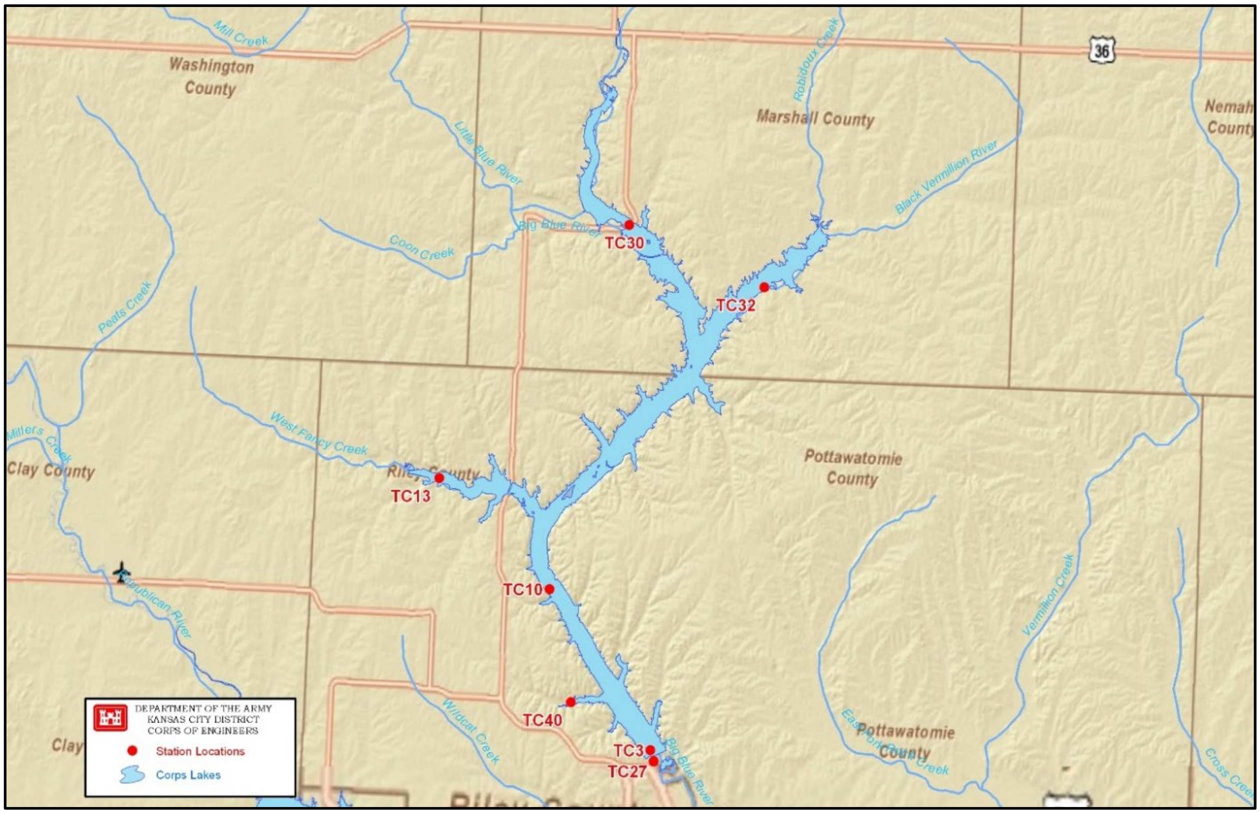
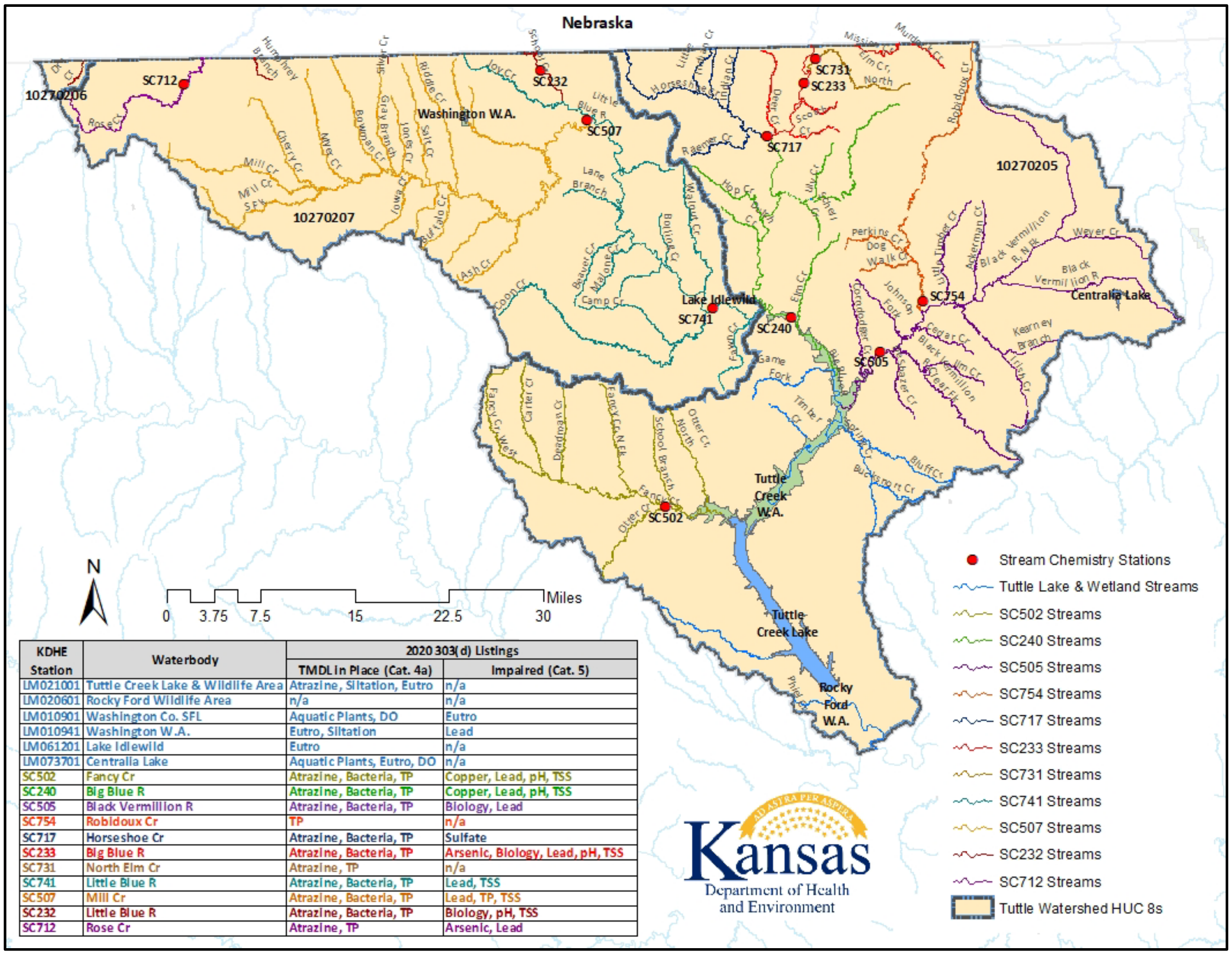


Figure 3-77. Tuttle Creek Lake historic USACE water quality sample sites. *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow.*

Impairments

Section 303(d) of the Clean Water Act requires that states develop a list of “impaired” water bodies that do not sufficiently meet water quality standards to support specific designated use(s). These impaired streams and lakes require additional protection (e.g., TMDLs) and restoration work (e.g., conservation planning, best management practices, in-stream and corridor improvements) in order to achieve water quality standards and restore designated uses of the waters.

The Tuttle Creek Lake and 10 stream segments in the watershed are listed on the 2020 303(d) list (Figure 3-78) most impacted by atrazine, bacteria, and phosphorus in the lake with impairments but no TMDLs listed for metals, pH, total suspended solids and impaired biological resources in inflow streams. Tuttle Creek Lake “eutrophication” TMDL indicates that silt and nutrients entering the lake accelerate the natural aging process and degrade water quality for aquatic life. Sediment driven turbidity limits sunlight penetration at Tuttle Creek Lake, thereby limiting primary productivity and lowering risk of HABs.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM021001	Tuttle Creek Lake & Wildlife Area	Atrazine, Siltation, Eutro	n/a
LM020601	Rocky Ford Wildlife Area	n/a	n/a
LM010901	Washington Co. SFL	Aquatic Plants, DO	Eutro
LM010941	Washington W.A.	Eutro, Siltation	Lead
LM061201	Lake Idlewild	Eutro	n/a
LM073701	Centralia Lake	Aquatic Plants, Eutro, DO	n/a
SC502	Fancy Cr	Atrazine, Bacteria, TP	Copper, Lead, pH, TSS
SC240	Big Blue R	Atrazine, Bacteria, TP	Copper, Lead, pH, TSS
SC505	Black Vermillion R	Atrazine, Bacteria, TP	Biology, Lead
SC754	Robidoux Cr	TP	n/a
SC717	Horseshoe Cr	Atrazine, Bacteria, TP	Sulfate
SC233	Big Blue R	Atrazine, Bacteria, TP	Arsenic, Biology, Lead, pH, TSS
SC731	North Elm Cr	Atrazine, TP	n/a
SC741	Little Blue R	Atrazine, Bacteria, TP	Lead, TSS
SC507	Mill Cr	Atrazine, Bacteria, TP	Lead, TP, TSS
SC232	Little Blue R	Atrazine, Bacteria, TP	Biology, pH, TSS
SC712	Rose Cr	Atrazine, TP	Arsenic, Lead

Figure 3-78. Tuttle Creek Lake impaired waters and TMDLs 2020. *Impaired waters and TMDLs of Tuttle Creek Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Inflow/Outflow

Lakes and reservoirs store sediment and associated chemical compounds carried by inflows and runoff. Sediment, nutrient, contaminant, and geological sources in the watershed and associated inflows influence lake water quality including water clarity, nutrient concentration, chemical contamination, and nutrient balance in receiving waters. These factors also have implications for biological response in the streams and receiving waters including trophic state and which type of plants and algae dominate primary production in the system.

Nutrients sources, geology, and land-use are primary influences on water quality in inflow streams in the watershed which influence Tuttle Creek Lake. Water exiting through the dam or outlet works of Corps' lakes can be quite different than the inflows as large amounts of sediment, nutrients, pesticides, and metals are processed and/or stored in the lake causing a sink effect (Satoh et al., 2002).

Herbicides have been monitored at Tuttle Creek Lake by Kansas City District Water Quality personnel since 1996. The list of herbicides detected have included chemical constituents of atrazine, alachlor, metolachlor, cyanazine, metribuzin, simazine, acetochlor as well as 2, 4-D and glyphosate. EPA regulation of herbicide licensing to reduce chemical persistence and mobility in the environment has helped reduce the number and concentration of chemicals detected in Kansas City District Water Quality samples in the last decade. Total atrazine and alachlor concentrations peak in the spring and are associated with runoff events as herbicides mobilize and enter the inflows in concentrations typically much higher and more variable than those exiting through the outlet (Figure 3-79). Kansas City District only collects herbicides samples during spring months when application and runoff are more likely. Alachlor, metolachlor and metribuzin are frequently below laboratory detection limits. Concentrations of atrazine and detectable levels of alachlor in the outflow were reported at levels below EPA drinking water standards 3 ug/L and 2 ug/L, respectively. Instances of total atrazine exceeding EPA drinking water standards of 3 ug/L are documented on most inflow streams above Tuttle Creek Lake between 2010-2019 according to USACE Water Quality Program Data (unpublished 1996-2019) and many are on the KDHE Impaired Waters list with TMDLs for atrazine (Figure 3-75).

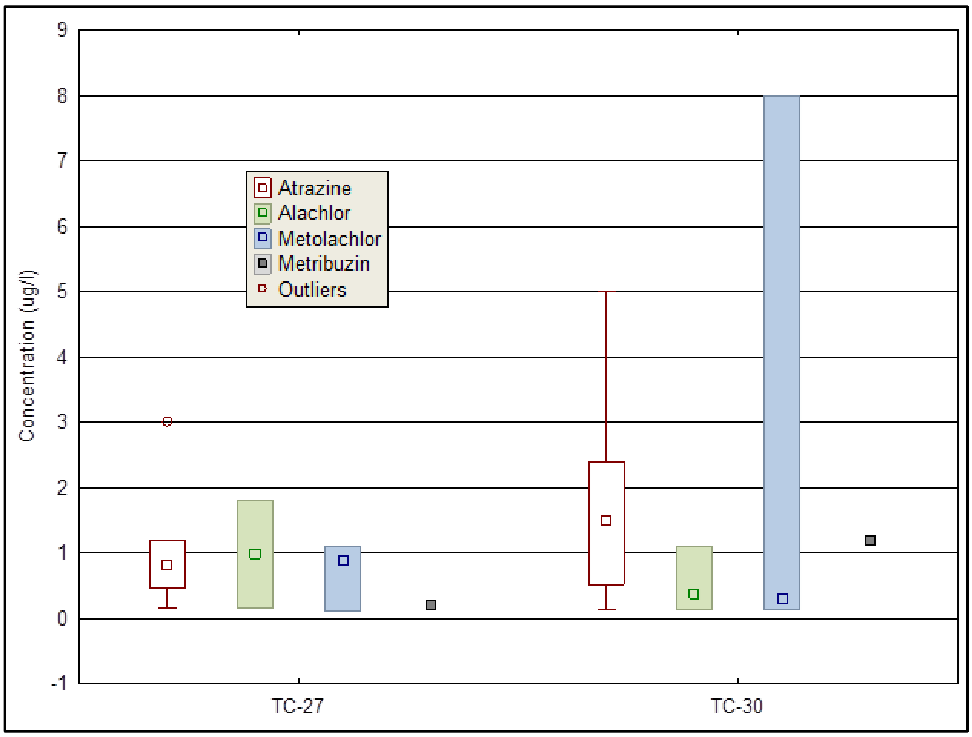


Figure 3-79. Herbicide concentrations upstream and downstream of Tuttle Creek Lake from 2010-2019. *Herbicide concentration measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) USACE water quality sample sites from 2010-2019.*

Total nitrogen and organic nitrogen (TKN) concentration decreased significantly from the inflow site to the outlet from attenuation and denitrification/biological uptake (Figure 3-80). Median bioavailable forms of nitrate/nitrites were similar at inflow and outflow sites with more variable results and outliers recorded at inflow site. Ammonia nitrogen increases from anoxic conditions found in the bottom strata near the dam leads to seasonal increases in ammonia in releases from many Kansas City District lakes including Tuttle Creek as demonstrated by ammonia sample results in Figure 3-80. Total phosphorus median concentrations in the inflow were significantly higher than median outflow concentrations and more variable as sediment bound phosphorus increases are associated with rain events and runoff. Seasonal increases of soluble orthophosphate resulting from anoxic conditions at the dam led to several outliers at the outflow. Median orthophosphate was slightly higher at inflow site (Figure 3-80).

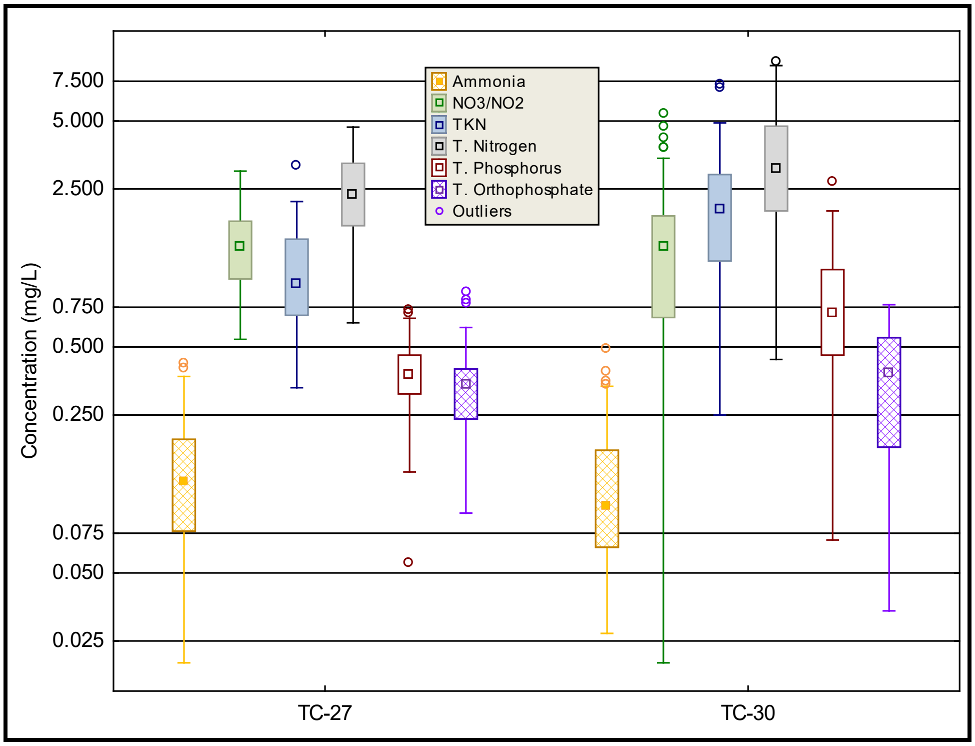


Figure 3-80. Nutrient concentrations upstream and downstream of Tuttle Creek Lake from 2010-2019. *Nutrient concentration measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) USACE water quality sample sites from 2010-2019.*

Inflow streams flowing into Tuttle Creek Lake are the primary influence on water quality. The Big Blue River (site TC-30) is historically very turbid with high sediment load leading to sedimentation issues, degraded aquatic habitat, increased turbidity, reduced light availability, inhibited phytoplankton and macrophyte growth, diminished sight and filter-feeding, water temperature effects, and increased eutrophication. Much of the water clarity is related to sediment and suspended particles. Sediment trapping efficiency has been estimated up to 98% (Juracek, 2011) for Tuttle Creek Lake. Consequently, median TSS and turbidity results from inflow (TC-30) exceed 99% of the comparable results from the outlet (Fig 3-78). Fine sediment particles remain in suspension throughout Tuttle Creek Lake including through the outflow as TSS and turbidity results are much higher than adjacent Milford Lake outflow (Figure 3-20). Total organic carbon results are slightly higher and more variable above Tuttle Creek Lake than the outflow (Fig 3-78).

Total metals in the watershed recurring in Kansas City District Water Quality Program sample results are iron, lead, manganese, arsenic, and copper. Copper, lead, and arsenic are listed as impairments by KDHE at seven inflow streams including Big Blue River (Figure 3-78). Iron, lead and copper are found in significantly greater concentration at the inflow site than the outlet while manganese and arsenic results are similar (Figure 3-82).

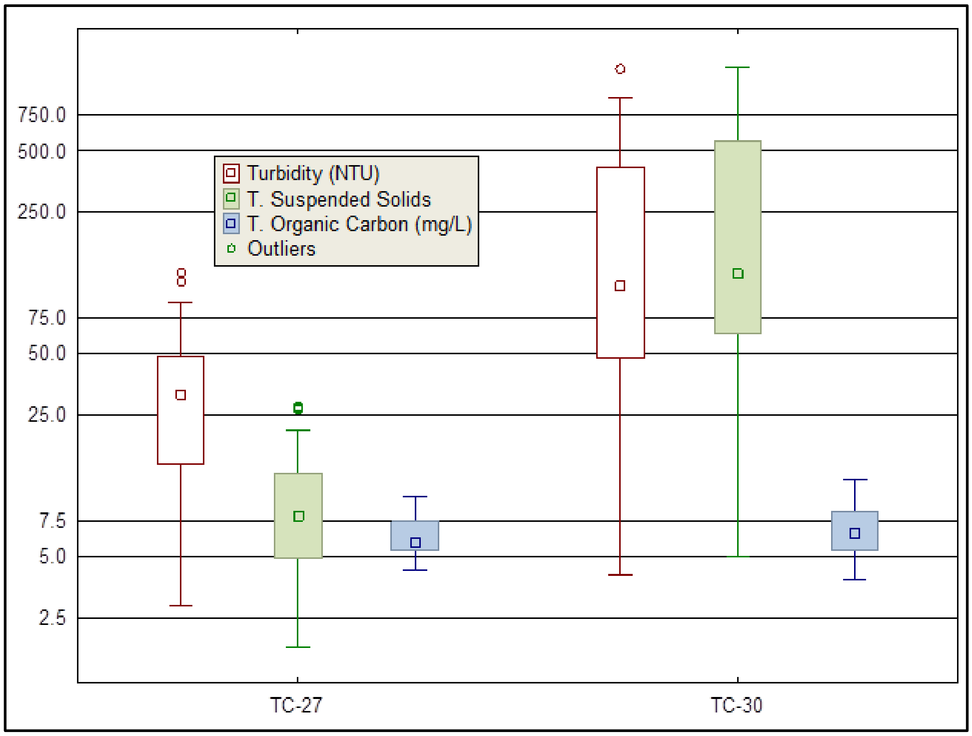


Figure 3-81. Water clarity metrics upstream and downstream of Tuttle Creek Lake from 2010-2019. *Water clarity metrics measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) USACE water quality sample sites from 2010-2019.*

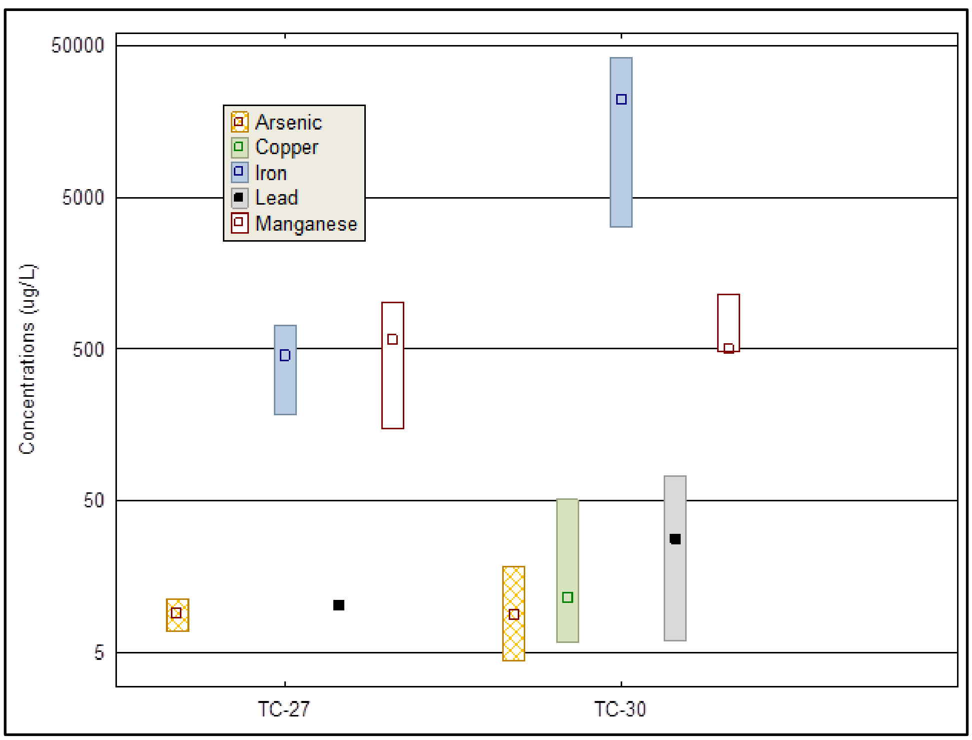


Figure 3-82. Total metal concentrations upstream and downstream of Tuttle Creek Lake from 2010-2019. *Total metal concentration measured from surface samples collected at Tuttle Creek Lake Outflow (TC-27) and main inflow (TC-30) USACE water quality sample sites from 2010-2019.*

Lake Water Quality

Tuttle Creek Lake has been listed as impaired by KDHE and classified as hypereutrophic due to excess phosphorus concentrations. TMDLs for Tuttle Creek Lake were developed to prioritize phosphorus, sediment, and atrazine reduction in the watershed.

Sediment from soil and stream bank erosion in the watershed consist of fine particle sized clay with high phosphorus content resulting in very turbid and nutrient rich water. Tuttle Creek Lake has ranked in the top two for total nitrogen and/or total phosphorus average concentration from 2010-2019 including a low water period due to drought in 2012 and record pool elevation in 2019 as well as a representative year in 2018 (Figure 3-1). High turbidity from suspended clay particles limit sunlight available for algae and cyanobacteria growth in Tuttle Creek Lake. Without light limitation, cyanobacteria would adapt well to the high nutrient environment leading to HABs that would likely exceed Milford Lake in magnitude and duration.

USACE and KDHE pesticide sample results indicate atrazine, alachlor, and metolachlor were occasionally detected in spring samples at Tuttle Creek Lake with higher concentrations at the upper lake site nearer inflow streams. Atrazine concentrations exceeding EPA drinking water criteria of 3 ug/L (Figure 3-83) were only found in the upper lake site. KDHE water quality monitoring results (KDHE 2007, 2010) from Tuttle Creek Lake documented detectable levels of aforementioned herbicides and atrazine degradation byproducts concentrations below EPA drinking water standards or KDHE numeric criteria for aquatic life (KDHE 2005). Atrazine and metolachlor were reported by KDHE as the most common and most concentrate herbicides, similar to Kansas City District Water Quality Program results (Figure 3-83).

Nutrient dynamics in Tuttle Creek Lake are less influenced by bio-attentuation due to light limited primary productivity than other district lakes. Total nitrogen, soluble forms of nitrate/nitrite, ammonia nitrogen, and orthophosphate were found at similar concentrations at upper and lower lake sites with slightly more variability due to proximity to inflow documented at upper lake sites (Figure 3-84). TKN and total phosphorus were reported in higher concentration and were more variable at the upper lake site than lower lake site (Figure 3-84) likely due to gravitational settling of sediment bound phosphorus and organic nitrogen related to suspended particle matter and bacterial activity (Tappin et al., 2010).

A positive trend is observed in the measured total phosphorus concentrations from 2010-2019 (Figure 3-87) from samples at the site TC-3 near the dam. This relatively common trend in Kansas City District lakes indicates an increasing concentration of phosphorus in the reservoir water over time. Concurrently, nitrogen concentrations did not display a significant trend, indicating that nitrogen levels have remained relatively stable during the same sampling period. A negative trend in the Total Nitrogen to Total Phosphorus ratio (TN:TP) can play a crucial role in the dominance of cyanobacteria within the phytoplankton community. Excessive phosphorus levels can potentially favor cyanobacteria over beneficial phytoplankton when the TN:TP ratio is less than 12 (Elser et al., 2007; Xiaofeng et al., 2012; Downing and Mckauley, 1992), as illustrated in Figure 3-88 at Tuttle Creek Lake. Detailed statistical trend analysis of a longer period of sample results are discussed in Future Without Project section.

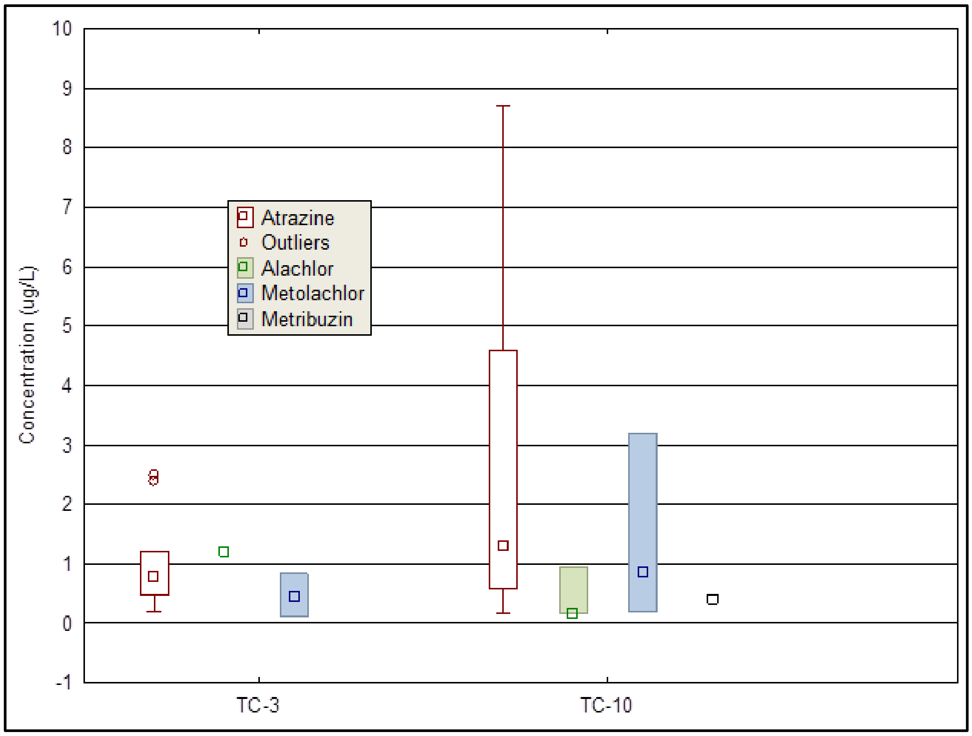


Figure 3-83. Tuttle Creek Lake Herbicide concentrations 2010-2019. *Herbicide concentration measured from surface samples collected at Tuttle Creek Lake USACE water quality sample sites from 2010-2019.*

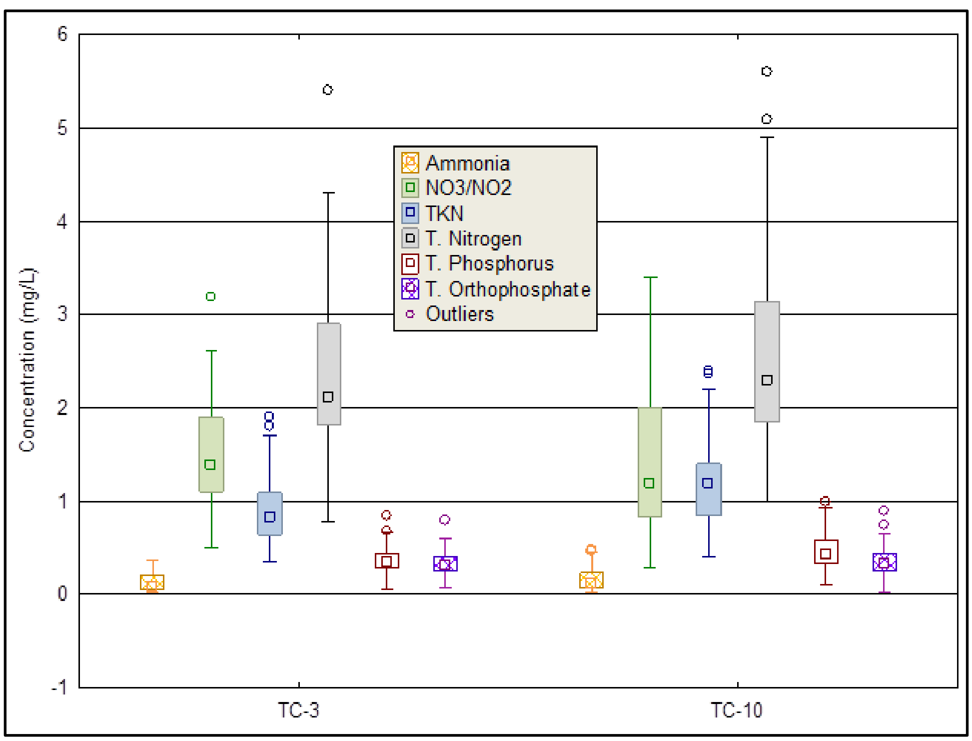


Figure 3-84. Tuttle Creek Lake nutrient concentrations 2010-2019. *Nutrient concentration measured from surface samples collected at Tuttle Creek Lake USACE water quality sample sites from 2010-2019.*

Factors influencing water clarity and light availability encompass inorganic sediment, organic carbon, turbidity, and phytoplankton (quantified through chlorophyll-a concentration) (Testa et al., 2019). The availability of light is critical to biological productivity by imposing limitations on photosynthesis due to light scarcity. Tuttle Creek Lake demonstrates hypereutrophic phosphorus concentrations (>0.096 mg/L), as defined by Carlson (1977), and light limited by inorganic turbidity. Nutrient and sediment influx leads to the classification of trophic states as either hypereutrophic or argillotrophic (KHDE, 2007 and 2010), contingent on the year of sampling. In either scenario, the elevated inorganic turbidity can hinder the establishment of a thriving phytoplankton community (Bhutaiani, 2009; Huisman, 1999).
Upper lake sites exhibit reduced water clarity as a result of higher turbidity, suspended solids, and chlorophyll from phytoplankton growth (Figure 3-85). Concentrations of total organic carbon are elevated and exhibit greater variability at the upper lake site. As depicted in Figure 3-85, lower lake site (TC-3) had significantly lower turbidity and suspended solids promoting greater Secchi depth measurements than the upper site when comparing median values of TC-3 to interquartile range of upper lake sites.

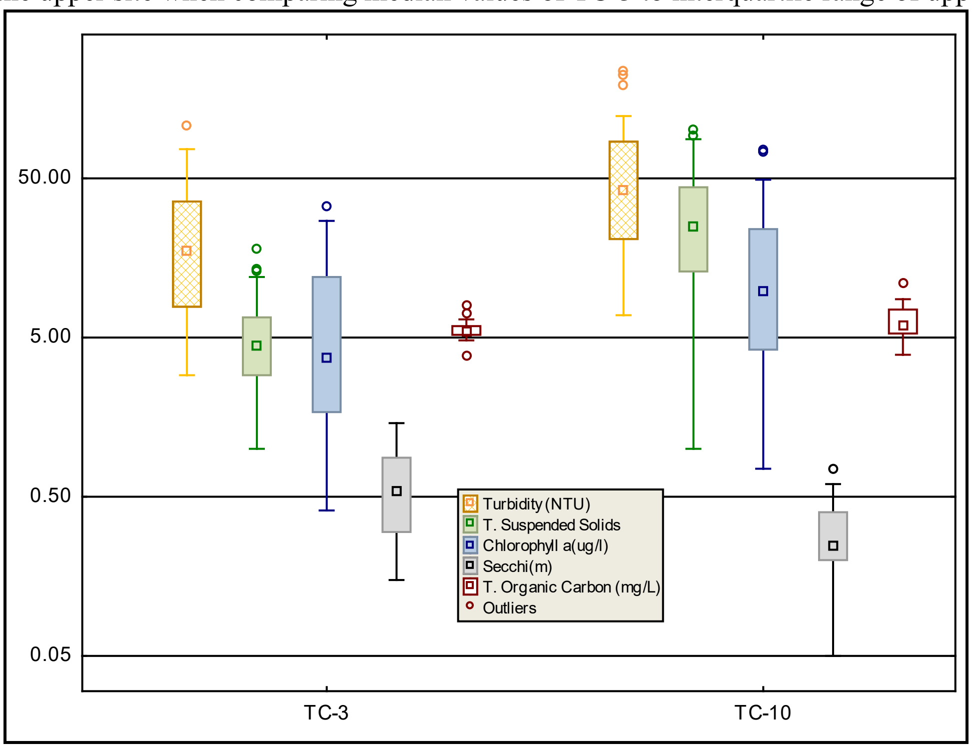


Figure 3-85. Tuttle Creek Lake water clarity metrics 2010-2019. *Water clarity metrics measured from surface samples collected at Tuttle Creek Lake USACE water quality sample sites from 2010-2019.*

Iron, lead, manganese, arsenic, and copper from total metals samples are commonly detected in Kansas City District Water Quality Program samples at Tuttle Creek Lake but have led to impairment designation. Seven inflow streams including Big Blue River are listed as impaired by KDHE (Figure 3-78) due to copper, lead, and arsenic impacts to aquatic life. Total metal concentrations in Tuttle Creek Lake water diminish through gravitational settling with relatively low concentrations found in water quality samples near the dam (TC-3) (Figure 3-86). Iron and manganese are the most common and concentrate metals found in water quality samples from Tuttle Creek Lake.

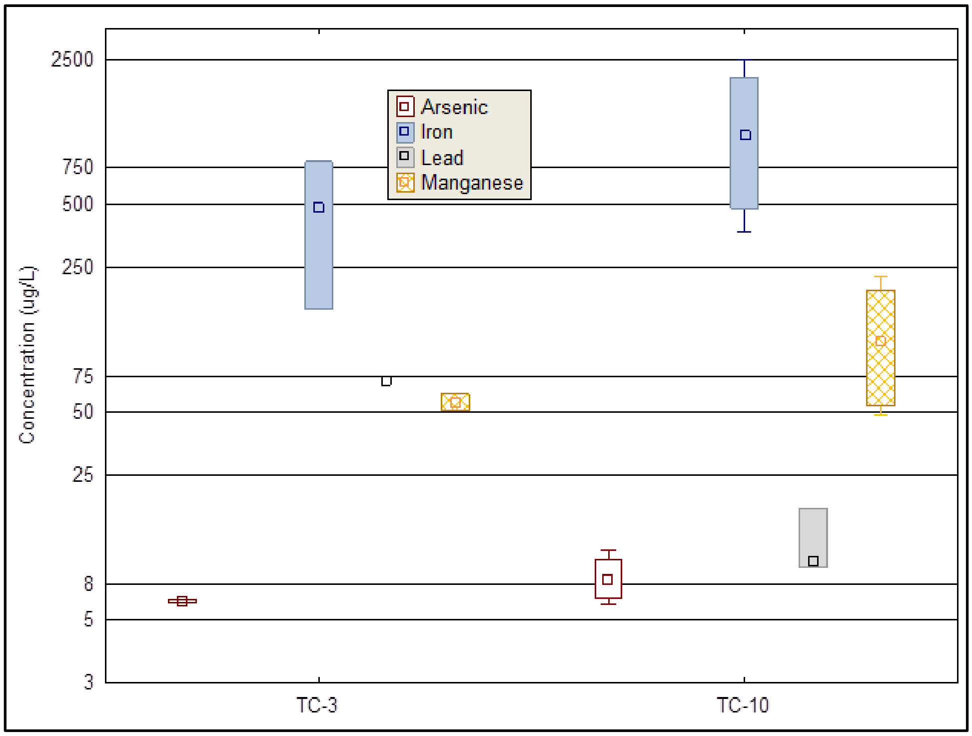


Figure 3-86. Tuttle Creek Lake total metal concentration 2010-2019. *Total metal concentration measured from surface samples collected at Tuttle Creek Lake USACE water quality sample sites from 2010-2019.*

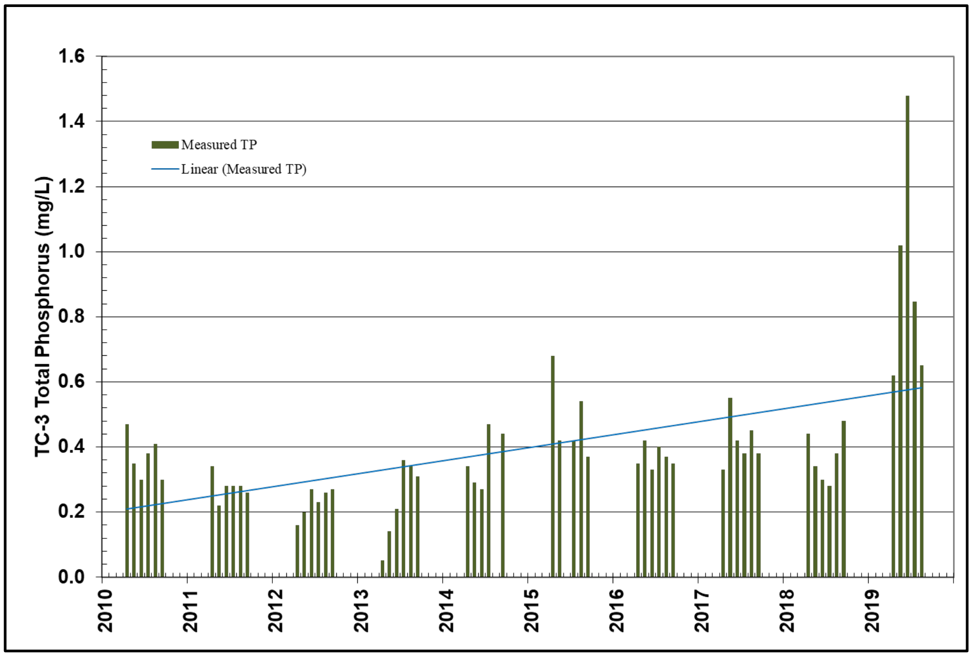


Figure 3-87. Tuttle Creek Lake total phosphorus concentration and linear trend line from 2010-2019. *Measured from surface samples at site TC-3 near dam.*

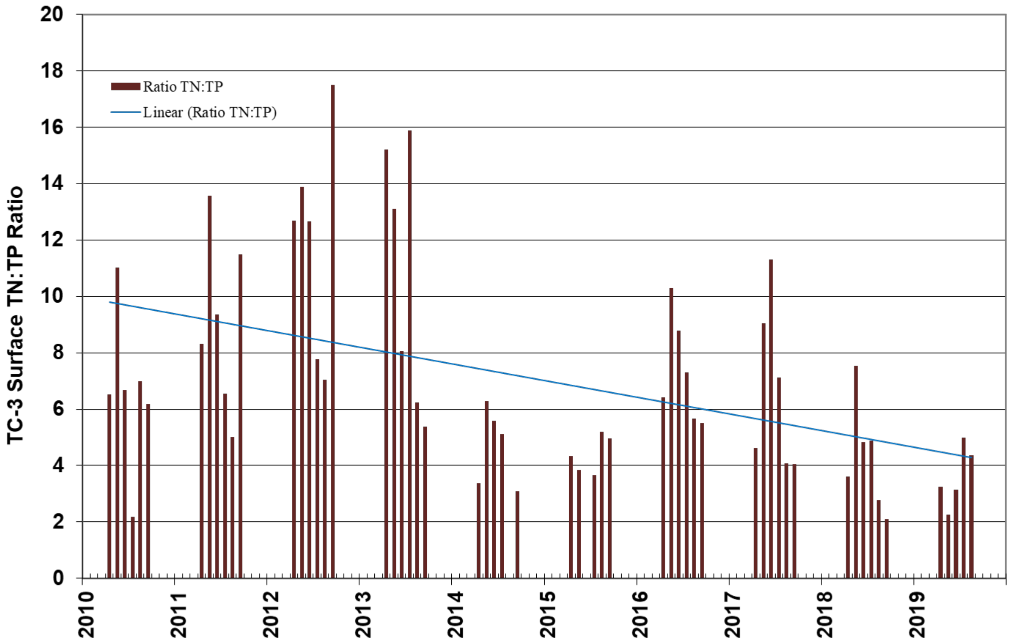


Figure 3-88. Tuttle Creek Lake ratio of total nitrogen to total phosphorus and linear trend line from 2010-2019. *Calculated from measured from surface samples at site TC-3 near dam.*

Annual nutrient measures in Tuttle Creek Lake rank near the top of all Kansas City District lakes (Figure 3-1). Mean and median surface and bottom measures at Tuttle Creek Lake are similar for chemical water quality parameters (Table 3-17) due in part to infrequent thermal stratification. From 2017-2019, bottom samples were only collected during the month of August which imparts a temporal or seasonal bias to bottom chemistry data as well as reduced sample size while demonstrating minor differences between surface and bottom samples when stratification should be most evident. No statistical differences between surface and bottom samples were detected.

Table 3-17. Tuttle Creek Lake summary statistics for chemical water quality parameters 2010-2019.

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.11	0.03	0.20	1.30	0.04	0.01	59
Ammonia (mg/L)	Bottom	0.03	0.01	0.03	0.11	0.02	0.01	13
NO3/NO2 (mg/L)	Surface	1.47	0.08	0.61	3.20	1.40	0.02	59
NO3/NO2 (mg/L)	Bottom	1.41	0.09	0.34	2.00	1.40	0.79	13
TKN (mg/L)	Surface	0.90	0.07	0.57	4.10	0.82	0.20	59
TKN (mg/L)	Bottom	0.64	0.11	0.40	1.50	0.72	0.20	13
Total Nitrogen (mg/L)	Surface	2.37	0.12	0.89	5.40	2.13	0.89	59
Total Nitrogen (mg/L)	Bottom	2.05	0.17	0.62	2.91	1.98	0.99	13
Total Phosphorus (mg/L)	Surface	0.40	0.03	0.23	1.48	0.35	0.05	59

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Total Phosphorus (mg/L)	Bottom	0.33	0.03	0.12	0.64	0.31	0.21	13
Total Orthophosphate (mg/L)	Surface	0.32	0.02	0.17	0.88	0.32	0.00	59
Total Orthophosphate (mg/L)	Bottom	0.27	0.03	0.12	0.46	0.26	0.09	13
Total Suspended Solids (mg/L)	Surface	5.68	0.64	4.88	27.40	4.50	0.00	59
Total Suspended Solids (mg/L)	Bottom	7.50	1.85	6.67	26.30	4.80	2.00	13
Total Organic Carbon (mg/L)	Surface	6.29	0.50	2.28	15.00	5.50	3.90	21
Total Organic Carbon (mg/L)	Bottom	6.13	0.75	2.71	15.00	5.30	4.80	13
Total Iron (ug/L)	Surface	515.67	189.68	328.53	802.00	588.00	157.00	3
Total Iron (ug/L)	Bottom	643.33	249.03	431.33	936.00	846.00	148.00	3
Total Manganese (ug/L)	Surface	57.33	3.23	5.60	61.60	59.40	51.00	3
Total Manganese (ug/L)	Bottom	195.13	74.67	129.33	326.00	192.00	67.40	3

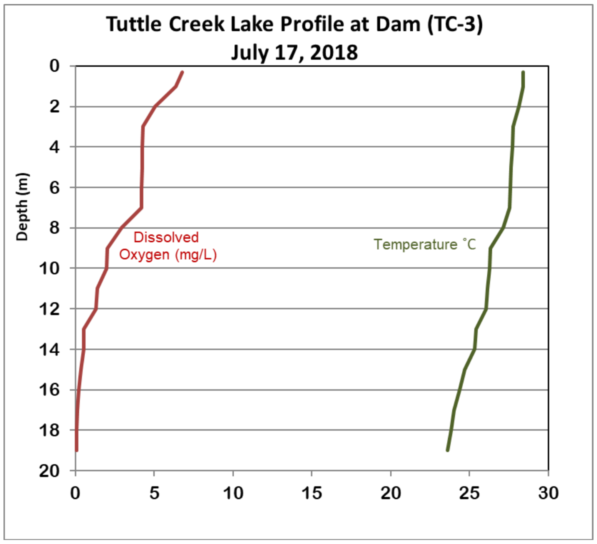
Note: Summary statistics for chemical water quality parameters from Tuttle Creek Lake site near the dam (TC-3), April 2010 through September 2019.

Physical water quality profiles are collected monthly by Kansas City District Water Quality Program to describe physical conditions, aquatic habitat, and define thermal strata. Descriptive statistics of surface and bottom data selected from profile dataset are provided in Table 3-18. Dissolved oxygen is critical to aquatic life and can be used to define available habitat under a variety of seasonal conditions. Tuttle Creek Lake does not frequently develop a defined thermocline in summer months and is best described a weakly stratified for less than two months of the summer as depicted in Figure 3-89. During the short period of stratification, the top 4-6 meters of depth provide well oxygenated habitat for aquatic life with small variations in temperature from top to bottom. The most notable physical water quality difference at Tuttle Creek Lake is that characteristically high turbidity is typically greater and more variable near the bottom while peak turbidity values are recorded near the surface at upper lake sites related to high flow periods (Figure 3-89).

Table 3-18. Tuttle Creek Lake summary statistics for physical water quality parameters 2010 - 2019.

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	7.6	0.2	1.9	12.8	7.3	3.6	106
Oxygen, Dissolved (mg/l)	Bottom	5.5	0.3	3.0	11.6	5.6	0.1	111
pH (Standard Units)	Surface	8.1	0.04	0.5	10.1	8.1	7.3	106
pH (Standard Units)	Bottom	7.9	0.04	0.5	10.1	7.9	7.0	119
Secchi Depth (m)	Surface	0.5	0.03	0.3	1.5	0.4	0.1	103
Chlorophyll *a*	Photic Zone	6.42	1.01	7.50	33.00	3.10	0.27	55
Specific Conductance (µS/cm)	Surface	462.5	10.8	110.7	760.0	453.3	220.0	106
Specific Conductance (µS/cm)	Bottom	461.9	9.6	104.9	740.0	464.8	230.9	119
Turbidity, Field (NTU)	Surface	60.3	14.0	144.8	1260.0	22.9	1.0	106
Turbidity, Field (NTU)	Bottom	107.5	21.4	232.2	119.0	39.8	1.0	119
Water Temperature (°C)	Surface	21.4	0.6	6.4	29.5	23.1	7.1	106
Water Temperature (°C)	Bottom	20.6	0.6	6.3	29.2	22.9	6.8	118

Note: Summary statistics for physical water quality parameters, from all lake sites and dates, Tuttle Creek Lake, April 2010 through September 2019.



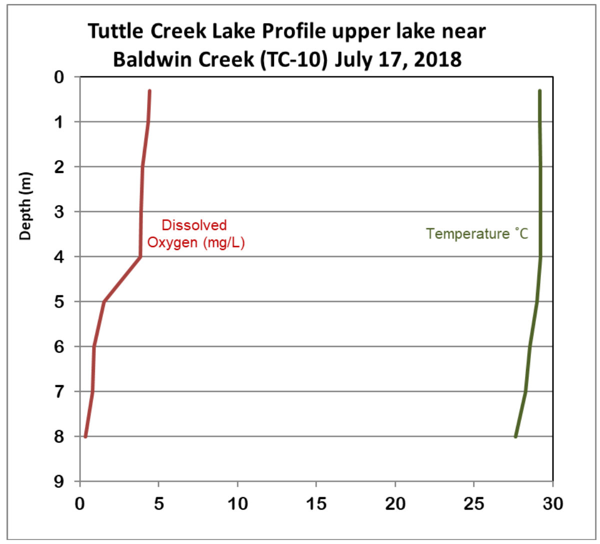


Figure 3-89. Tuttle Creek Lake Representative temperature and dissolved oxygen profiles 2018. *Tuttle Creek Lake representative temperature and dissolved oxygen profiles measured from Tuttle Creek Lake USACE water quality sample sites July 18, 2018.*

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or "recycle" nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). Kansas City District Water Quality Program initiated collection of baseline lake bed sediment data focused on nutrients and herbicides at Tuttle Creek Lake in 2017 (Table 3-19) which have been pooled for this report with more comprehensive lake bed sediment results collected in 2018 for discussions of potential bed sediment removal project(s) at Tuttle Creek Lake.

Median concentrations of nitrogen, phosphorus, and iron from Tuttle Creek samples exceeded those of Kansas City District Lakes in the Kansas River watershed (Figure 3-15). Comparable results of lake bed sediments from Midwest reservoirs were not available. Tuttle Creek nitrogen and phosphorus concentrations were low to moderate when results were compared to lakes from southeast and northern United States (Barko, J.W. and R.M Smart. 1986). Median values of phosphorus and TKN from Kansas City District bed sediment results (Table 3-19) both exceeded respective maximum values reported in a similar USGS study of Tuttle Creek bed sediment (Juracek and Mau, 2002). Trend analysis of phosphorus concentration in cesium-aged sediment cores by Juracek and Mau (2002) did not reveal significant trends from the 1960s-1999 time-period. Metal concentrations reported in Kansas City District bed sediment results (Table 3-19) did not exceed the "probable effect concentration" (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed (MacDonald et al., 2000). Similarly, Juracek and Mau (2002) reported concentrations of arsenic, chromium, copper, nickel, silver, and zinc in bottom-sediment samples of Tuttle Creek Lake exceeded the threshold-effects level as outlined in EPA sediment quality guidelines (U.S. Environmental Protection Agency, 1997) while nickel was the only analyte tested with one sample exceeding the probable-effect level where toxic effects are frequent.

Table 3-19. Tuttle Creek Lake bed sediment chemical concentrations 2017 and 2018.*

Station	Date mm/dd/yyyy	Ammonia Nitrogen mg/kg	Total Kjeldahl Nitrogen mg/kg	Phosphorus mg/kg	Arsenic mg/kg	Copper mg/kg	Iron mg/kg	Lead mg/kg	Manganese mg/kg	Mercury mg/kg	Nickel mg/kg	Zinc mg/kg	Cadmium mg/kg	Chromium mg/kg	Selenium mg/kg	Aluminum mg/kg	Barium mg/kg	Beryllium mg/kg	Cobalt mg/kg	Vanadium mg/kg	Total Solids %
TC-3	8/23/2017	137	2800	1190	10	33	37900	28	1250	0.50	41	142	0.70	40							23
TC-3.1	8/23/2017	250	2990	1150	12	36	42800	41	1100	<0.3	43	162	0.91	48							22
TC-3.2	8/23/2017	145	2450	926	9	30	36500	31	1060	<0.3	39	138	0.72	40							24
TC-3.3	8/23/2017	151	2750	1130	9	32	39200	32	1200	<0.3	41	145	0.81	43							22
TC-4	8/23/2017	298	2820	1190	12	36	40400	33	1030	<0.3	43	150	0.81	45							23
TC-4.1	8/23/2017	318	2570	1200	11	33	40100	33	1120	0.4	40	142	0.77	44			no data				21
TC-5	8/23/2017	232	2740	1150	11	38	42500	33	1130	0.31	45	163	0.87	46							24
TC-6	8/23/2017	199	2510	1190	12	32	38300	34	878	0.34	40	143	0.87	42							28
TC-7	8/23/2017	263	2210	1110	10	30	36000	30	771	0.32	39	136	0.79	40							30
TC-10	8/23/2017	167	2250	931	10	29	33500	25	765	<0.3	37	126	0.74	37							33
TC-10.5	8/23/2017	253	2200	899	9	27	28100	23	767	0.27	33	108	0.75	31							37
TC-11	8/23/2017	247	1840	819	8	22	24000	21	719	<0.3	28	92	0.67	27							43
TC-S2	8/24/2018	75	3660	1120	12	30	37900	30	1070	<0.3	36	140	0.48	44		49000	386	2.8	15	79	23
TC-S3	8/25/2018	86	2240	991	12	27	34900	27	847	<0.3	34	131	0.48	40		44900	360	2.6	14	73	25
TC-S4	8/26/2018	192	2300	1010	11	27	35100	27	1050	<0.3	33	131	0.48	41	1.32	45900	359	2.6	13	74	22
TC-S5	8/27/2018	307	2470	1150	14	29	38100	30	1120	<0.3	36	142	0.56	44	1.82	49800	382	2.8	15	77	22
TC-S6	8/28/2018	167	2620	1040	14	30	39600	30	1020	<0.3	36	149	0.47	46	2.40	51900	386	2.9	14	83	21
TC-S7	8/29/2018	245	2320	938	12	23	29800	21	1130	<0.3	29	105	0.36	35	2.86	38100	304	2.2	13	62	26
Median		216	2490	1115	11	30	37900	30	1055	0.33	38	141	0.73	41	2.11	47450	371	2.7	14	76	23

*Note: *Analytes not detected at quantifiable concentration in USACE samples include 121 herbicides, pesticides, pcb, and metals.*

Internal loading of legacy phosphorus back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al. 2003) increases the potential of HABs in lakes and changes in biota in receiving waters during sediment management/removal activities are concerns expressed by management agencies and stakeholders of many aging lakes in Kansas City District. ERDC Environmental Lab study of sediment characteristics of Kansas City District lakes (James. Unpublished Report., 2009) provides useful information related to fate of nutrients in lakes and bed sediment perturbation. The importance of iron-phosphorus interactions in sediment phosphorus recycling in Kansas City District lakes was highlighted by James (2009). As previously reported, frequent mixing of the water column at Tuttle Creek Lake limits periods of anoxic release of phosphorus and iron from lake bed sediments. Jensen et al. (1992) found that under oxic conditions, release rates decreased with increasing Fe:P ratio in lake bed sediments. Tuttle Creek Fe:P ratio from recent lake bed sediment results mean ratio value of 33 exceeds the threshold of 10-15 described by Jensen et al., (1992) where phosphorus release from sediments is regulated by iron binding sites under oxic conditions. James (2009) calculated potential rates of phosphorus release under anoxic conditions using regression relationships between redox-sensitive phosphorus and anoxic phosphorus release rates (anoxic P release = (redox-sensitive P, g·m-2·cm-1 · 15.1) – 0.7) developed by Pilgrim et al. (2007) for eutrophic lakes in Minnesota. Potential rates ranged between ~ 12 and 37 mg·m-2·d-1 (Figure 3-90). Caution needs to be used in this extrapolation because redox-sensitive phosphorus values for Kansas City District lakes were generally greater than those used in the regression model developed by Pilgrim et al. (2007). Estimates of anoxic phosphorus release are very high at upper Tuttle Creek which and have potential to contribute additional phosphorus to very high ambient conditions.

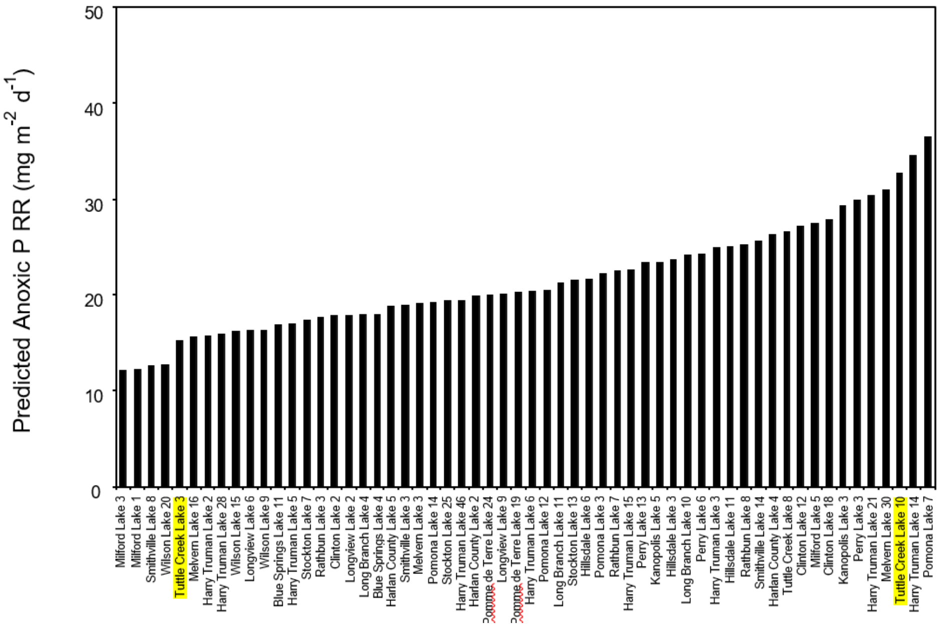


Figure 3-90. Ranges in the predicted phosphorus (P) release rate (RR) under anoxic conditions as a function of Kansas City District lake and station. (James. Unpublished report. 2009)

3.1.7 Clinton Lake

Clinton Lake is a 7,205 acre multi-purpose impoundment built on the Wakarusa River, reaching full pool in 1980. Flood control, water quality, recreation, fish and wildlife, and water supply to most of Douglas County, KS are Clinton Lake Project operating purposes.

Watershed conservation efforts have increased in priority for state and local rankings to address sedimentation and water quality issues at Clinton Lake. The Watershed Restoration and Protection Strategy (WRAPS) program is a KDHE planning and management tool used to identify watershed restoration and protection needs, establish management goals, establish plans (e.g., EPA approved 9-Element Watershed Plans) and implement goals to address water resource concerns (https://www.kdheks.gov/nps/wraps/). Most priority goals/targets of the approved WRAPS Plans for subbasins in the Kanas River Watershed align with strategies and measures included in this study. The WRAPS process is in the implementation and monitoring phase of their process to administer programs using BMPs in Clinton Lake watershed to meet TMDLs on inflow streams and reduce nutrient and fecal loads to meet water quality milestones in Clinton Lake (KDHE 2020).

Reservoir Hydrologic Data Summary

Water management data is critical to interpreting water quality results as hydrologic conditions factor into critical metrics related to flow (i.e., volume, load, and concentration), water residence time, and lake mixing/stratification which in turn influence physical and chemical process, frequently resulting in biological response. Figure 3-91 illustrates reservoir hydrologic data with overlay of water quality sampling events.

Water quality sampling events by Kansas City District staff were conducted monthly from 2010-2019 coinciding with the typical recreational season (April-September). Low inflow periods were observed in 2013-2014 with surface elevation falling below 872 ft while recovery period is apparent beginning late spring of 2015. Significant flooding with a corresponding high-water period was observed in 2019 as inflows peaked at 12,500 cfs with four events exceeding 9,000 cfs from April through August. Surface elevation of Clinton Lake peaked at 21' above conservation-pool elevation (CPE) and exceeded CPE for 271 days in 2019.

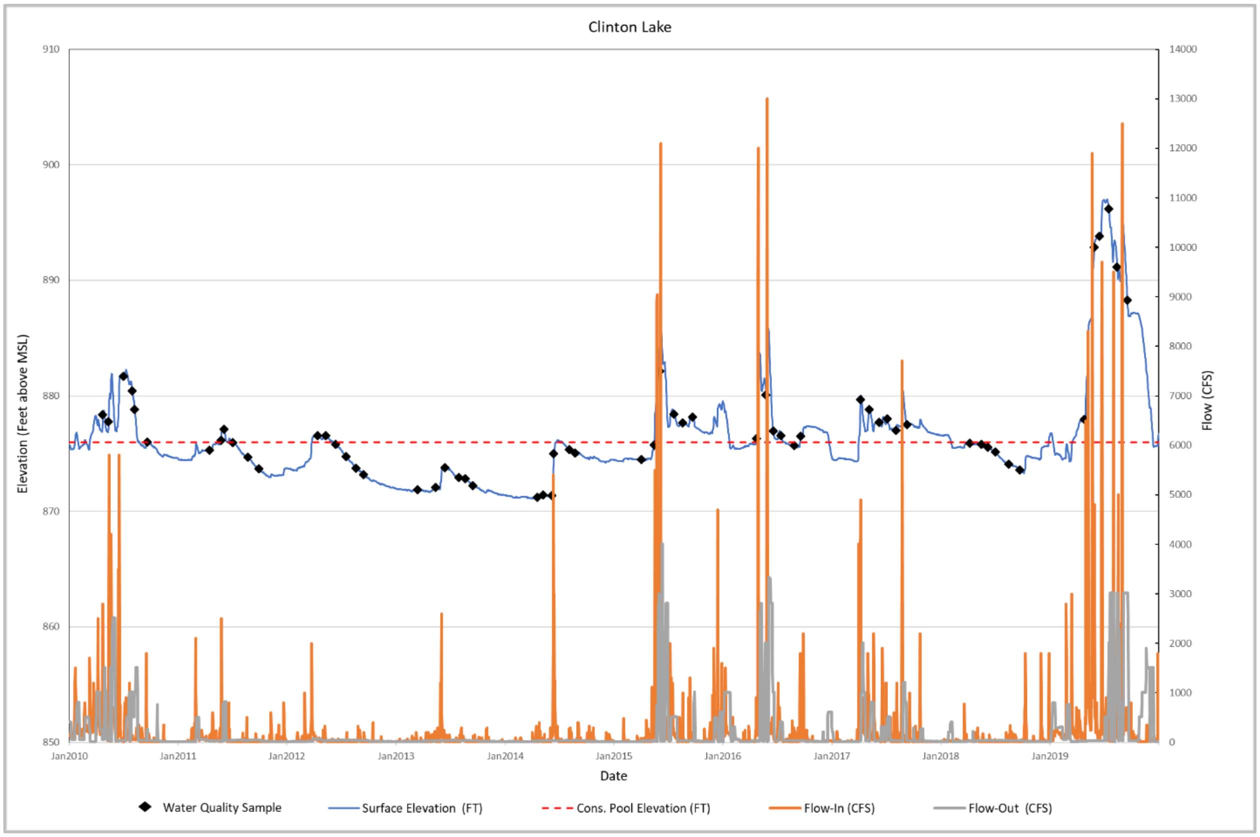


Figure 3-91. Clinton Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Water Quality Sample Locations

Historic water quality sample sites at Kansas City District lake projects are generally named in decreasing numeric order from inflow sites to the outflow site below the dam (Figure 3-92). To provide a representative collection of chemical and physical water quality conditions as water moves from inflow streams, through the lake and exits through the outflow, sample sites are strategically located at safe bridges at stable inflow locations, in the river channel of each main tributary arm of the lake, in the old river channel near the dam, and in an accessible area in the channel of the outflow.

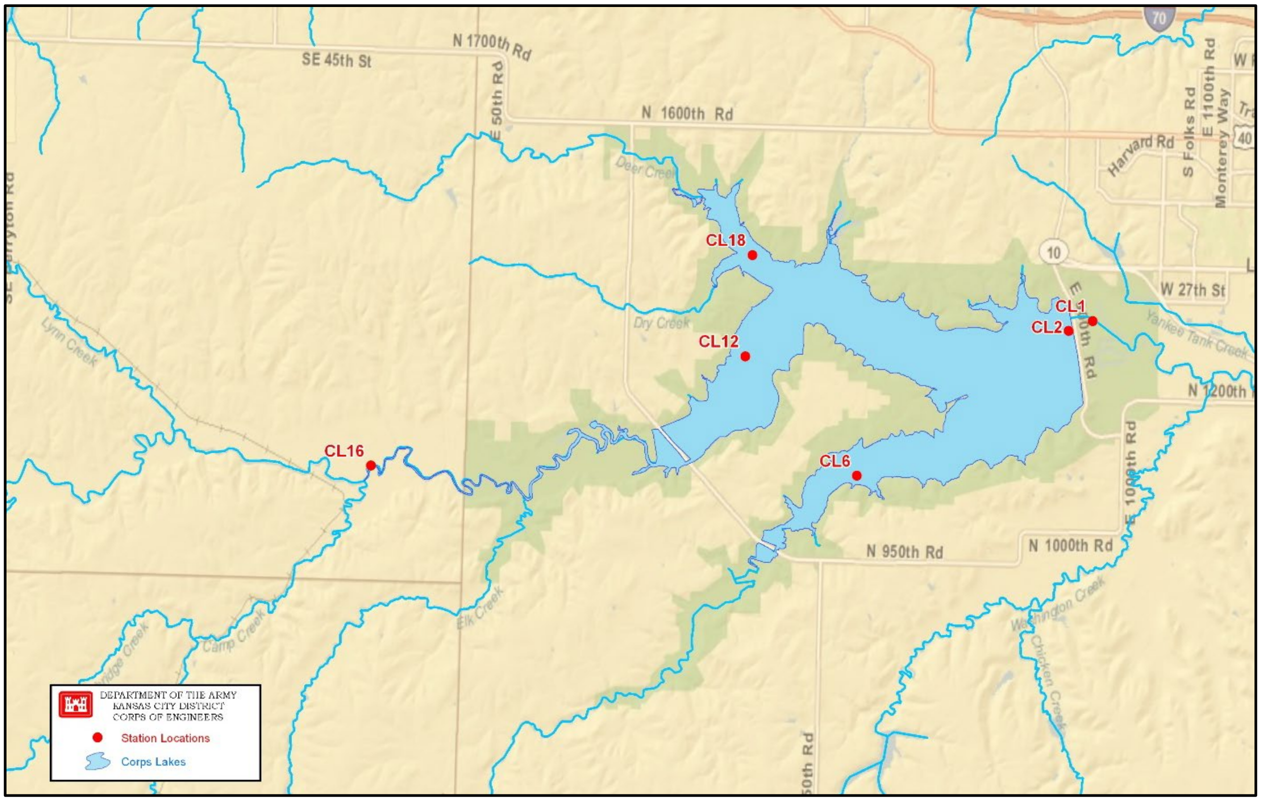


Figure 3-92. Clinton Lake USACE water quality sample sites. *Map of historic USACE water quality sample sites including inflow stream(s), lake water quality/bed sediment sample sites, and outflow.*

Impairments

Excess nutrients and fecal bacteria comprise Clinton Lake and inflow TMDLs defined in 303(d) list provided by KDHE (Figure 3-93). Excess nutrients leading to elevated algal density as defined by chlorophyll *a* concentration is the basis of KDHE eutrophication TMDL. Cyanobacteria blooms occur at low to moderate cell density at Clinton Lake but frequently results in taste and odor issues for drinking water customers utilizing Clinton Lake.

Frequent fecal coliform bacteria exceedances at Wakarusa River and other Clinton Lake tributaries continue to support impaired status. Permitted municipal waste-water treatment, livestock waste management systems, inadequate rural on-site septic systems, and wildlife contribute to the fecal load and the TMDL which has remained since 2000 (KDHE 2000). Fecal bacteria TMDL impacts support of aquatic life, primary contact recreation, and all other designated uses of affected areas. USACE managed swim beaches at Clinton Lake are infrequently closed due to E. coli bacteria, but frequent use by Canada geese and local runoff is the most likely source of contamination.

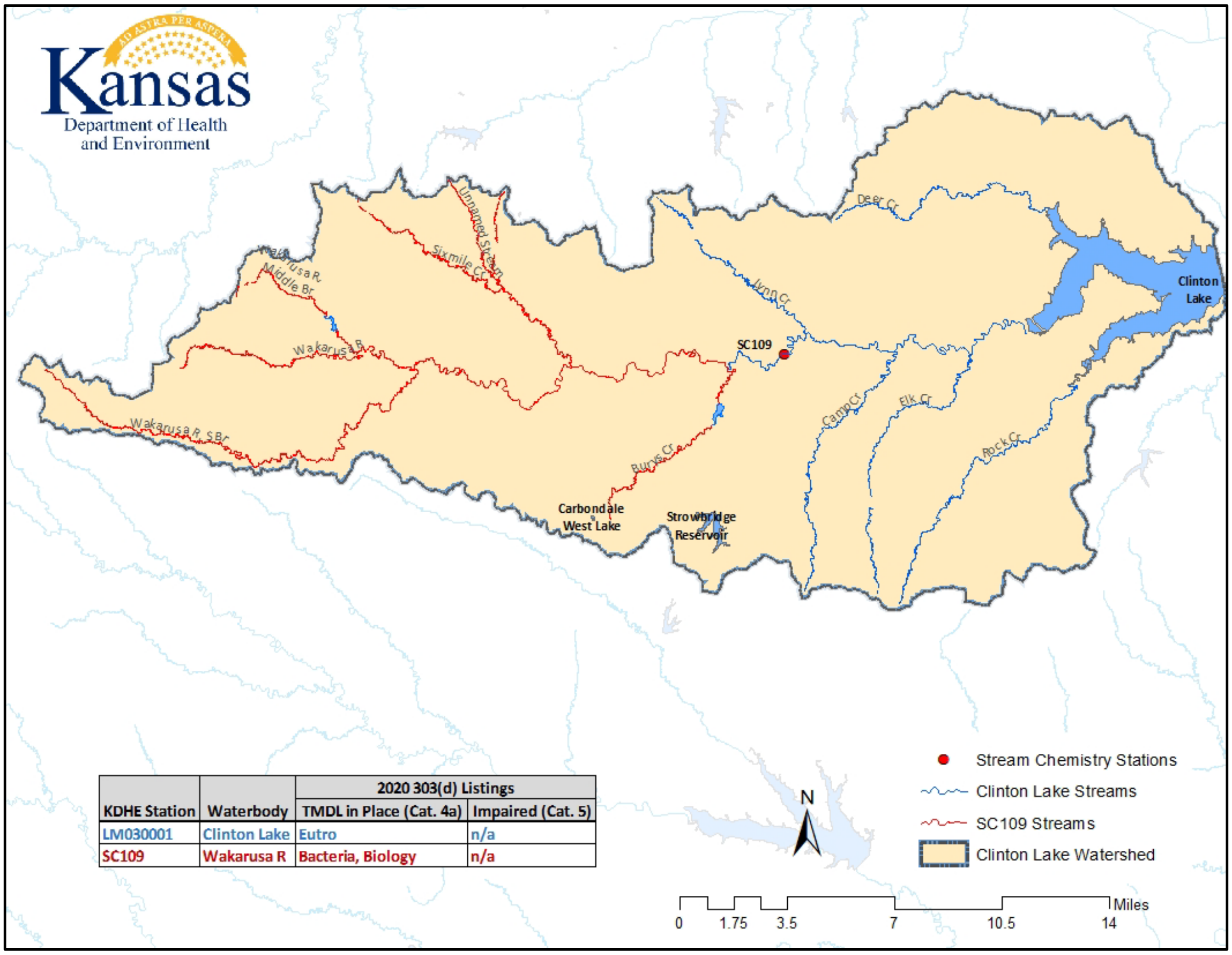


Figure 3-93. Clinton Lake TMDLs 2020. *Impaired waters and TMDLs of Clinton Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Inflow/Outflow

Lakes and reservoirs store sediment and associated chemical compounds carried by inflows and runoff. Sediment, suspended particles, and soluble chemicals enter reservoirs from runoff, groundwater, and inflow streams. Different nutrient and geological sources associated with inflows and source water influence water quality in physical, chemical, and biological composition. Nutrient balance in receiving waters has direct implications on trophic state and is linked to types of plant and algae species or primary production in the lake. Water exiting through the dam or outlet works of Corps' lakes can be quite different than the inflows as large amounts of nutrients, pesticides, and metals are attenuated (i.e., processed/converted to other forms, diluted) or stored in the lake causing a sink effect (Satoh et al., 2002). Many physical changes including temperature, turbidity and dissolved oxygen concentration in outflows are related to release of anoxic water from depths during stratified periods or potential for supersaturation during flood releases.

Clinton Lake inflow streams originate at the eastern edge of the Flint Hills in the Upper Wakarusa watershed extending 40 miles west from the largely forested Lawrence-Douglas County area out into the Tallgrass Prairie areas of Shawnee, Osage and Wabaunsee counties. Natural Resource Conservation

Service (NRCS) data for the BMP applications and surveys of the watershed indicate that approximately 60% of the cropland and 40% of the grassland in the watershed are still in need of conservation practices to minimize runoff and erosion (KDHE 2011a).

Herbicides have been monitored at Clinton Lake by Kansas City District Water Quality personnel since 1996. The list of herbicides detected have included mostly chlorinated species and chemical constituents of atrazine, alachlor, metolachlor, cyanazine, metribuzin, simazine, acetochlor, 2, 4-D, and glyphosate. EPA regulation of herbicide licensing to reduce chemical persistence and mobility in the environment have reduced the number and concentration of chemicals detected in KANSAS CITY DISTRICT Water Quality samples. Total atrazine and alachlor concentrations peak during planting season in the spring and are associated with runoff events as herbicides mobilize and enter the Republican River in concentrations typically much higher than those exiting through the outlet. Median concentrations of atrazine in Figure 3-94 indicate inflows consistently have higher atrazine than the outflow (CL-1) while median values and interquartile range of data at both sample sites during the period of analysis fall below the EPA drinking water criteria of 3 ug/L. Similarly, detectable levels of metolachlor and alachlor in the inflow and outflow are less than EPA drinking water standards 3 ug/L and 2 ug/L, respectively (EPA 1995).

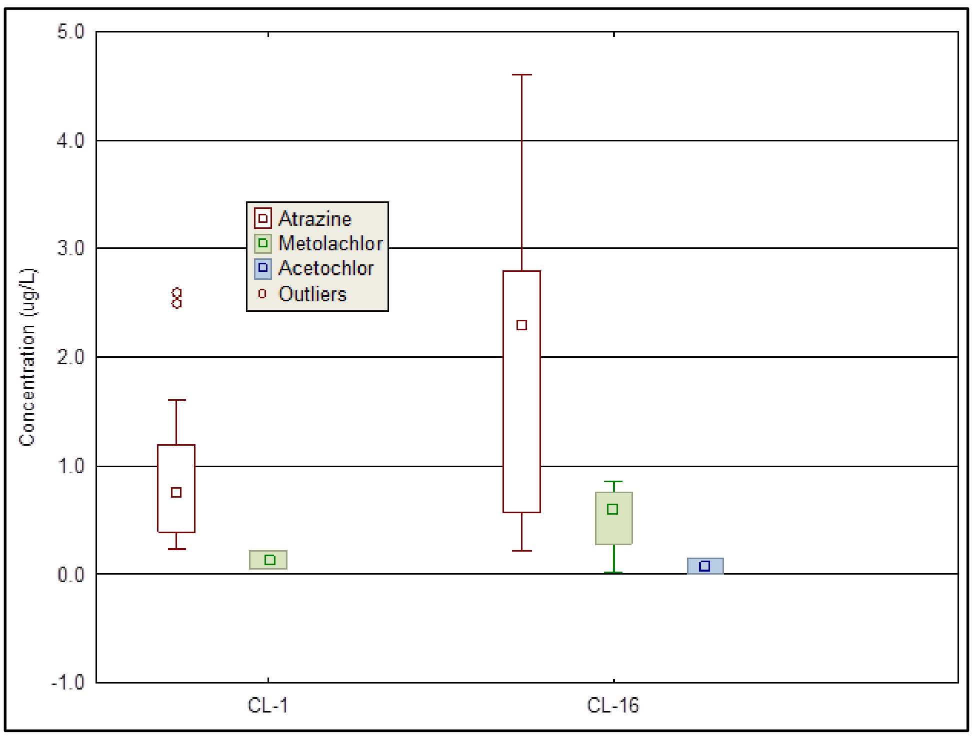


Figure 3-94. Herbicide concentrations upstream and downstream of Clinton Lake from 2010-2019. *Herbicide concentration measured from surface samples collected at Clinton Lake Outflow (CL-1)) and main inflow (CL-16) USACE water quality sample sites from 2010-2019.*

Inflows into Clinton Lake carry nutrient loads (Figure 3-95) associated with sediment as well as point and non-point source nutrients. Median values for total nitrogen, nitrate/nitrite, and total phosphorus measured at inflow site exceeds the 75th percentile (Q3) found in the outflow which is indicative of significant attenuation and denitrification occurring in Clinton Lake. Mann-Whitney U Tests of all nutrient analytes grouped by sample site in Figure 3-95 detect significant differences ($P<0.05$) in sample means between inflow and outflow $N0_3/N0_2$, TKN, TN, and TP.

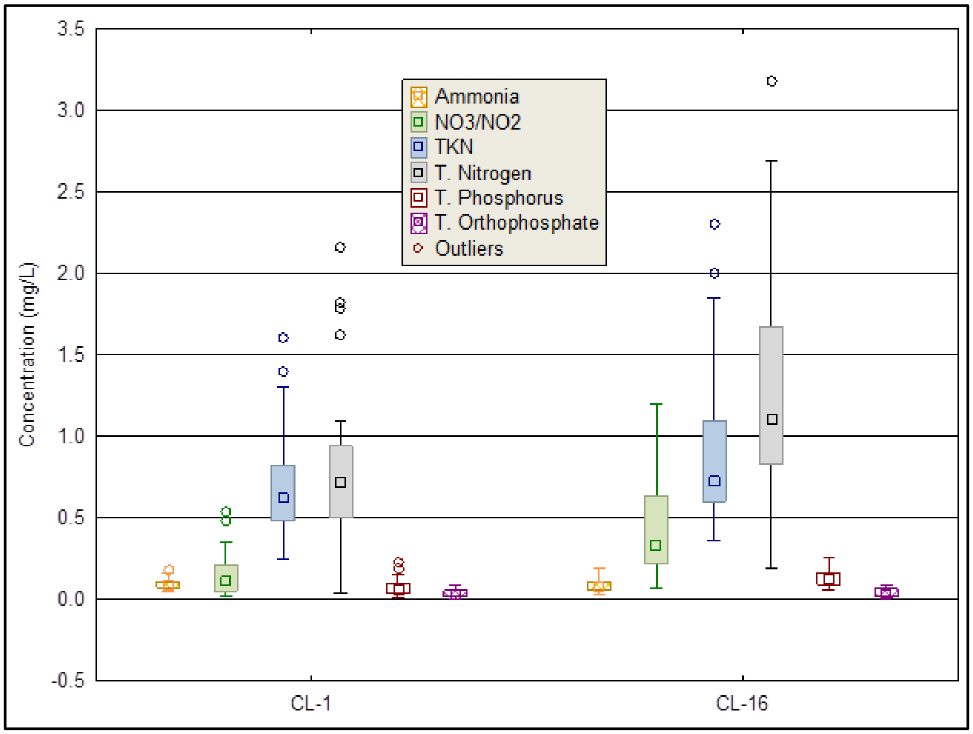


Figure 3-95. Nutrient concentration upstream and downstream of Clinton Lake from 2010-2019. *Nutrient concentration measured from surface samples collected at Clinton Lake Outflow (CL-1)) and main inflow (CL-16) USACE water quality sample sites from 2010-2019.*

Water clarity improves from residency in Clinton Lake as suspended particles and sediment settle out. Median turbidity and total suspended solids are up to three times greater at inflow sites than the outflow (Figure 3-96) while total organic carbon mean values at inflows and outflow were not significantly different (P=0.096).

Total metals discussions for Clinton Lake inflows and outflow (Figure 3-97) are limited for valid comparison due to small sample size related to concentrations below minimum detection limit (e.g., As, Cu, Ni, and Zn) combined with the 3-year sample frequency allowing for maximum of 3 data sets in a 10-year period of analysis. Mean values of total iron (μ=1,441 ug/L), total lead (μ=5.4 ug/L), and total manganese (μ=265 ug/L) calculated for samples at Cl-16 on the Wakarusa River did not exceed acute criteria Kansas water quality standards (KDHE 2018).

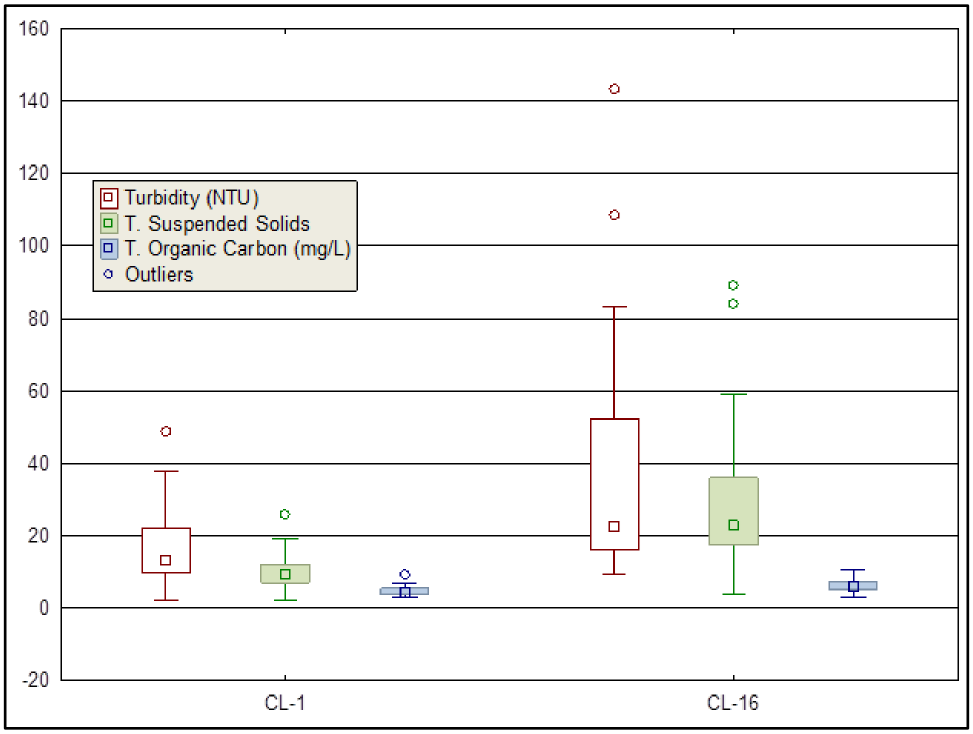


Figure 3-96. Water clarity metrics upstream and downstream of Clinton Lake from 2010-2019.
Water clarity metrics measured from surface samples collected at Clinton Lake Outflow (CL-1)) and main inflow (CL-16) USACE water quality sample sites from 2010-2019.

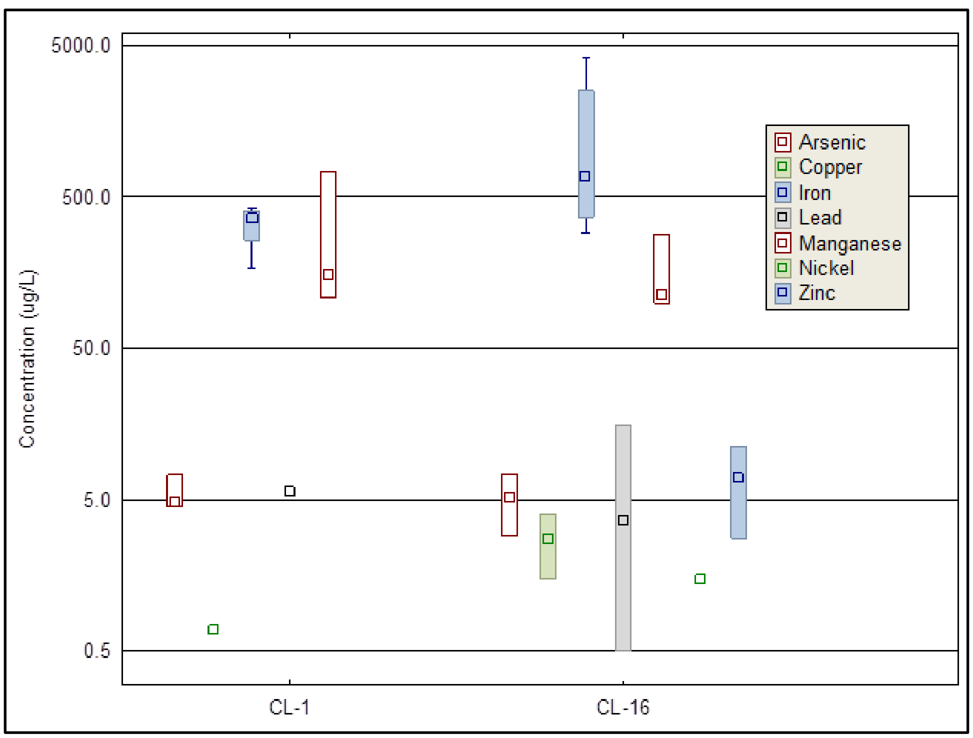


Figure 3-97.Total metals upstream and downstream of Clinton Lake from 2010-2019.
Total metals surface samples collected at Clinton Lake Outflow (CL-1)) and main inflow (CL-16) USACE water quality from 2010-2019.

Lake Water Quality

Physical and chemical attenuation (e.g., dilution, dispersion, chemical changes, and uptake by organisms) of compounds and settling of suspended matter leads to a general decrease in concentration of many constituents of water quality, often interpreted as improved water quality, as water moves through a reservoir system (Bosch et al., 2009). This process will be evident with many analytes in graphic representations in lake water quality sections. The following section is an overview of chemical and physical data from surface samples from four lakes sites, describes chemical and physical differences between surface and bottom strata at the site near the dam and stratification, and briefly describes available phytoplankton and cyanobacteria data related to public health advisories.

Herbicides are detected in relatively low concentration in Clinton Lake samples. Three common herbicides detected in lake samples include atrazine, metolachlor, and acetochlor (Figure 3-98). EPA recommendations for maximum exposure of 3 ppb of atrazine was exceeded in one of fifty-five samples collected from 2010-2019.

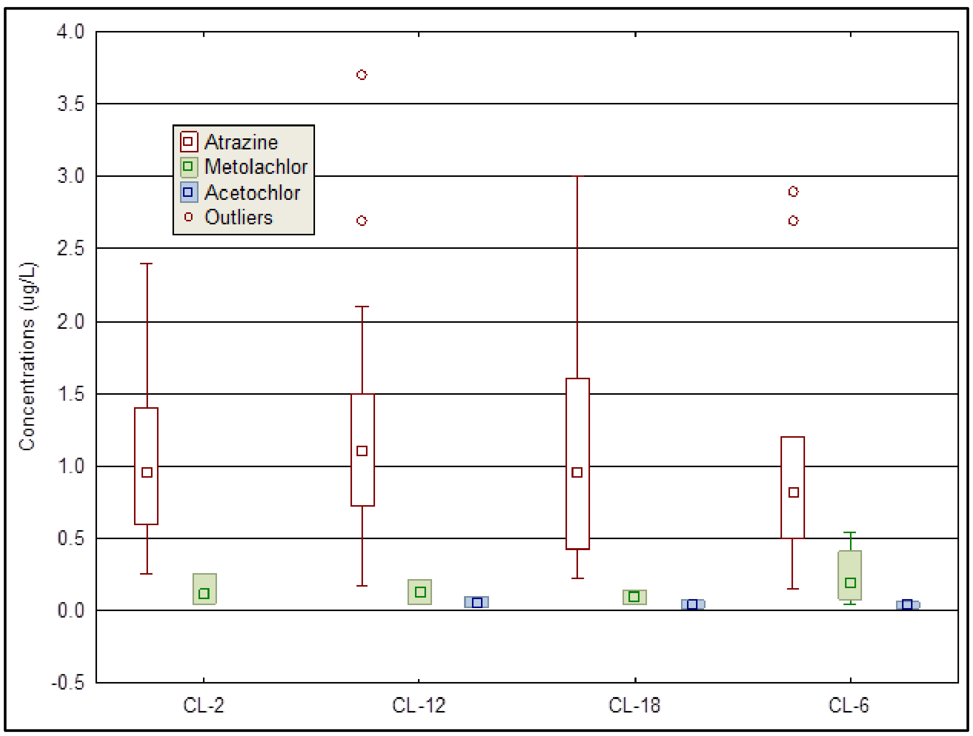


Figure 3-98. Clinton Lake herbicide concentrations 2010-2019. *Herbicide concentration measured from surface samples collected at Clinton Lake USACE water quality sample sites from 2010-2019.*

Nutrient enrichment and sediment loads degrade water quality and reduce expected lifespan of USACE district lakes including Clinton Lake. Sediment and phosphorus reduction goals for Clinton Lake with a BMP implementation schedule spanning 50 years are outlined in Upper Wakarusa River WRAPS 9 Element Watershed Plan (KDHE 2020). WRAPs 10-year milestones for total phosphorus in Clinton Lake is 0.048 ug/L for the 2011-2021 evaluation period. Mean and median total phosphorus from 2010-2019 at the lower lake site near the tower was 0.06 mg/L and 0.05 mg/L, respectively (Figure 3-99, Table 3-20). Nutrient concentrations are all more variable and frequently measured higher concentrations at the Rock Creek Arm site (CL-6) with median values for TN, TKN, and TP exceeding the interquartile range of the respective medians at CL-2, CL-12, and CL-18.

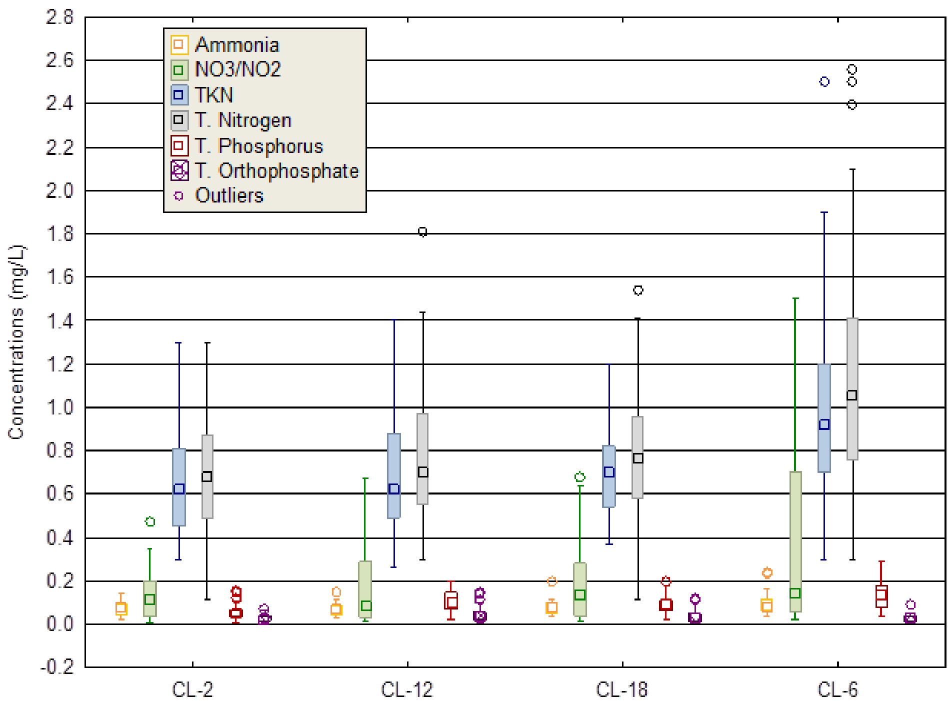


Figure 3-99. Clinton Lake nutrient concentrations 2010-2019. *Nutrient concentration measured from surface samples collected at Clinton Lake USACE water quality sample sites from 2010-2019.*

Clinton Lake inflows carry inorganic sediment and well as suspended organic matter impacting water clarity. Attenuation of sediment and other compounds affecting water clarity through Clinton Lake is apparent as median TSS, turbidity, total organic carbon, and chlorophyll a at the three upper lake sites (CL-12, CL-18, CL-6) all exceed 75th percentile (Q3) of the respective data reported from the lower Clinton Lake site (CL-2) (Figure 3-100). Similarly, median Secchi depth measures at the CL-2 exceeded 80-99% of Secchi data from upper lake sites as water transparency increased from decreased turbidity and suspended matter.

Total metals concentration from surface samples from Clinton Lake sites are represented in Figure 3-101. Small sample size due to limited sampling effort and several sample results below minimum reporting limit have limited the utility of the data. Ranked in order of relative abundance, iron, manganese, arsenic, copper and lead were present at all at Clinton Lake USACE water quality sample sites from 2010-2019. Seven additional metals were included in total metals analysis from 2010-2019 with results reported as below the minimum detection level. Median total manganese and total lead values at sample site CL-2 are below the 25^{th} percentile (Q1) of the three upper lakes sites indicating a significant decline from upper to lower lake sites. Several sample results below minimum reporting limit for copper, arsenic and lead at CL-2 indicate a similar decline in metal concentration from upper to lower lake sites.

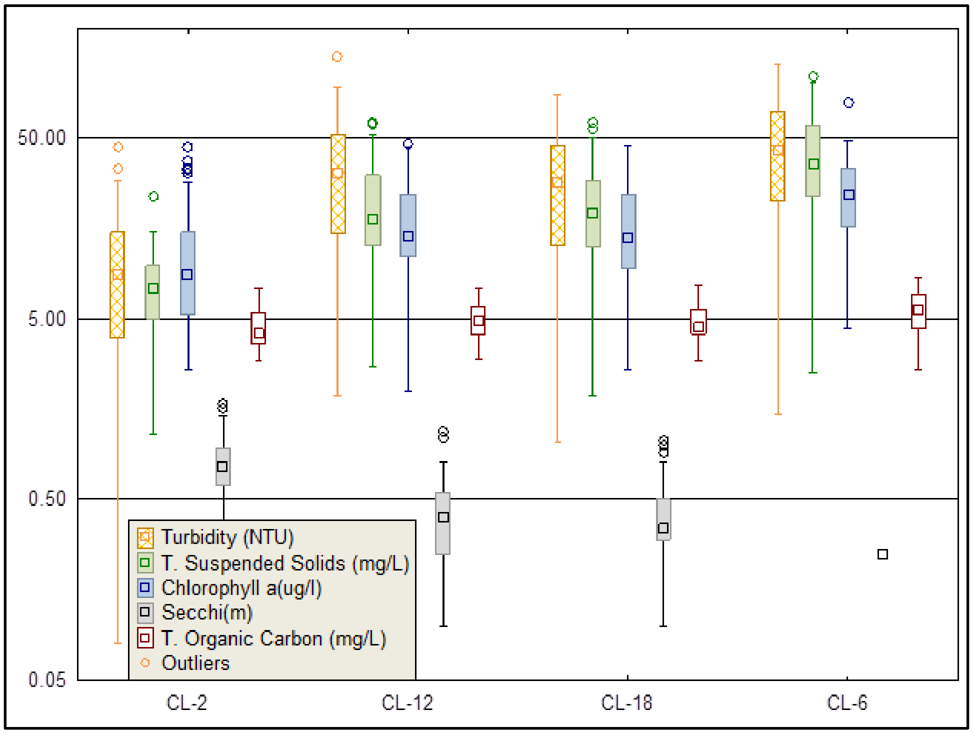


Figure 3-100. Clinton Lake water clarity metrics 2010-2019. *Water clarity metrics measured from surface samples collected at Clinton Lake USACE water quality sample sites from 2010-2019.*

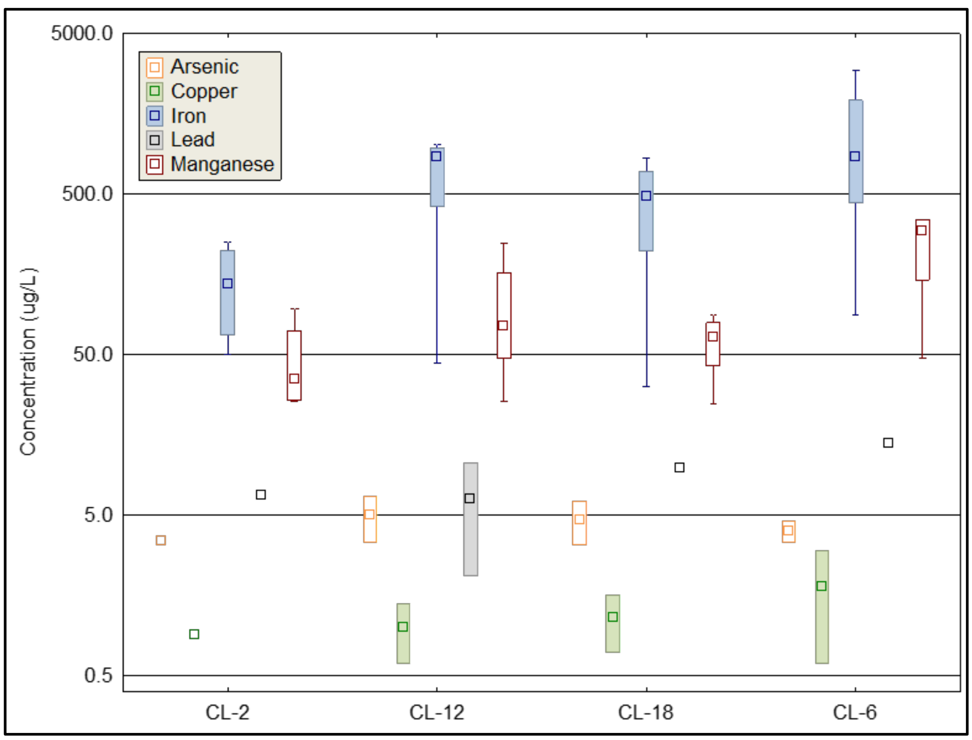


Figure 3-101. Clinton Lake total metal concentration 2010-2019. *Total metal concentration measured from surface samples collected at Clinton Lake USACE water quality sample sites from 2010-2019.*

Water quality chemistry differences between surface and bottom samples at Clinton Lake site nearest the dam (CL-2) are described in statistical summary Table 3-20. USACE collects bottom samples routinely from Kansas City District lakes every third year with total metals collected during the month of August when stratified conditions are most likely to show increased metal solubility due to anoxic conditions near the bottom. When the lake is not stratified (mixed) bottom sample results are similar to surface sample results for most analytes. Clinton Lake chemical results were significantly different (Wilcoxon Signed-Rank Test; $p<0.05$) between top and bottom sample groups for ammonia, total phosphorus, total orthophosphate, total suspended solids, total iron and total manganese.

Table 3-20. Clinton Lake summary statistics for chemical water quality parameters 2010-2019.[1]

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Ammonia (mg/L)	Surface	0.04	0.01	0.04	0.14	0.04	0.02	60
Ammonia (mg/L)	Bottom	0.14	0.06	0.21	0.74	0.03	0.02	14
NO_3/NO_2 (mg/L)	Surface	0.08	0.01	0.11	0.47	0.02	0.007	60
NO_3/NO_2 (mg/L)	Bottom	0.16	0.05	0.20	0.76	0.11	0.01	14
TKN (mg/L)	Surface	0.58	0.04	0.29	1.30	0.56	0.14	60
TKN (mg/L)	Bottom	0.86	0.19	0.69	2.70	0.59	0.14	14
Total Nitrogen (mg/L)	Surface	0.66	0.04	0.30	1.31	0.66	0.15	60
Total Nitrogen (mg/L)	Bottom	1.02	0.22	0.84	3.46	0.66	0.29	14
Total Phosphorus (mg/L)	Surface	0.06	0.01	0.03	0.16	0.05	0.01	60
Total Phosphorus (mg/L)	Bottom	0.11	0.03	0.12	0.50	0.06	0.01	14
Total Orthophosphate (mg/L)	Surface	0.02	0.01	0.02	0.07	0.01	0.01	60
Total Orthophosphate (mg/L)	Bottom	0.04	0.02	0.06	0.18	0.01	0.01	14
Total Suspended Solids (mg/L)	Surface	8.02	0.70	5.42	37.00	7.20	1.00	60
Total Suspended Solids (mg/L)	Bottom	18.26	3.08	11.53	45.00	14.00	6.60	14
Total Organic Carbon (mg/L)	Surface	4.94	0.45	2.61	16.10	4.20	2.90	33
Total Organic Carbon (mg/L)	Bottom	4.64	0.30	0.91	6.15	4.30	3.70	9
Chlorophyll *a* (ug/L)	Photic Zone	11.9	1.29	9.43	44.0	8.7	2.6	53
Total Iron (ug/L)	Surface	175.43	49.68	86.05	252.00	192.00	82.30	4
Total Iron (ug/L)	Bottom	1084.7	639.29	1278.59	2930.0	679.50	49.80	4
Total Manganese (ug/L)	Surface	181.58	126.69	253.38	559.00	70.40	26.50	4
Total Manganese (ug/L)	Bottom	661.43	461.06	922.11	2030.00	295.00	25.70	4

Note: [1/] Summary statistics for chemical water quality parameters from Clinton Lake site near the dam (CL-2), April 2010 through September 2019.

Physical water quality differences between surface and bottom samples pooled from all Clinton Lake water quality sites are described in statistical summary Table 3-21. USACE collects physical water quality data profiles at all lakes sites monthly during sampling season. When the lake is not stratified (mixed) bottom sample results are similar to surface sample results for many analytes. Specific conductance was the only physical characteristic that was similar from surface to bottom results reported in Table 3-21. Paired T-Tests results indicate surface and bottom sample means were significantly different (P<0.05) for temperature, dissolved oxygen, turbidity, and pH. Physical water quality conditions at all sites on Clinton Lake, similar to most stratified lakes, experience seasonal conditions which are not ideal for aquatic life and usable habitat is limited by adequate dissolved oxygen or species-specific physical conditions. Reduced habitat due to low D.O. and elevated temperature under stratified conditions is common below the thermocline as noted near the dam (CL-2) in Figure 3-102. Upper lake sites may mix enough to prevent formation of a thermocline but still experience lower oxygen near the bottom without being anoxic as illustrated at site CL-12 in Figure 3-102. Dissolved oxygen sag frequently is associated with low light conditions and/or large inflows combined with extended periods of cloudy weather associated with storms. Dissolved oxygen sags from respiration caused by excess algae production, as defined by chlorophyll *a* concentration exceeding 12 ug/L (Figure 3-99, Table 3-20), is the most common short-term impact of eutrophication and is basis for TMDL on Clinton Lake.

Table 3-21. Clinton Lake Summary statistics for physical water quality parameters 2010-2019.[1]

Parameter	Sample Depth	Mean	SE	SD	Maximum	Median	Minimum	N
Oxygen, Dissolved (mg/l)	Surface	8.3	0.1	1.4	12.0	8.1	4.7	124
Oxygen, Dissolved (mg/l)	Bottom	5.0	0.3	3.0	10.5	6.6	0.1	127
Water Temperature (°C)	Surface	24.2	0.5	5.2	32.9	25.7	9.4	124
Water Temperature (°C)	Bottom	21.3	0.4	4.9	29.5	22.8	8.9	127
pH (Standard Units)	Surface	8.2	0.03	0.3	9.3	8.2	7.6	124
pH (Standard Units)	Bottom	7.9	0.03	0.4	8.6	7.9	7.1	127
Secchi Depth (m)	Surface	0.6	0.03	0.3	1.9	0.5	0.1	108
Secchi Depth (m)	Bottom							NA
Specific Conductance (µS/cm)	Surface	327.9	3.9	43.3	523.0	323.6	223.3	124
Specific Conductance (µS/cm)	Bottom	331.6	3.6	40.6	414.1	327.0	242.9	127
Turbidity, Field (NTU)	Surface	23.9	4.4	48.9	501	13.2	1.0	124
Turbidity, Field (NTU)	Bottom	54.1	6.2	58.6	580.2	30.4	1.0	125

Note: *Summary statistics for physical water quality parameters, from all sites and dates, Clinton Lake, April 2010 through September 2019.*

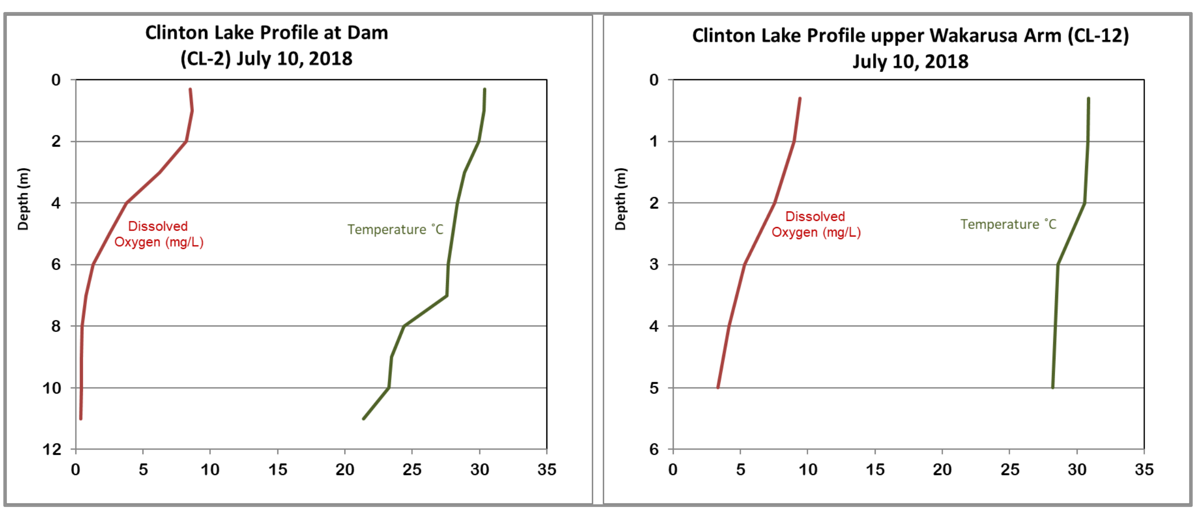


Figure 3-102. Clinton Lake representative temperature and dissolved oxygen profile 2018. *Representative temperature and dissolved oxygen profile measured from Clinton Lake USACE water quality sample sites July 10, 2018.*

Lake bed Sediment Quality

Sediment quality (i.e., nutrients and contaminants) is frequently ignored in water quality discussions until aging lakes begin to release or "recycle" nutrients (e.g., phosphorus) back into the water column by various mechanisms (Pettersson 1998; Søndergaard et al., 2003) and/or sediment removal discussions trigger contaminant concerns (Peterson, S.A. 1984). Kansas City District Water Quality Program initiated collection of baseline lake bed sediment data focused on nutrients and herbicides at Clinton Lake in 2016 (Table 3-22).

Median concentrations of nitrogen, manganese, and iron from Clinton Lake bed samples ranked as top two of seven Kansas City District Lakes in the Kansas River watershed (Figure 3-15) while sediment phosphorus ranks near the median for District lakes. Median total nitrogen and total phosphorus bed sediment results from 2016 and 2019 Kansas City District bed sediment results (Table 3-22) from all Clinton Lake sites were 775 mg/kg and 852 mg/kg, respectively. A study of Clinton Lake bed sediment by USGS (Juracek, 2011) reported higher median nutrient values of 2,300 mg/kg and 990 mg/kg, respectively with uniform nitrogen distribution between lake sites and in core samples indicating consistent nitrogen inputs over time with inconclusive trend results to clearly define a possible increase in phosphorus inputs over time. Clinton Lake sediment concentrations of arsenic, cadmium, and nickel exceeded the respective threshold-effects guidelines (MacDonald et al., 2000) in which toxic biological effects occasionally occur. This is typical for reservoirs in eastern Kansas (Juracek, 2003, 2004; Juracek and Mau, 2002) and comparable TEC exceedances for arsenic, chromium, and nickel reported for Clinton Lake sediment USGS (Juracek, 2011). Metal and trace element concentrations reported by USGS and Kansas City District bed sediment results (Table 3-22) did not exceed the "probable effect concentration" (PEC) in which harmful effects to sediment dwelling aquatic organisms are likely to be observed.

Table 3-22. Clinton Lake Chemical concentration in lake bed sediment samples 2016 and 2019.

Station	Date	Ammonia MG/KG	Total Nitrogen MG/KG	Phosphorus MG/KG	Copper MG/KG	Iron MG/KG	Lead MG/KG	Manganese MG/KG	Nickel MG/KG	Zinc MG/KG	Arsenic MG/KG	Cadmium MG/KG	Chromium MG/KG
CL-12	9/13/2016	212.0	1983.0	1010.0	22.0	36900.0	24.1	1440.0	38.8	120.0	15.3	1.0	37.7
CL-18	9/13/2016	50.4	1123.0	532.0	12.4	18600.0	14.2	599.0	22.2	62.9	9.7	0.7	19.9
CL-6	9/13/2016	66.6	1563.0	90.9	17.8	19700.0	16.2	435.0	28.7	74.8	8.1	1.1	22.6
Site Median		**66.6**	**1563.0**	**532.0**	**17.8**	**19700.0**	**16.2**	**599.0**	**28.7**	**74.8**	**9.7**	**1.0**	**22.6**
Mean		**109.7**	**1556.3**	**544.3**	**17.4**	**25066.7**	**18.2**	**824.7**	**29.9**	**85.9**	**11.0**	**0.9**	**26.7**
CL-12	9/17/2019	99.8	775.0	920.0	15.0	37500.0	21.4	416.0	34.1	68.0	6.8	0.5	12.6
CL-18	9/17/2019	85.4	676.0	874.0	15.0	33300.0	21.0	407.0	32.9	67.6	6.6	0.8	13.1
CL-2	9/17/2019	53.2	628.0	693.0	11.8	28200.0	15.6	358.0	25.0	49.1	6.1	0.3	11.5
CL-6	9/17/2019	99.2	664.0	852.0	15.2	33700.0	20.1	294.0	32.4	66.1	6.2	0.8	13.0
Site Median		**92.3**	**670.0**	**863.0**	**15.0**	**33500.0**	**20.6**	**382.5**	**32.7**	**66.9**	**6.4**	**0.6**	**12.8**
Mean		**84.4**	**685.8**	**834.8**	**14.3**	**33175.0**	**19.5**	**368.8**	**31.1**	**62.7**	**6.4**	**0.6**	**12.6**

3.2 Upstream USBR Reservoirs

Six USBR reservoirs in the Kansas River watershed are described herein using USBR documents and water quality data and TMDL information provided by KDHE. Hydrological and water management data was provided by USACE using Hydrologic Engineering Center Data Storage System Visual Utility Engine.

For detailed information on sample collection methods, see the Lake and Wetland Chemistry Monitoring Program Quality Assurance Management Plan. Website link: http://www.kdheks.gov/environment/qmp/download/Lake_and_Wetland_Part_III.pdf

3.2.1 Keith Sebelius Lake

Keith Sebelius Lake (conservation pool area of 2,181 acres, volume of 34,510 ac-ft, and a 715 mi^2 drainage area) was created in 1967 in Norton County, KS on the Prairie Dog Creek as part of USBR water supply project called the Almena Unit. The project consists of Norton Dam and Keith Sebelius Reservoir (formerly Norton Reservoir), Almena Diversion Dam, Almena Main and South Canals, and a system of laterals and drains serving 5,763 acres of project lands and the city of Norton, KS. Flood protection, recreation, and fish and wildlife benefits are also project purposes as authorized by the Flood Control Act of 1946.

Reservoir Hydrologic Data Summary

Surface elevation of Keith Sebelius Lake did not meet conservation pool elevation in 2010-2019 evaluation period (Figure 3-103). Four water quality sampling events are plotted with lake surface elevation for reference. Water quality sampling in 2019 followed the most significant pool raise of the decade. Low inflow periods were observed in 2012-2015 with surface elevation falling 17 ft below conservation pool while recovery period is apparent beginning fall of 2016.

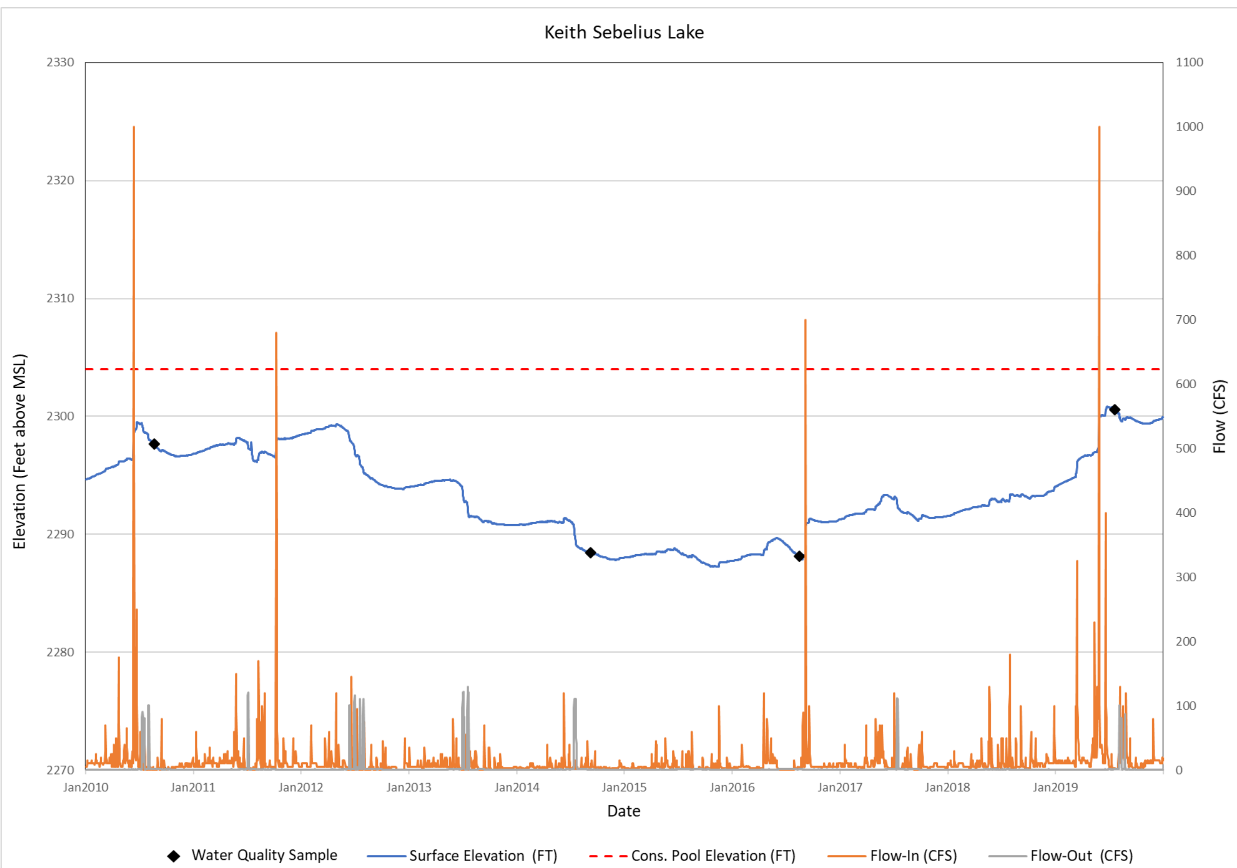
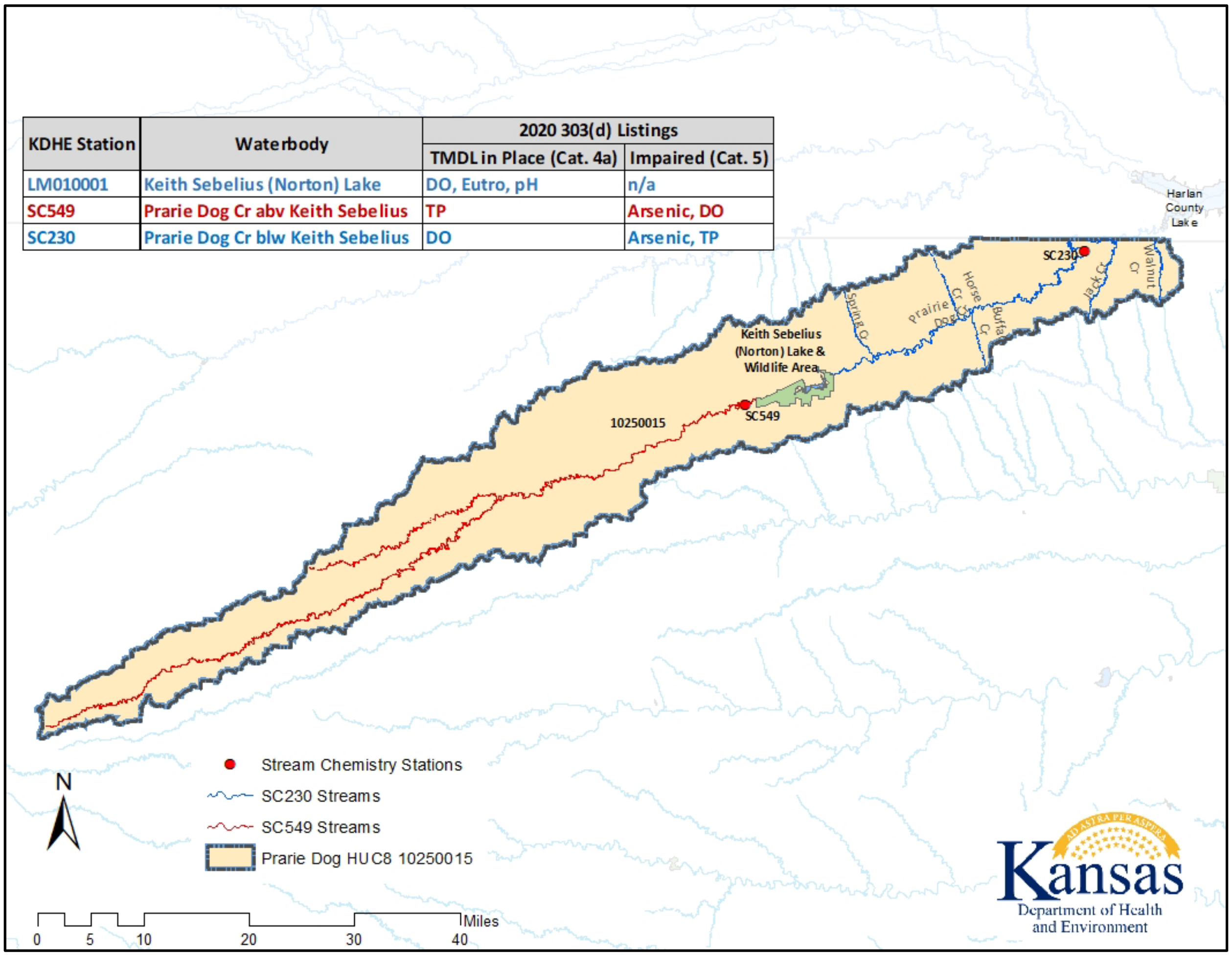


Figure 3-103. Keith Sebelius Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Impairments to Keith Sebelius Lake and Prairie Dog Creek are associated with high phosphorus load and naturally occurring arsenic in the watershed (Figure 3-104). The TMDL designated for accelerated eutrophication or enrichment from phosphorus is linked to increased aquatic plant growth as measured by average chlorophyll *a* concentration exceeding 12 ug/L (KDHE 2003). Prolific algae growth can be beneficial algae or cyanobacteria but high densities create conditions for secondary water quality problems for aquatic life also listed as TMDLs for dissolved oxygen sags and elevated pH. To determine impairments (TMDLs) for Upper and Lower Prairie Dog Creek, and Keith Sebelius Lake, Prairie Dog Creek WRAPS consulted with KDHE to determine load reductions targets needed for focused BMPs and water quality milestones for Keith Sebelius Lake (Norton Lake in WRAPS Plan)(KDHE 2012).



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM010001	Keith Sebelius (Norton) Lake	DO, Eutro, pH	n/a
SC549	Prarie Dog Cr abv Keith Sebelius	TP	Arsenic, DO
SC230	Prarie Dog Cr blw Keith Sebelius	DO	Arsenic, TP

Figure 3-104.Keith Sebelius Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Keith Sebelius Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Field Measured Water Quality Data Summary

Physical water quality conditions for Keith Sebelius Lake are provided in Table 3-23. Minimum dissolved oxygen value of 5 mg/L and maximum pH of 8.3 represent the worst conditions for two variables collected during the sample period for surface samples. These values do not exceed their respective water quality criteria as observed in Prairie Dog Creek data used for TMDL justification (KDHE 2003). Mean and median Secchi values of approximately one meter and median turbidity of 8.6 NTU provide for a functional photic zone and do not suggest light limitation to productivity, similar to previous water quality report for Keith Sebelius (Norton) Lake (KDHE 2012).

Temperature and dissolved oxygen profiles for field data collected from 2014-2019 are presented in Figure 3-105. Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Increased water depth and a likely increase in biochemical oxygen demand associated with nutrient pulse from large inflow provided better conditions for thermal stratification at Keith Sebelius and other Kansas lakes in 2019 as evidence of a defined thermocline with dissolved oxygen and temperature decline at 5 meters of depth. The profiles for 2014 and 2016 are more common during summer conditions at the USBR Lakes in Kansas.

Table 3-23. Physical water quality statistics from KDHE field measurements of Keith Sebelius Lake from 2010-2019.

	Keith Sebelius Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	8	7.47	7.17	5.00	10.51	5.53	9.44	2.27	0.80
Temp °C	10	26.15	26.60	24.20	27.00	26.00	27.00	1.07	0.34
Secchi (m)	4	0.99	0.97	0.58	1.45	0.61	1.38	0.45	0.22
pH	8	8.17	8.20	7.89	8.30	8.07	8.30	0.16	0.06
Conductivity umho/cm	8	734.56	730.00	632.90	840.00	651.80	820.00	91.38	32.31
Turbidity NTU	8	9.39	8.64	4.30	17.00	4.76	13.50	5.19	1.84

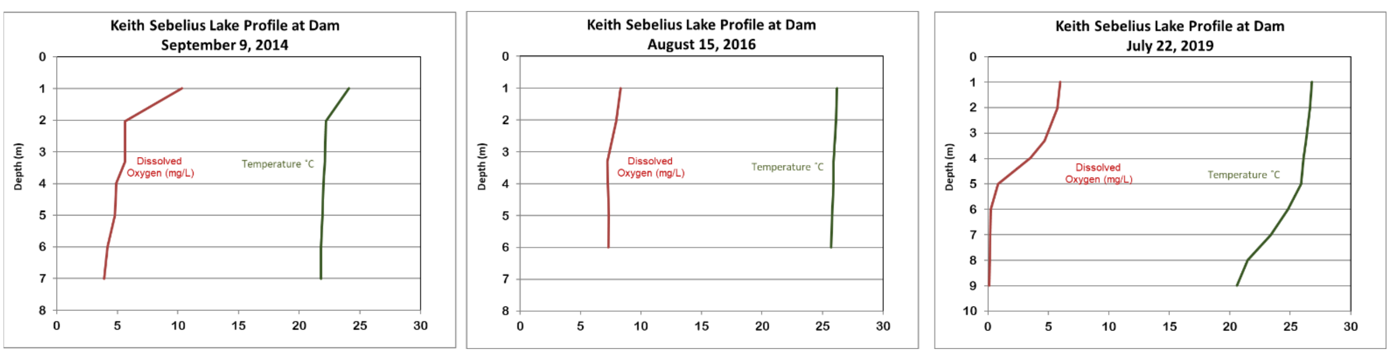


Figure 3-105. Keith Sebelius Lake representative temperature and dissolved oxygen profiles 2014-2019. *Field data collected 2010-2019 provided courtesy of KDHE.*

Laboratory Water Quality Analysis Summary

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Keith Sebelius Lake in Table 3-24. Values below minimum reporting limits influence sample size in some analytes (e.g., zinc and total suspended solids) while other analytes (e.g., ammonia, orthophosphate, mercury) measured below reporting limits in all samples and consequently were omitted from results table.

Pesticide detections were infrequent and well below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in KS lakes. Maximum concentrations of atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Keith Sebelius Lake was 1.16 mg/L which compares to the high nitrogen USACE lakes (e.g., Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeds EPA Ecoregional Recommended Criteria of 0.62 mg/L (EPA 2001). Total nitrogen mean was less than 10-year lake milestone of 1.17 mg/L defined in WRAPS 9-Element for 2011-2020 (KDHE 2012).

Keith Sebelius Lake total phosphorus mean of 0.182 mg/L is above the hypereutrophic threshold (Carlson 1977) and more than two times the 10-year lake milestone of 0.078 mg/L defined in WRAPS 9-Element for 2011-2020 (KDHE 2012). Eutrophic conditions with high phosphorus load has combined with adequate water clarity to increase algal production. Mean chlorophyll a concentration of 31.2 ug/L was more than two times the WRAPS 10-year lake milestone of 12.2 ug/L as well as TMDL goal (KDHE 2003). Cyanobacteria blooms have led to increased HAB Warnings due to toxic algae including the most recent public health warning lasting 5 weeks of the recreational season of 2022.

Bromide concentrations are of concern for water treatment operations due to byproducts as bromide is converted to bromate in their treatment process and there are EPA disinfection byproduct limitations on the amounts of bromate (KWO personal communication, 2022). Increasing bromide trends from 1995 to present in Upper Republican watershed, including Prairie Dog Creek subbasin, is of concern for future water supply. Median Keith Sebelius Lake bromide concentration of 0.48 mg/L is nearly twice the median bromide value of 1995-2019 Prairie Dog Creek values (KDHE unpublished report).

Total metals in Keith Sebelius Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria including Domestic Water Supply of 0.010 mg/L of total arsenic (KDHE 2018).

Table 3-24. Water quality chemistry statistics from KDHE surface samples of Keith Sebelius Lake from 2010-2019. *Metals and metalloid values represent total recoverable concentration (mg/L).*

	Keith Sebelius Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	5	1.012	0.710	0.560	1.900	0.590	1.300	0.580	0.259
Metolachlor µg/L	1	0.330	0.330	0.330	0.330	0.330	0.330		
TKN nitrogen mg/L	8	1.168	1.180	0.770	1.600	0.855	1.450	0.340	0.120
T. nitrogen mg/L	8	1.168	1.180	0.770	1.600	0.855	1.450	0.340	0.120
Chlorophyll a µg/L	8	31.2	26.9	17.5	52.5	18.7	44.2	14.9	5.3
Alkalinity mg CaCO3/L	8	205.5	210.0	190.0	212.2	200.0	211.0	9.6	3.4
Bromide mg/L	8	0.537	0.485	0.250	0.930	0.345	0.730	0.265	0.094
Chloride mg/L	8	74.2	75.0	49.5	97.0	55.4	93.0	20.8	7.4
Sulfate mg/L	8	54.3	55.0	40.7	67.0	42.4	66.0	12.6	4.4
Total organic carbon mg/L	8	9.149	9.150	8.141	10.000	8.376	10.000	0.822	0.291
Phosphorus mg/L	8	0.182	0.170	0.110	0.260	0.140	0.232	0.057	0.020
Total suspended solids mg/L	2	21.500	21.500	21.000	22.000	21.000	22.000	0.707	0.500
Arsenic mg/L	8	0.007	0.008	0.006	0.008	0.007	0.008	0.001	0.0002
Boron mg/L	8	0.122	0.123	0.078	0.170	0.086	0.155	0.039	0.014
Copper mg/L	5	0.002	0.001	0.001	0.002	0.001	0.001	0.000	0.0002
Iron mg/L	8	0.208	0.177	0.054	0.420	0.087	0.330	0.146	0.052
Magnesium mg/L	8	29.6	29.0	22.0	38.0	23.0	36.5	7.2	2.6
Manganese mg/L	8	0.120	0.113	0.090	0.159	0.093	0.149	0.030	0.011
Nickel mg/L	8	0.002	0.002	0.001	0.002	0.001	0.002	0.0003	0.0001
Selenium mg/L	6	0.002	0.003	0.002	0.003	0.002	0.003	0.001	0.0002
Zinc mg/L	1	0.007	0.007	0.007	0.007	0.007	0.007		
Strontium mg/L	6	0.546	0.575	0.479	0.590	0.479	0.580	0.053	0.021
Uranium mg/L	5	0.006	0.006	0.003	0.006	0.006	0.006	0.001	0.001

3.2.2 Lovewell Lake

Lovewell Lake in Jewell County, KS was completed on White Rock Creek in the Republican River basin in 1957 for flood control and irrigation. Lovewell Lake is managed by USBR with recreation bolstered by a popular state park managed by KDWP including 2,215 acres of land adjacent to the 2,987 acre lake.

Reservoir Hydrologic Data Summary

Surface elevation of Lovewell Lake moves around conservation pool elevation as flood control and irrigation requirements were apparent during 2010-2019 period (Figure 3-106). Four water quality sampling events are plotted with lake surface elevation for reference. Water quality sampling events were near normal pool including 2019 which followed a significant pool fluctuation but occurred at conservation pool elevation. Low periods of inflow were observed in 2012-2015 with conservation pool elevation attained annually during the spring rise.

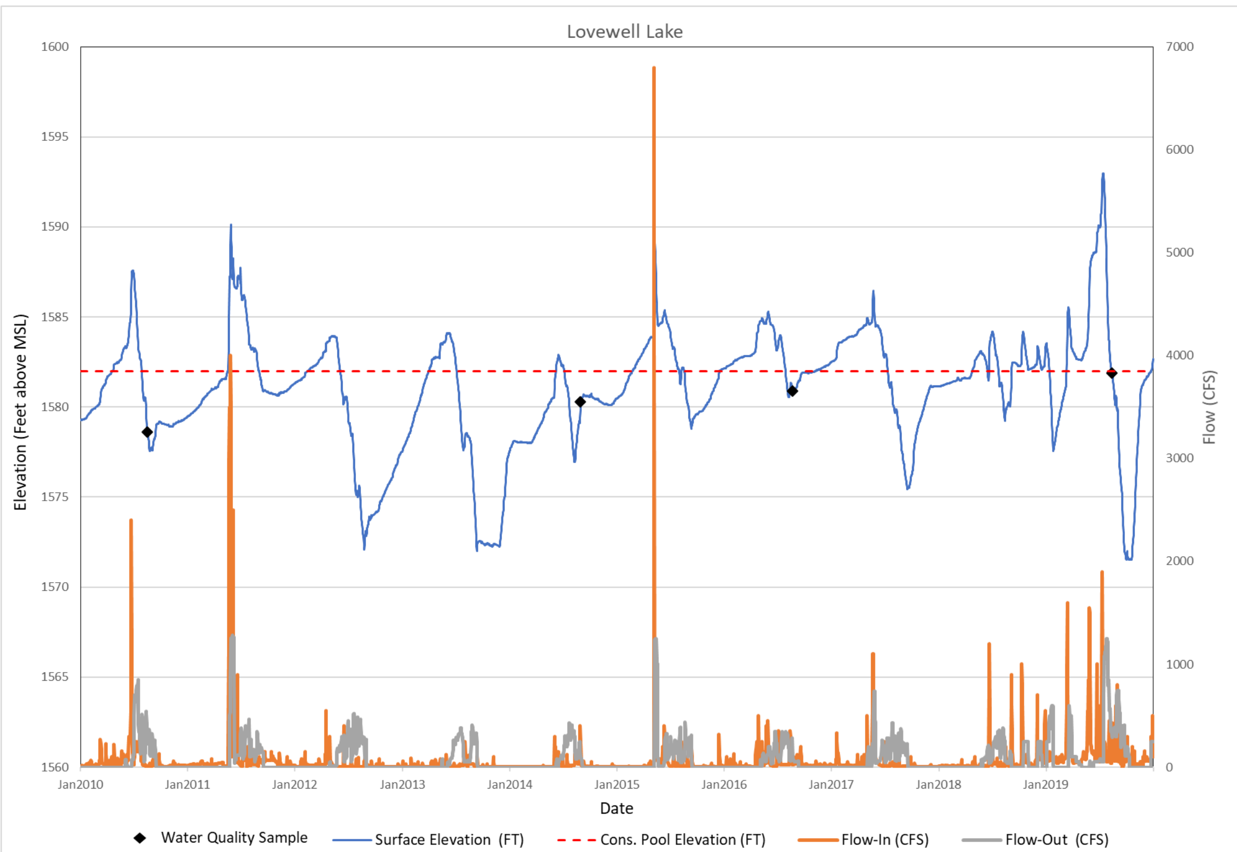
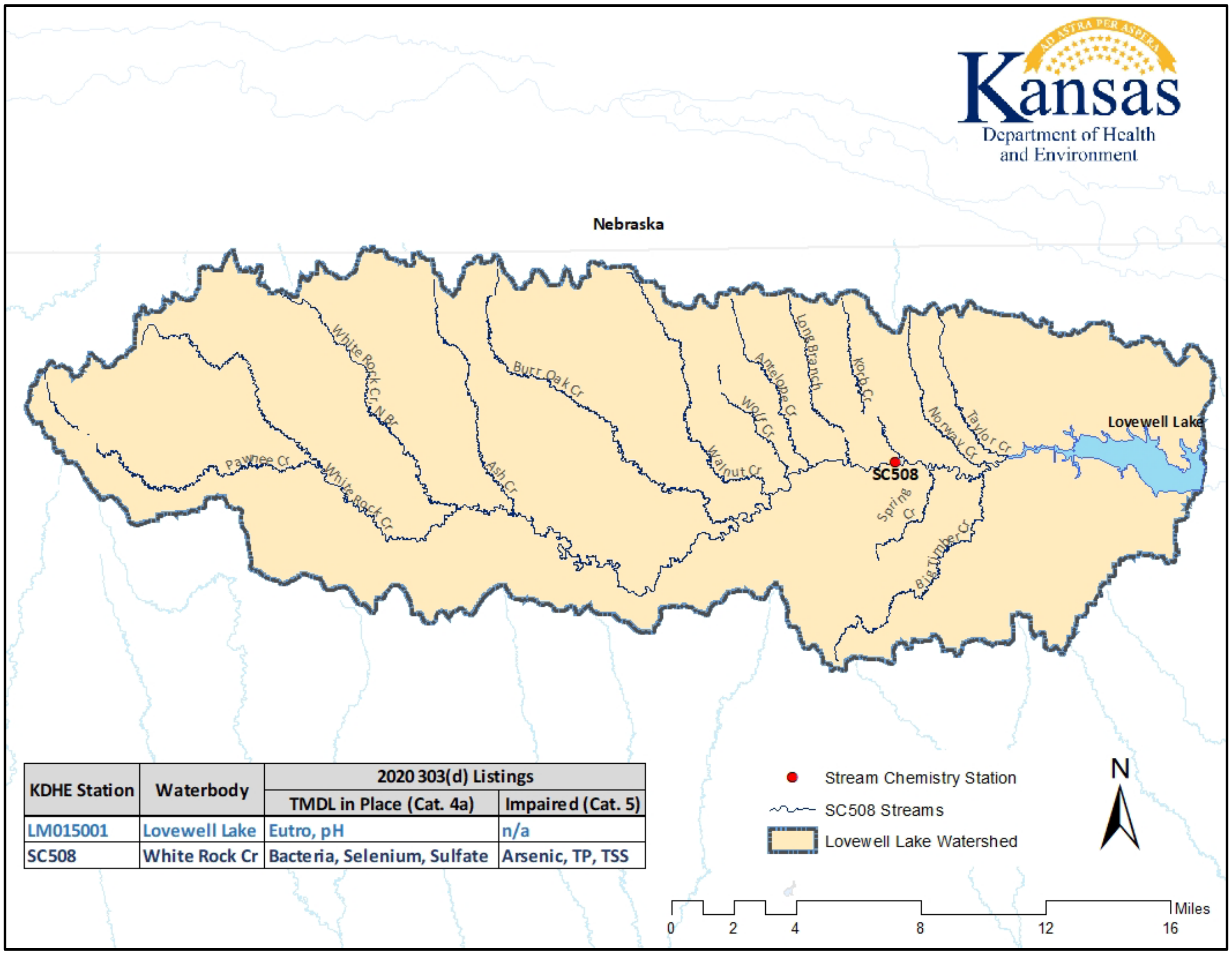


Figure 3-106. Lovewell Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Impairments to Lovewell Lake and White Rock Creek are associated with high phosphorus load and naturally occurring arsenic and selenium in the watershed (Figure 3-107). The TMDL designated for accelerated eutrophication or enrichment from phosphorus is linked to increased aquatic plant growth as measured by average chlorophyll *a* concentration exceeding 12 ug/L and resulting in elevated pH (KDHE 2003).



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM015001	Lovewell Lake	Eutro, pH	n/a
SC508	White Rock Cr	Bacteria, Selenium, Sulfate	Arsenic, TP, TSS

Figure 3-107. Lovewell Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Lovewell Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Field Measured Water Quality Summary

Physical water quality conditions for Lovewell Lake are provided in Table 3-25. Daytime conditions recorded by field staff highlight minimum dissolved oxygen value of 6.4 mg/L and maximum pH of 8.1 as the worst conditions for two variables potentially impacted from eutrophication. These values do not exceed their respective water quality criteria. Mean and median Secchi values of less than 0.5 meter and median turbidity of 24 NTU support the assertion that light limitation to primary productivity may occur at Lovewell Lake with high values for shading coefficient and non-algal turbidity reported by KDHE (2012).

Temperature and dissolved oxygen profiles for field data collected from 2014-2019 are presented in Figure 3-108. Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Increased water depth and a likely increase in biochemical oxygen demand associated with nutrient pulse from large inflow provided conditions for rapid dissolved oxygen decline at depth of 4 meters with minor evidence of thermal stratification at Lovewell Lake in 2019. The profiles for 2014 and 2016 show full mixing from top to bottom which are more common during summer conditions at the USBR Lakes in Kansas.

Table 3-25. Physical water quality statistics from KDHE field measurements of Lovewell Lake from 2010-2019.

	Lovewell Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	8	8.09	7.82	6.43	9.93	6.85	9.52	1.45	0.51
Temp °C	10	26.75	27.10	24.40	29.00	25.00	28.40	1.79	0.57
Secchi (m)	4	0.41	0.42	0.37	0.45	0.38	0.45	0.04	0.02
pH	8	7.92	8.01	7.50	8.10	7.80	8.07	0.23	0.08
Conductivity umho/cm	8	605.76	600.00	590.00	633.50	590.00	621.30	18.97	6.71
Turbidity NTU	8	22.24	24.00	11.00	32.70	17.60	25.50	7.27	2.57

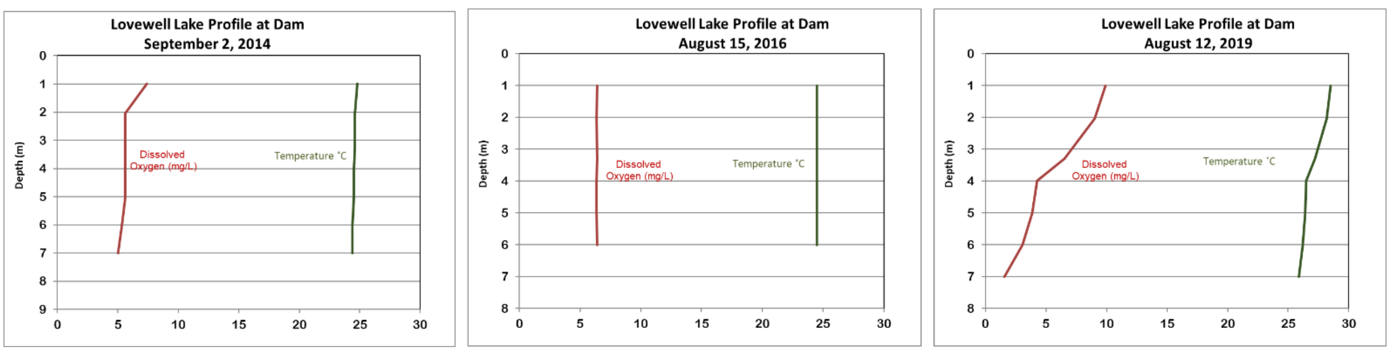


Figure 3-108. Lovewell Lake representative temperature and dissolved oxygen profiles 2014-2019. *Field data collected 2010-2019 provided courtesy of KDHE.*

Laboratory Water Quality Analysis Summary

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Lovewell Lake in Table 3-26. Values below minimum reporting limits influence sample size in some analytes (e.g., nitrate, metolachlor) while other analytes (e.g., zinc, ammonia, orthophosphate, mercury) measured below reporting limits in all samples and consequently were omitted from results table.

Pesticide detections were infrequent and well below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in Kansas lakes. Maximum concentrations of atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Lovewell Lake was 1.1 mg/L which compares to the high nitrogen USACE lakes (e.g. Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeded EPA Ecoregional Recommended Criteria of 0.62 mg/L (EPA 2001). Soluble nutrients like ammonia and nitrate were relatively low concentration.

Lovewell Lake total phosphorus mean of 0.292 mg/L is above the hypereutrophic threshold (Carlson 1977) and is the primary cause of eutrophic conditions leading to biological response of increased algal production. Mean chlorophyll a concentration of 47.3 ug/L far exceeds hypereutrophy threshold of 30 ug/L (KDHE 2003). Cyanobacteria typically comprises less than 60% of the phytoplankton population at Lovewell Lake according to KDHE report (2012). The most recent KDHE issued HAB warning was June 2021 which resulted in state park beach closure.

Total metals in Keith Sebelius Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria with exception of one sample matching the Domestic Water Supply criteria of 0.010 mg/L of total arsenic (KDHE 2018).

Table 3-26. Water quality chemistry statistics from KDHE surface samples of Lovewell Lake from 2010-2019. *Metals and metalloid values represent total recoverable concentration (mg/L).*

	Lovewell Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	4	0.998	1.005	0.780	1.200	0.845	1.150	0.188	0.094
Metolachlor µg/L	1	0.580	0.580	0.580	0.580	0.580	0.580		
Nitrate mg/L	4	0.282	0.282	0.200	0.364	0.200	0.364	0.094	0.047
TKN nitrogen mg/L	8	0.975	1.035	0.490	1.395	0.740	1.184	0.326	0.115
T. nitrogen mg/L	8	1.116	1.135	0.490	1.758	0.805	1.401	0.454	0.161
Chlorophyll a µg/L	8	47.36	47.22	39.97	55.34	42.51	52.05	5.56	1.97
Alkalinity mg CaCO3/L	8	192.81	195.00	180.00	201.42	185.00	200.52	9.17	3.24
Bromide mg/L	6	0.431	0.348	0.290	0.660	0.300	0.640	0.171	0.070
Chloride mg/L	8	26.93	26.83	22.00	32.00	24.50	29.38	3.48	1.23
Sulfate mg/L	8	78.18	74.00	73.00	90.88	74.00	82.80	7.77	2.75
Total organic carbon mg/L	8	7.151	7.273	6.300	7.900	6.432	7.800	0.718	0.254
Phosphorus mg/L	8	0.292	0.282	0.260	0.350	0.265	0.317	0.034	0.012
Total suspended solids mg/L	8	22.88	21.50	11.00	39.00	12.00	33.00	11.57	4.09
Arsenic mg/L	8	0.009	0.009	0.008	0.010	0.008	0.009	0.001	0.000
Boron mg/L	8	0.090	0.089	0.069	0.120	0.076	0.100	0.018	0.006
Copper mg/L	6	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.000
Iron mg/L	8	0.454	0.430	0.250	0.727	0.265	0.633	0.198	0.070
Magnesium mg/L	8	18.32	18.49	15.00	22.00	16.28	20.00	2.52	0.89
Manganese mg/L	8	0.102	0.104	0.092	0.110	0.094	0.110	0.009	0.003
Nickel mg/L	8	0.002	0.002	0.002	0.003	0.002	0.003	0.000	0.000
Selenium mg/L	8	0.002	0.002	0.002	0.003	0.002	0.003	0.000	0.000
Strontium mg/L	8	0.566	0.565	0.550	0.586	0.555	0.576	0.013	0.005
Uranium mg/L	6	0.007	0.007	0.006	0.008	0.006	0.008	0.001	0.000

3.2.3 Waconda Lake

Glen Elder Dam forming Waconda Lake was completed in 1969. USBR describes benefits of flood protection to the lower Solomon River Valley and dependable water supply to Beloit and three rural water districts. Downstream water quality support and irrigation of approximately 30,000 acres are also listed as project purposes as authorized. Waconda Lake is 12,602 surface acres located in Mitchell and Osbourne Counties, KS on the Solomon River flowing into the Smoky Hill River basin. KDWP manages 13,200 acres of wildlife area as well as Glen Elder State Park offering outstanding outdoor recreational opportunities for anglers, camping, swimming, bicycling, horseshoes, volleyball, softball, boating, archery, and water skiing.

Reservoir Hydrologic Data Summary

Surface elevation of Waconda Lake demonstrates a typical wave form of flood control and irrigation peaks associated with a spring rise/flood control while water supply and irrigation lend to the trough

(Figure 3-109). Seasonal inflow events and flood control needs are noted in 2011 and 2019. Four water quality sampling events are plotted with lake surface elevation for reference. Water quality sampling events were near normal pool in 2010 and 2016 while 2019 sample event coincided with a significant pool fluctuation. Low inflow period was observed in 2013-2015 with conservation pool elevation attained annually during the spring rise after 2016.

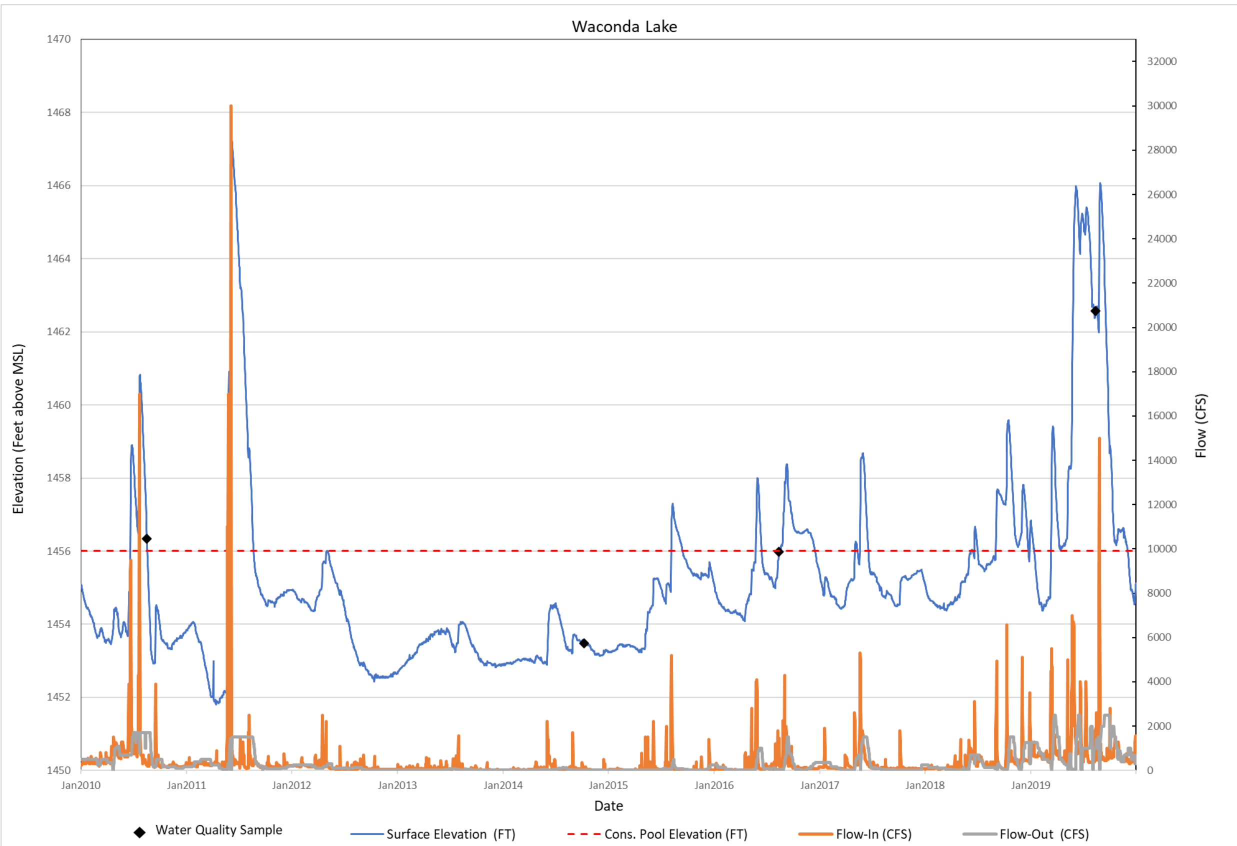
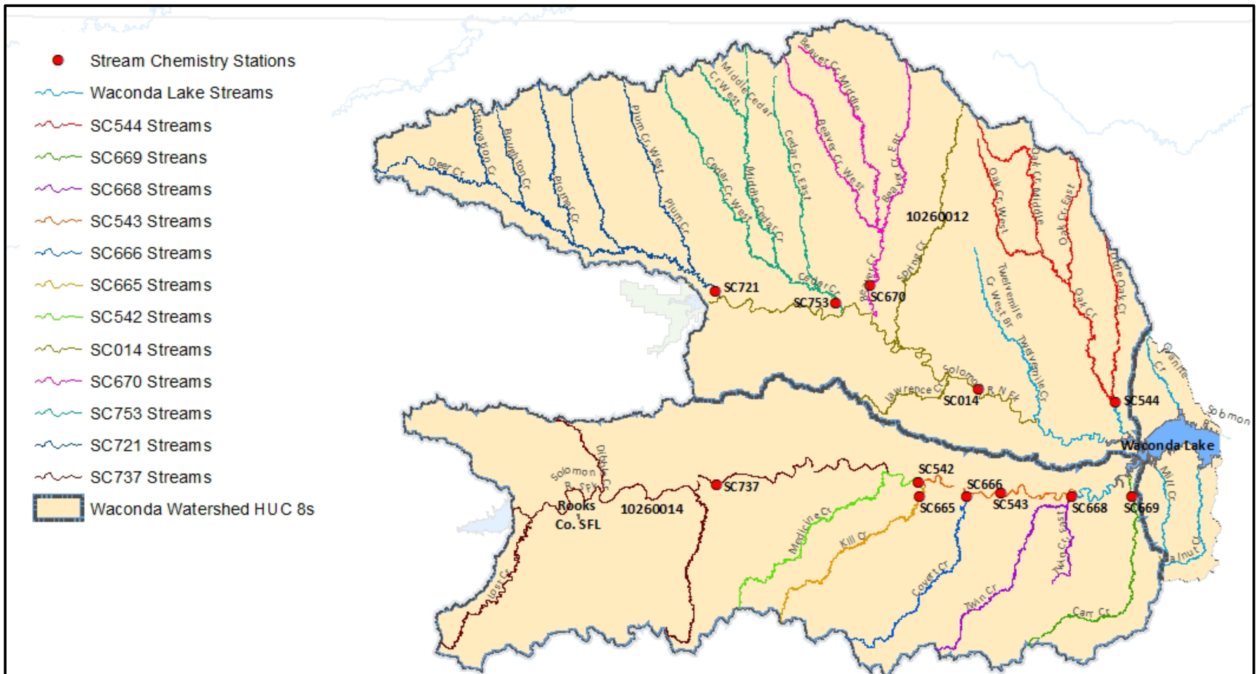


Figure 3-109. Waconda Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Waconda Lake TMDL is associated with high phosphorus from inflows captured by eutrophication TMDL and sulfates (Figure 3-110). The eutrophication TMDL hopes to curb enrichment from phosphorus which manifests in increased aquatic plant growth as measured by average chlorophyll *a* concentration exceeding 12 ug/L (KDHE 2003). A range of TMDLs and impairments to inflow streams include high priority E. coli TMDL on South Fork Solomon River with others of lower priority related to nutrients, metals and biological impairment (KDHE 2011c).



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM018001	Waconda Lake	Eutro, Sulfate	n/a
SC544	Oak Cr	Selenium, Sulfate	DO, TP, TSS
SC669	Carr Cr	Selenium, Sulfate	TP, TSS
SC668	Twin Cr	DO, Selenium, Sulfate	TP
SC543	S. Fk. Solomon R	Bacteria, Biology, Selenium, Sulfate	TP, TSS
SC666	Covert Cr	Selenium, Sulfate	n/a
SC665	Kill Cr	Selenium, Sulfate	n/a
SC542	S. Fk. Solomon R	Bacteria, Biology, Selenium, Sulfate	n/a
SC014	N. Fk. Solomon R	Bacteria, Selenium, Sulfate	Arsenic, Biology, TP
SC670	Beaver Cr	Selenium, Sulfate	Arsenic, DO, TP
SC753	Cedar Cr	n/a	Arsenic, Selenium, TP
SC721	Deer Cr	Selenium, Sulfate	Arsenic, TP
SC737	S. Fk. Solomon R	Selenium, Sulfate	Arsenic, DO

Figure 3-110. Waconda Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Waconda Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Field Measured Water Quality Data Summary

Physical water quality conditions for Waconda Lake are provided in Table 3-27. Daytime field measurements of surface water near the dam are likely to provide the best of water quality results. Attenuation of nutrient and sediment impacts reported in inflow streams are evident as data presented from KDHE field samples in Table 3-27 describe optimum physical water quality for support of aquatic life.

Temperature and dissolved oxygen profiles for field data collected from 2014-2019 are presented in Figure 3-111. Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Increased water depth and a likely increase in biochemical oxygen demand associated with nutrient pulse from large inflows provided better conditions for thermal stratification and rapid decline of dissolved oxygen with depth at Waconnda Lake in 2019. Profiles for 2014 and 2016 are more common during summer conditions at Waconda Lake and other USBR Lakes in Kansas.

Table 3-27. Physical water quality statistics from KDHE field measurements of Waconda Lake from 2010-2019.

Variable	Waconda Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	8	8.31	7.35	6.97	11.62	7.09	9.52	2.01	0.71
Temp °C	10	27.31	27.90	25.60	28.10	27.00	28.00	0.99	0.31
Secchi (m)	4	1.13	1.01	0.92	1.60	0.96	1.31	0.31	0.16
pH	8	7.92	7.91	7.60	8.20	7.75	8.12	0.23	0.08
Conductivity umho/cm	8	956.29	937.60	850.00	1100.00	862.55	1050.00	107.50	38.01
Turbidity NTU	8	5.51	4.41	3.80	9.90	4.05	6.73	2.29	0.81

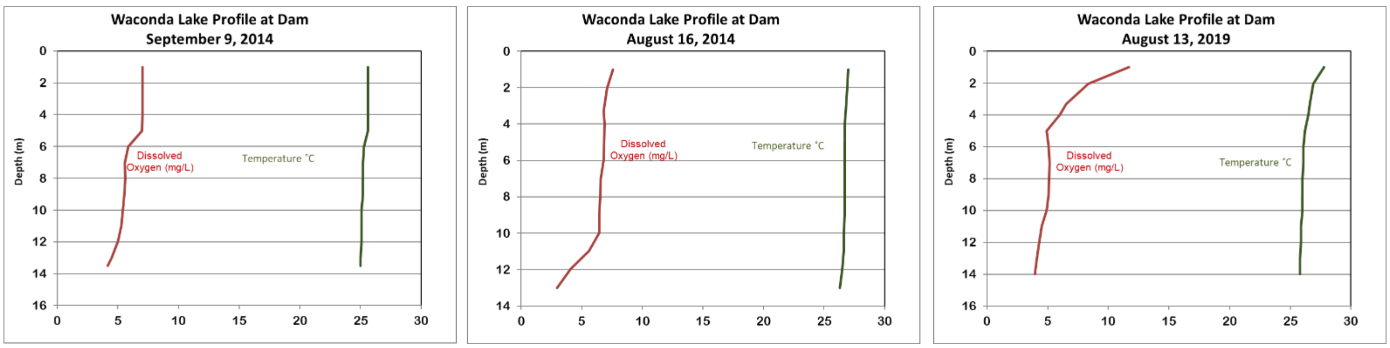


Figure 3-111. Waconda Lake representative temperature and dissolved oxygen profiles 2014-2019. *Field data collected 2010-2019 provided courtesy of KDHE.*

Laboratory Water Quality Analysis

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Waconda Lake in Table 3-28. Values below minimum reporting limits influence sample size in some analytes (e.g., nitrate, metolachlor, copper) while other analytes (e.g., ammonia, orthophosphate, mercury) measured below reporting limits in all samples and consequently were omitted from results table.

Pesticide detections were infrequent with atrazine and metolachlor maxima well below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in KS lakes. Atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Waconda Lake was 0.92 mg/L which compares to the high nitrogen USACE lakes (e.g. Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeds EPA Ecoregional Recommended Criteria for subecoregion 27 of 0.62 mg/L (EPA 2001). Soluble nutrients like ammonia and nitrate were relatively low in concentration or below reporting limits.

Waconda Lake total phosphorus mean of 0.104 mg/L is above the hypereutrophic threshold (Carlson 1977) and is the primary cause of eutrophic conditions leading to biological response of increased algal production. Similarly, mean chlorophyll concentration of 24.7 ug/L is considered eutrophic (KDHE 2003). Cyanobacteria can dominate phytoplankton community with 91% blue-green cell composition reported in 2010 KDHE (2012). Cyanobacteria have not prompted KDHE HAB warnings in recent years.

Total metals in Waconda Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria (KDHE 2018).

Table 3-28. Water quality chemistry statistics from KDHE surface samples of Waconda Lake from 2010-2019.

	Waconda Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	4	1.275	1.300	1.100	1.400	1.200	1.350	0.126	0.063
Metolachlor µg/L	4	0.428	0.455	0.330	0.470	0.390	0.465	0.066	0.033
Nitrate mg/L	2	0.510	0.510	0.506	0.513	0.506	0.513	0.005	0.004
Nitrite mg/L	2	0.158	0.158	0.158	0.158	0.158	0.158	0.0000	0.0000
TKN nitrogen mg/L	8	0.750	0.755	0.650	0.840	0.685	0.815	0.076	0.027
T. nitrogen mg/L	8	0.917	0.755	0.650	1.503	0.685	1.151	0.355	0.125
Chlorophyll a µg/L	8	24.77	25.51	19.76	29.10	20.91	28.23	3.84	1.36
Alkalinity mg CaCO3/L	8	144.90	139.75	130.00	170.00	130.00	159.85	17.70	6.26
Bromide mg/L	8	0.471	0.407	0.400	0.670	0.401	0.540	0.123	0.044
Chloride mg/L	8	75.57	74.00	63.70	91.00	67.45	83.50	10.48	3.71
Sulfate mg/L	8	224.85	229.83	180.00	260.00	189.55	260.00	38.29	13.54
Total organic carbon mg/L	8	7.840	7.629	6.700	9.500	7.100	8.531	1.061	0.375
Phosphorus mg/L	8	0.104	0.095	0.062	0.160	0.066	0.144	0.043	0.015
Arsenic mg/L	8	0.007	0.007	0.005	0.008	0.005	0.008	0.001	0.0005
Boron mg/L	8	0.113	0.115	0.083	0.140	0.094	0.130	0.022	0.008
Copper mg/L	6	0.002	0.002	0.001	0.002	0.001	0.002	0.000	0.000
Iron mg/L	8	0.108	0.105	0.042	0.160	0.083	0.142	0.040	0.014
Magnesium mg/L	8	20.60	20.50	17.11	24.00	18.34	23.00	2.64	0.93
Manganese mg/L	8	0.038	0.039	0.028	0.044	0.034	0.042	0.006	0.002
Nickel mg/L	8	0.005	0.003	0.002	0.025	0.002	0.003	0.008	0.003
Selenium mg/L	8	0.003	0.003	0.002	0.004	0.003	0.004	0.001	0.0002
Zinc mg/L	1	0.006	0.006	0.006	0.006	0.006	0.006		
Strontium mg/L	8	0.960	0.969	0.800	1.100	0.819	1.100	0.151	0.053
Uranium mg/L	6	0.007	0.007	0.005	0.009	0.005	0.009	0.002	0.001

3.2.4 Cedar Bluff Lake

Cedar Bluff Lake earthen dam and reservoir were completed in 1951. USBR describes benefits of flood protection to Smoky Hill River Basin and water supply to the Cedar Bluff National Fish Hatchery and the city of Russell, Kansas. Irrigation of approximately 6,800 acres and recreation are also listed as project purposes as authorized. Cedar Bluff Lake is 6,869 surface acres located in Trego County, KS on the Smoky Hill River. KDWP manages 9,000 acres of wildlife area in addition to Cedar Bluff State Park providing an excellent base camp for hunters, fishermen, and year-round explorers.

Reservoir Hydrologic Data Summary

Surface elevation of Cedar Bluff Lake did not meet conservation pool elevation in 2010-2019 evaluation period (Figure 3-112). Three water quality sampling events are plotted with lake surface elevation for reference. Low inflow periods were observed in 2011-2014 with surface elevation falling 28 ft below conservation pool while recovery period began in 2019.

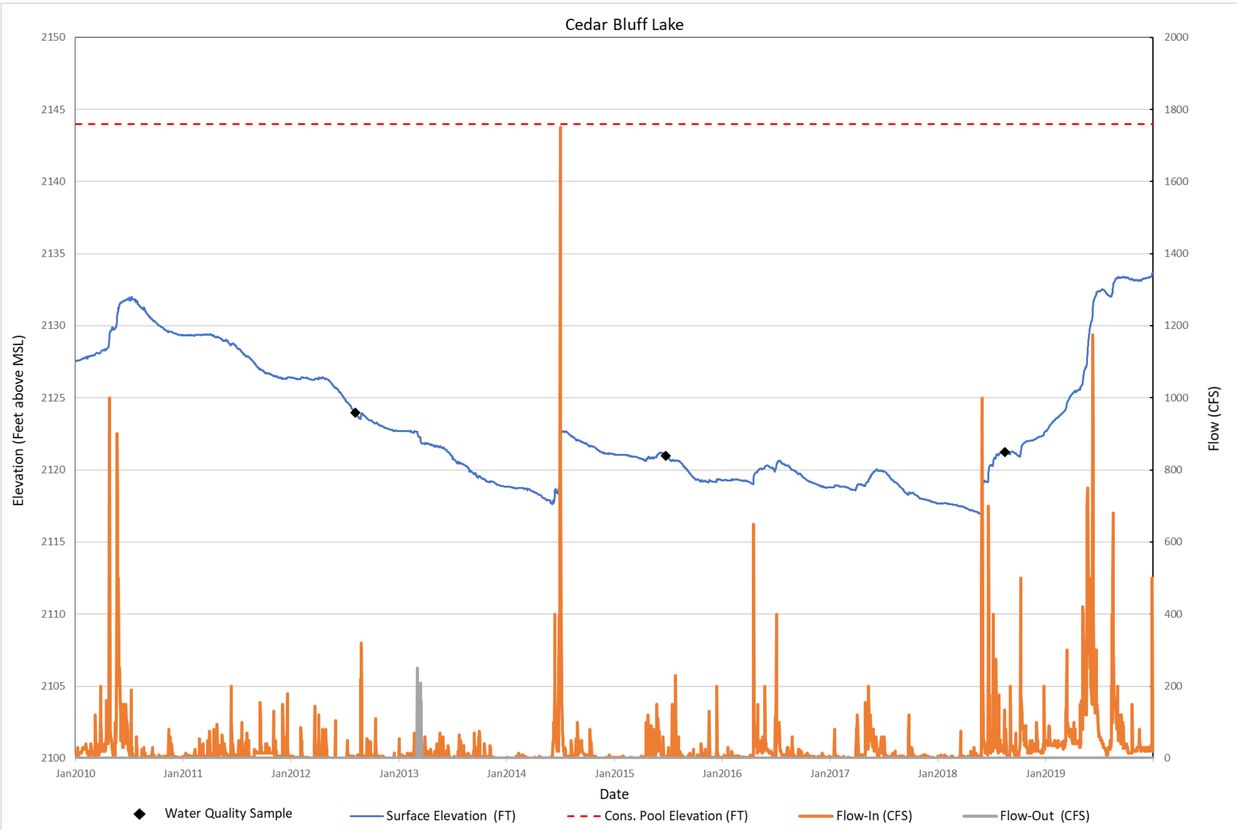
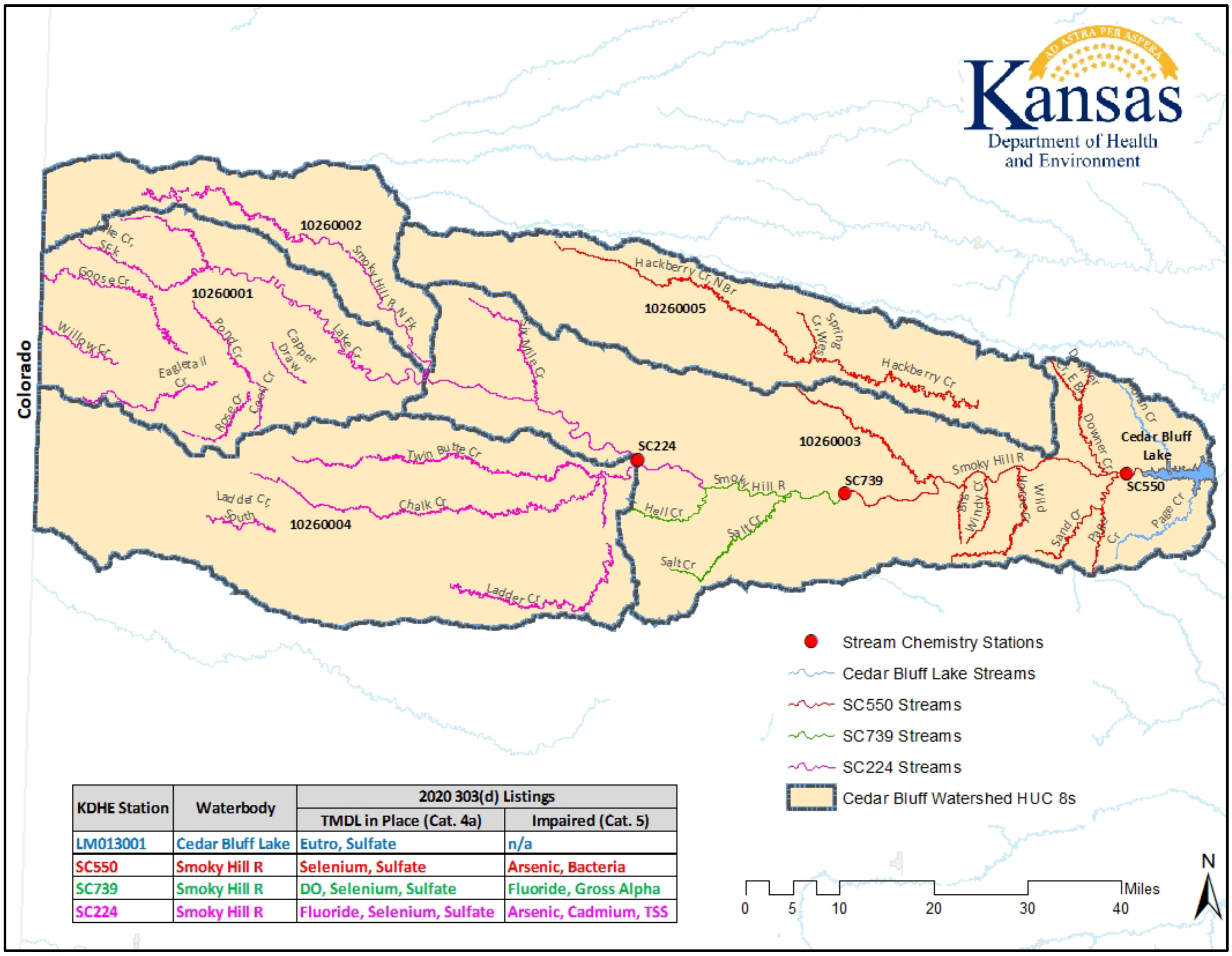


Figure 3-112. Cedar Bluff Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Impairments to Cedar Bluff Lake and Upper Smoky Hill River are associated with high phosphorus load and naturally occurring sulfate in the lake, and naturally occurring metals, suspended solids and bacteria in the watershed (Figure 3-113). The TMDL designated for accelerated eutrophication or enrichment from phosphorus is linked to increased aquatic plant growth as measured by average chlorophyll *a* concentration exceeding 12 ug/L (KDHE 2003a). Cedar Bluff Lake trophic state and chlorophyll a concentration are highly variable due to weather and hydrologic conditions associated with sampling events with average summer chlorophyll a reported as 7.5 ug/L 2008-2012 while 1991 survey reported chlorophyll a values up to 58.9 ug/L under hypereutrophic TSI conditions.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM013001	Cedar Bluff Lake	Eutro, Sulfate	n/a
SC550	Smoky Hill R	Selenium, Sulfate	Arsenic, Bacteria
SC739	Smoky Hill R	DO, Selenium, Sulfate	Fluoride, Gross Alpha
SC224	Smoky Hill R	Fluoride, Selenium, Sulfate	Arsenic, Cadmium, TSS

Figure 3-113. Cedar Bluff Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Cedar Bluff Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Field Measured Water Quality Data Summary

Physical water quality conditions for Cedar Bluff Lake are provided in Table 3-29. Daytime conditions recorded by KDHE field staff highlight minimum dissolved oxygen value of 4.7 mg/L and maximum conductivity value of 2900 umho/cm due to elevated ion concentrations. Mean and median Secchi values exceeding 1.5 meters and median turbidity less than 5 NTU support the assertion light limitation and shading are not impacting primary productivity (KDHE 2012).

Temperature and dissolved oxygen profiles for field data collected from 2015-2018 are presented in Figure 3-114. Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Both profiles at Cedar Bluff Lake during low water years 2015 and 2018 indicate thermal mixing with gradual dissolved oxygen decline at depths of 4 and 8 meters, respectively (Figure 3-114).

Table 3-29. Physical water quality statistics from KDHE field measurements of Cedar Bluff Lake from 2010-2019.

Variable	Cedar Bluff Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	6	7.20	7.70	4.47	9.30	4.71	9.30	2.14	0.88
Temp °C	8	26.85	27.05	25.50	28.00	26.00	27.60	0.94	0.33
Secchi (m)	3	1.90	1.83	1.51	2.36	1.51	2.36	0.43	0.25
pH	6	7.81	7.92	7.30	8.20	7.40	8.10	0.37	0.15
Conductivity umho/cm	6	2730.83	2800.00	2479.00	2900.00	2506.00	2900.00	190.14	77.63
Turbidity NTU	6	4.56	4.00	2.50	7.22	2.80	6.81	2.01	0.82

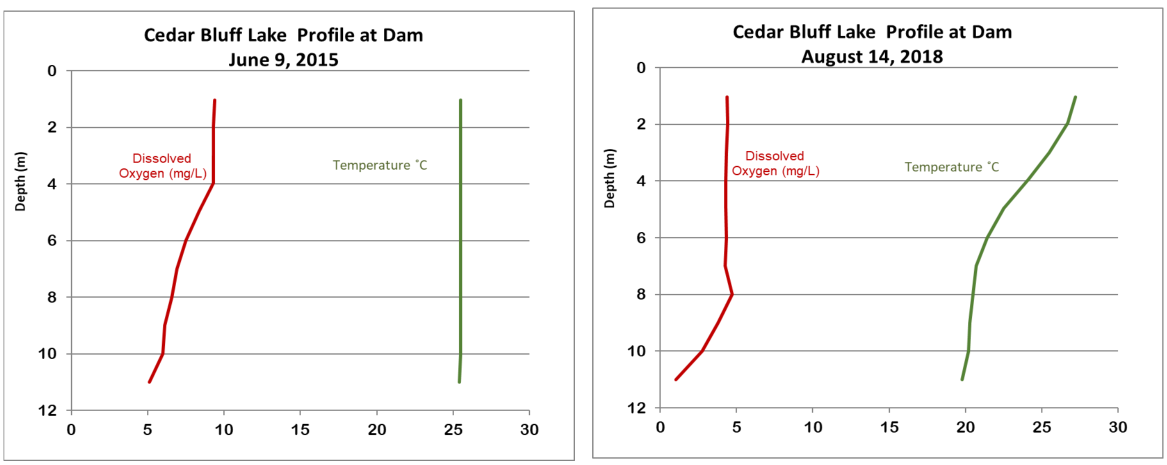


Figure 3-114. Cedar Bluff Lake representative temperature and dissolved oxygen profiles 2014-2019. *Field data collected 2010-2019 provided courtesy of KDHE.*

Laboratory Water Quality Analysis

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Cedar Bluff Lake in Table 3-30. Values below minimum reporting limits influence sample size in some analytes (e.g., nitrate, metolachlor) while other analytes (e.g., ammonia, orthophosphate, mercury) measured below reporting limits in all samples and consequently were omitted from results table.

Pesticide detections were infrequent and well below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in KS lakes. Maximum concentrations of atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Cedar Bluff Lake of 1.3 mg/L which compares to the high nitrogen USACE lakes (e.g. Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeded EPA Ecoregional Recommended Criteria of 0.62 mg/L (EPA 2001). Soluble nitrogen forms ammonia and nitrate were below detection limit.

Cedar Bluff Lake total phosphorus mean of 0.047 mg/L was comparable to slightly eutrophic value of 0.044 mg/L reported in interim conditions for 2008-2012 period of analysis for TMDL establishment (KDHE 2003a updated in 2014). Mean chlorophyll concentration of 14.5 ug/L exceeds eutrophic threshold but was lower than 58.9 ug/L under hypereutrophic TSI conditions also reported from in TMDL data discussion from 1991 (KDHE 2003a). Cyanobacteria comprised 79% of the phytoplankton population at Cedar Bluff Lake (KDHE (2010). The most recent KDHE issued HAB warning was June 2012.

Total metals in Cedar Bluff Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria (KDHE 2018).

Maxima value of total selenium from Cedar Bluff Lake samples of 5 ug/L is equal to the chronic concentration numeric criteria for support of aquatic life due to background levels in Smoky Hill River above Cedar Bluff Lake.

Median sulfate concentration of 1,200 mg/L exceeded the 700 mg/L as defined as natural background concentration reported in Kansas Surface Water Standards (KDHE 2018). Samples collected in low water years of 2015 and 2018 are likely to see higher concentration in the absence of dilution from fresh water provided from rainfall events.

Similarly, bromide concentrations in Cedar Bluff Lake during low water years may be concerning to downstream water supply/treatment operations. Median value of 0.822 mg/L and maxima of 1.2 mg/L were the highest respective values in the KDHE data set from USBR lakes in 2010-2019.

Table 3-30. Water quality chemistry statistics from KDHE surface samples of Cedar Bluff Lake from 2010-2019.

	Cedar Bluff Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	3	0.797	0.610	0.3800	1.400	0.3800	1.400	0.5350	0.30889
TKN nitrogen mg/L	6	1.334	1.308	1.2900	1.400	1.3000	1.400	0.0516	0.02107
T. nitrogen mg/L	6	1.334	1.308	1.2900	1.400	1.3000	1.400	0.0516	0.02107
Chlorophyll a µg/L	6	14.55	12.13	6.47	25.42	7.27	23.90	8.22	3.36
Alkalinity n mg CaCO3/L	6	102.71	95.50	92.59	120.00	92.69	120.00	13.45	5.49
Bromide mg/L	6	0.937	0.822	0.7700	1.200	0.8093	1.200	0.2046	0.08354
Chloride mg/L	6	209.62	210.00	198.79	220.00	198.95	220.00	9.46	3.86
Sulfate mg/L	6	1105.00	1200.00	910.00	1200.00	920.00	1200.00	147.21	60.10
Total organic carbon mg/L	6	14.080	14.000	12.9100	15.000	13.5700	15.000	0.8167	0.33340
Phosphorus mg/L	3	0.047	0.054	0.0330	0.055	0.0330	0.055	0.0124	0.00717
Arsenic mg/L	4	0.005	0.005	0.0038	0.005	0.0039	0.005	0.0008	0.00039
Boron mg/L	6	0.322	0.321	0.3100	0.330	0.3183	0.330	0.0076	0.00310
Copper mg/L	6	0.009	0.003	0.0031	0.020	0.0033	0.020	0.0086	0.00352
Iron mg/L	4	0.047	0.047	0.0330	0.061	0.0335	0.061	0.0159	0.00794
Magnesium mg/L	6	102.17	100.00	96.13	110.00	96.87	110.00	6.27	2.56
Manganese mg/L	4	0.103	0.103	0.1000	0.107	0.1000	0.107	0.0039	0.00195
Nickel mg/L	6	0.010	0.005	0.0037	0.020	0.0040	0.020	0.0080	0.00327
Selenium mg/L	4	0.005	0.005	0.0048	0.005	0.0049	0.005	0.0002	0.00009
Zinc mg/L	3	0.006	0.007	0.0051	0.007	0.0051	0.007	0.0011	0.00065
Strontium mg/L	6	4.319	4.400	4.0453	4.500	4.0671	4.500	0.2083	0.08505
Uranium mg/L	6	0.018	0.017	0.0167	0.020	0.0167	0.020	0.0016	0.00067

3.2.5 Webster Lake

Webster Lake is a 3,767 acre impoundment of South Fork Solomon River built in Rooks County, KS in 1953. The USBR Webster Unit provides flood control benefits, irrigation water to 8,500 acres of the Webster Irrigation District No. 4, fish and wildlife conservation, and recreation opportunities. The area around Webster Lake includes an 880-acre state park managed by KDWP within surrounding public land totaling 3,164 land acres with 50 miles of shoreline.

Reservoir Hydrologic Data Summary

Webster Lake conservation pool elevation was difficult to maintain during much of the 2010-2019 evaluation period (Figure 3-115) due to low inflows from 2012-2016 as water demand for irrigation outpaced inflows. Conservation pool elevation was maintained 2017-2019 as rainfall events allowed for recharge of the pool volume. Three water quality sampling events are plotted with lake surface elevation for reference in Figure 3-115. Water quality sampling events were near conservation pool in 2019 while previous samples were at surface elevation 11ft and 22ft below conservation pool elevation.

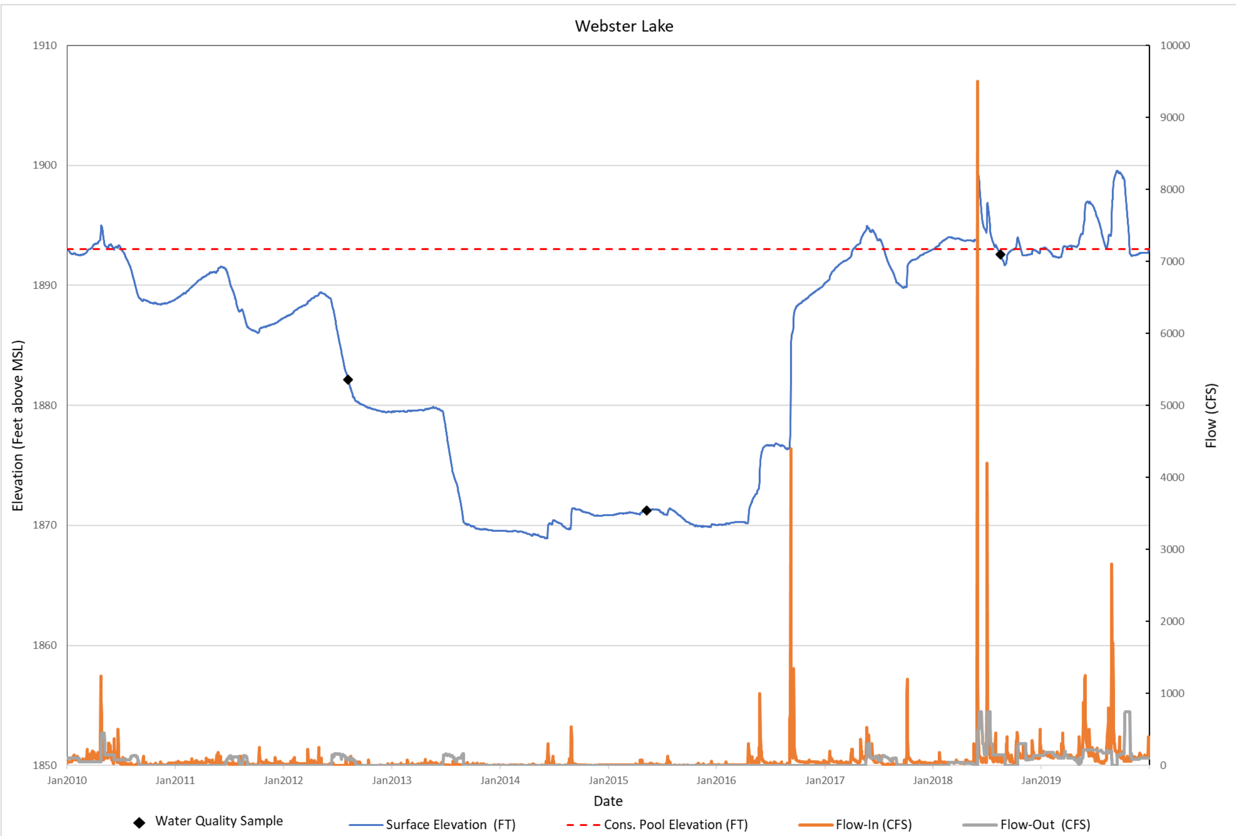
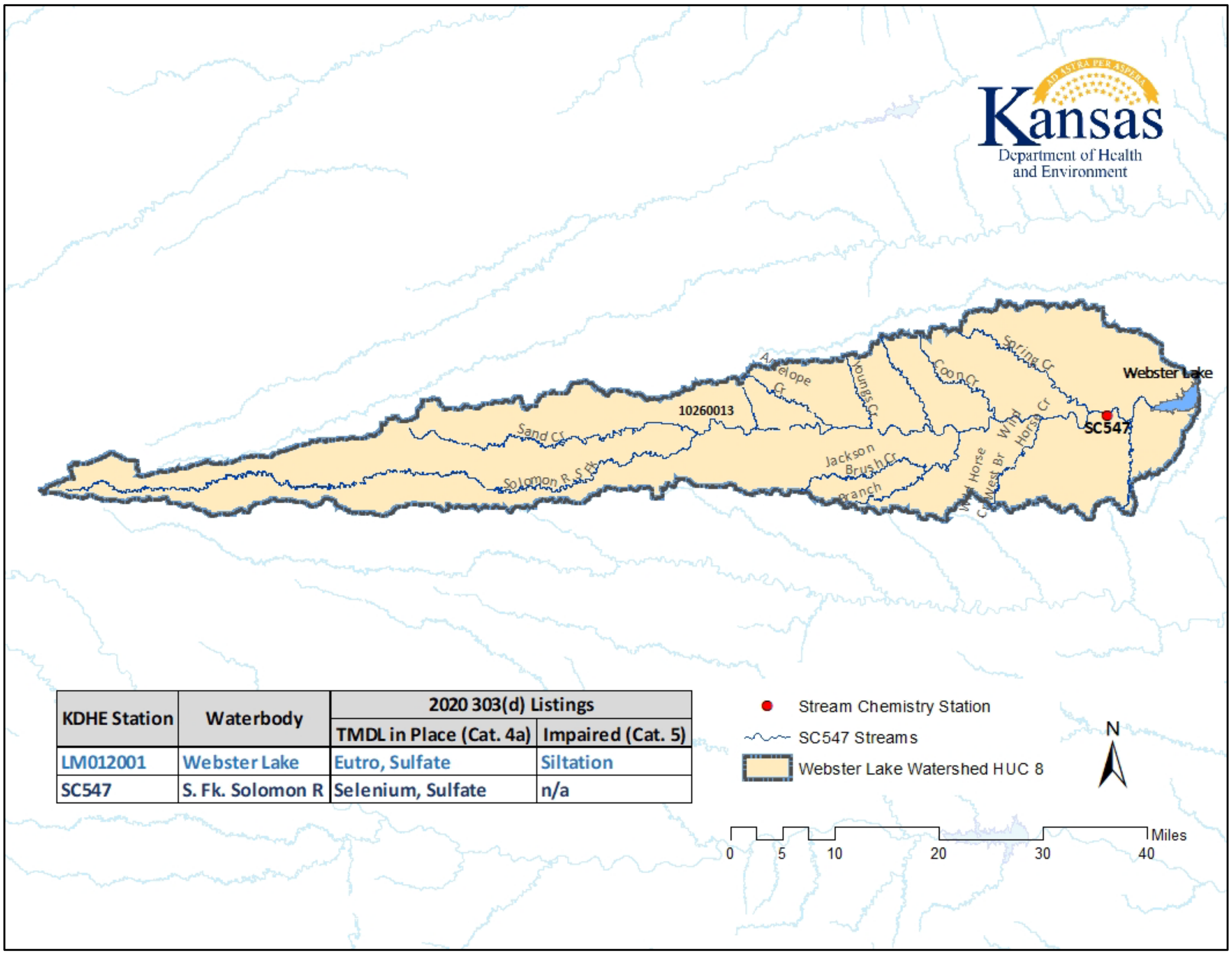


Figure 3-115. Webster Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Impairments to Webster Lake and South Fork of Solomon River are associated with high phosphorus and sediment load, naturally occurring sulfate in the lake, and naturally occurring sulfate and selenium in the watershed (Figure 3-116). The TMDL designated for accelerated eutrophication or enrichment from phosphorus is linked to increased aquatic plant growth as measured by average chlorophyll *a* concentration exceeding 12 ug/L (KDHE 2003b). Webster Lake trophic state was classified as eutrophic based on summer chlorophyll a concentration (KDHE 2010). Siltation and selenium impairments affect upper areas and river above Webster Lake with minimal effect on water quality near the dam.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM012001	Webster Lake	Eutro, Sulfate	Siltation
SC547	S. Fk. Solomon R	Selenium, Sulfate	n/a

Figure 3-116.Webster Lake impaired waters and TMDLs. *Impaired waters and TMDLs of Webster Lake and watershed from 2020 303(d) list (Courtesy of KDHE).*

Field Measured Water Quality Data Summary

Physical water quality conditions for Webster Lake are provided in Table 3-31. Minimum dissolved oxygen value of 8 mg/L and maximum pH of 8.2 are acceptable values which represent the worst conditions for two physical analytes from surface samples collected during the sample period which may degrade due to eutrophication. Median Secchi values of approximately one meter and median turbidity of 12.6 NTU provide for a functional photic zone and do not suggest light limitation to productivity similar to previous water quality reports for Webster Lake (KDHE 2007, 2010).

Temperature and dissolved oxygen profile for one field sample collected in August 2018 indicates weak thermal stratification with significant oxygen decline at depth (Figure 3-117). Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Biochemical oxygen demand resulting from high algae density are apparent when thermal stratification occurs and when thermal variation is low and while dissolved oxygen declines rapidly at depth as illustrated in this instance (Figure 3-117).

Table 3-31. Physical water quality statistics from KDHE field measurements of Webster Lake from 2010-2019.

Variable	Webster Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	6	9.6	9.9	8.7	10.3	8.7	10.2	0.7	0.3
Temp °C	8	28.2	28.8	26.7	29.0	27.0	29.0	1.1	0.4
Secchi (m)	3	1.1	1.0	0.8	1.4	0.8	1.4	0.3	0.2
pH	6	8.1	8.1	8.1	8.2	8.1	8.2	0.0	0.0
Conductivity umho/cm	6	1485.5	1556.5	1000.0	1900.0	1000.0	1900.0	406.2	165.8
Turbidity NTU	6	13.5	12.7	6.2	22.0	6.2	21.0	6.9	2.8

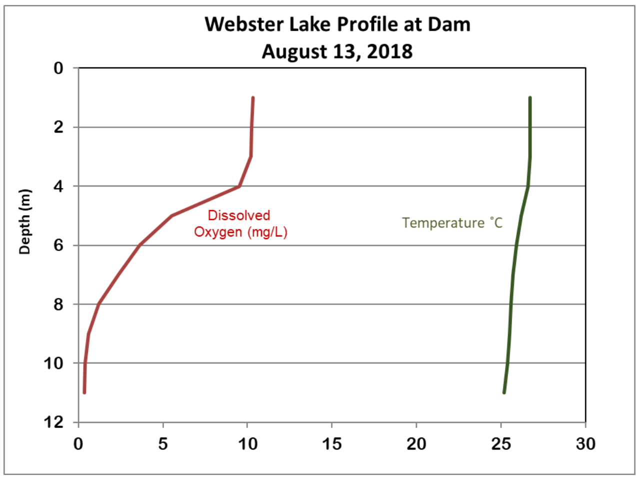


Figure 3-117. Webster Lake representative temperature and dissolved oxygen profile 2018. *Field data collected 2018 provided courtesy of KDHE***.**

Laboratory Water Quality Analysis

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Webster Lake in Table 3-32. Values below minimum reporting limits influence sample size in some analytes (e.g., zinc and nitrate) while other analytes (e.g., ammonia, orthophosphate, mercury) measured below reporting limits in all samples and consequently were omitted from results table.

Pesticide detections were infrequent and well below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in KS lakes. Maximum concentrations of atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Webster Lake was 1.36 mg/L which compares to the high nitrogen USACE lakes (e.g., Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeds EPA Ecoregional Recommended Criteria of 0.62 mg/L (EPA 2001).

Webster Lake total phosphorus mean of 0.08 mg/L is in the eutrophic category (Carlson 1977). Eutrophic conditions with high phosphorus load has combined with adequate water clarity to increase algal production. Mean chlorophyll a concentration of 41.4 ug/L is more than four times the TMDL goal of 8 ug/L (KDHE 2003b). Average chlorophyll a concentrations are reportedly elevated during drought conditions when compared to high water periods due to increased “clay turbidity” associated with inflows

(KDHE 2003b). Cyanobacteria blooms have led to increased HAB Warnings due to toxic algae including the most recent public health warning lasting 12 weeks of the recreational season of 2021.

Bromide concentrations are of concern for water treatment operations due to byproducts as bromide is converted to bromate in their treatment process and there are EPA disinfection byproduct limitations on the amounts of bromate (KWO personal communication, 2022). Increasing bromide trends from 1995 to present in Solomon River Basin is of concern for future water supply. Webster Lake median bromide concentration of 0.615 mg/L is similar to 2020 values found in Upper South Fork Solomon River (KDHE unpublished report).

Total metals in Webster Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria including Domestic Water Supply of 0.010 mg/L of total arsenic (KDHE 2018).

Table 3-32. Water quality chemistry statistics from KDHE surface samples of Webster Lake from 2010-2019.

	Webster Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	3	0.973	0.770	0.350	1.800	0.350	1.800	0.746	0.431
Metolachlor µg/L	1	0.310	0.310	0.310	0.310	0.310	0.310		
Nitrate mg/L	1	0.194	0.194	0.194	0.194	0.194	0.194		
TKN nitrogen mg/L	6	1.327	1.200	1.080	1.700	1.181	1.600	0.256	0.105
T. nitrogen mg/L	6	1.359	1.288	1.080	1.700	1.200	1.600	0.246	0.101
Chlorophyll a µg/L	6	41.390	33.000	9.900	81.400	10.220	80.820	32.638	13.324
Alkalinity mg CaCO3/L	6	125.735	127.205	120.000	130.000	120.000	130.000	4.616	1.884
Bromide mg/L	6	0.624	0.615	0.545	0.710	0.549	0.710	0.073	0.030
Chloride mg/L	6	146.582	155.747	84.000	200.000	84.000	200.000	52.360	21.376
Sulfate mg/L	6	445.167	495.502	280.000	610.000	280.000	510.000	134.909	55.076
Total organic carbon mg/L	6	12.335	12.000	10.980	14.000	11.030	14.000	1.364	0.557
Phosphorus mg/L	4	0.085	0.087	0.073	0.092	0.080	0.090	0.008	0.004
Total suspended solids mg/L	4	15.500	15.000	12.000	20.000	12.500	18.500	3.697	1.848
Arsenic mg/L	4	0.006	0.006	0.006	0.007	0.006	0.007	0.000	0.000
Boron mg/L	6	0.155	0.166	0.100	0.200	0.100	0.200	0.045	0.019
Copper mg/L	6	0.008	0.002	0.002	0.020	0.002	0.020	0.009	0.004
Iron mg/L	4	0.091	0.090	0.085	0.099	0.087	0.095	0.006	0.003
Magnesium mg/L	6	40.601	42.804	24.000	55.000	25.000	54.000	13.532	5.524
Manganese mg/L	2	0.060	0.060	0.060	0.060	0.060	0.060	0.000	0.000
Nickel mg/L	6	0.010	0.005	0.003	0.020	0.004	0.020	0.008	0.003
Selenium mg/L	4	0.004	0.004	0.004	0.005	0.004	0.005	0.001	0.000
Zinc mg/L	1	0.006	0.006	0.006	0.006	0.006	0.006		
Strontium mg/L	6	1.533	1.645	0.950	2.000	0.960	2.000	0.475	0.194
Uranium mg/L	6	0.018	0.019	0.016	0.020	0.016	0.020	0.002	0.001

3.2.6 Kirwin Lake

Kirwin Dam, on the North Fork of the Solomon River near Kirwin, Kansas, was completed in August 1955. Authorized by the Flood Control Act of December 1944, Kirwin Lake provides flood control benefits; irrigation for 11,435 acres; Bureau of Sport Fisheries and Wildlife administers 10,700 acres of Kirwin Reservoir and lands as the Kirwin National Wildlife Refuge; popular recreational activities at Kirwin include fishing, boating, swimming, camping, wildlife viewing, and water skiing.

Reservoir Hydrologic Data Summary

Kirwin Lake conservation pool elevation was difficult to maintain during much of the 2010-2019 evaluation period (Figure 3-118) due to low inflows from 2012-2016 as water demand for irrigation outpaced inflows. Conservation pool elevation was maintained 2018-2019 as rainfall events allowed for recharge of the pool volume. Four water quality sampling events are plotted with lake surface elevation for reference in Figure 3-118. Water quality sampling events were near conservation pool in 2010 while subsequent samples were at surface elevation 15 ft and 17 ft below conservation pool elevation. Following a wetter year, 2019 water quality sample occurred 4 ft above conservation pool elevation.

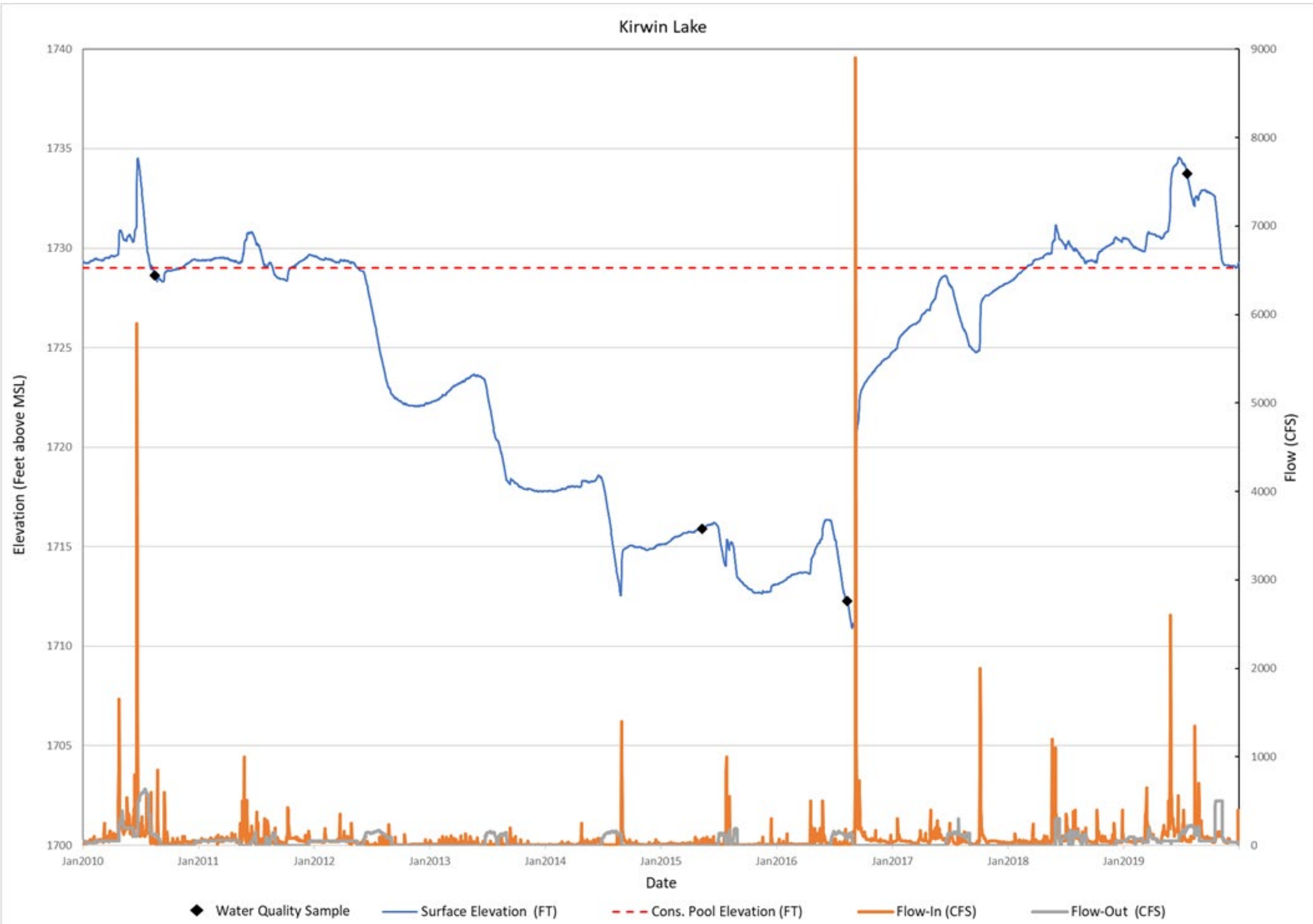
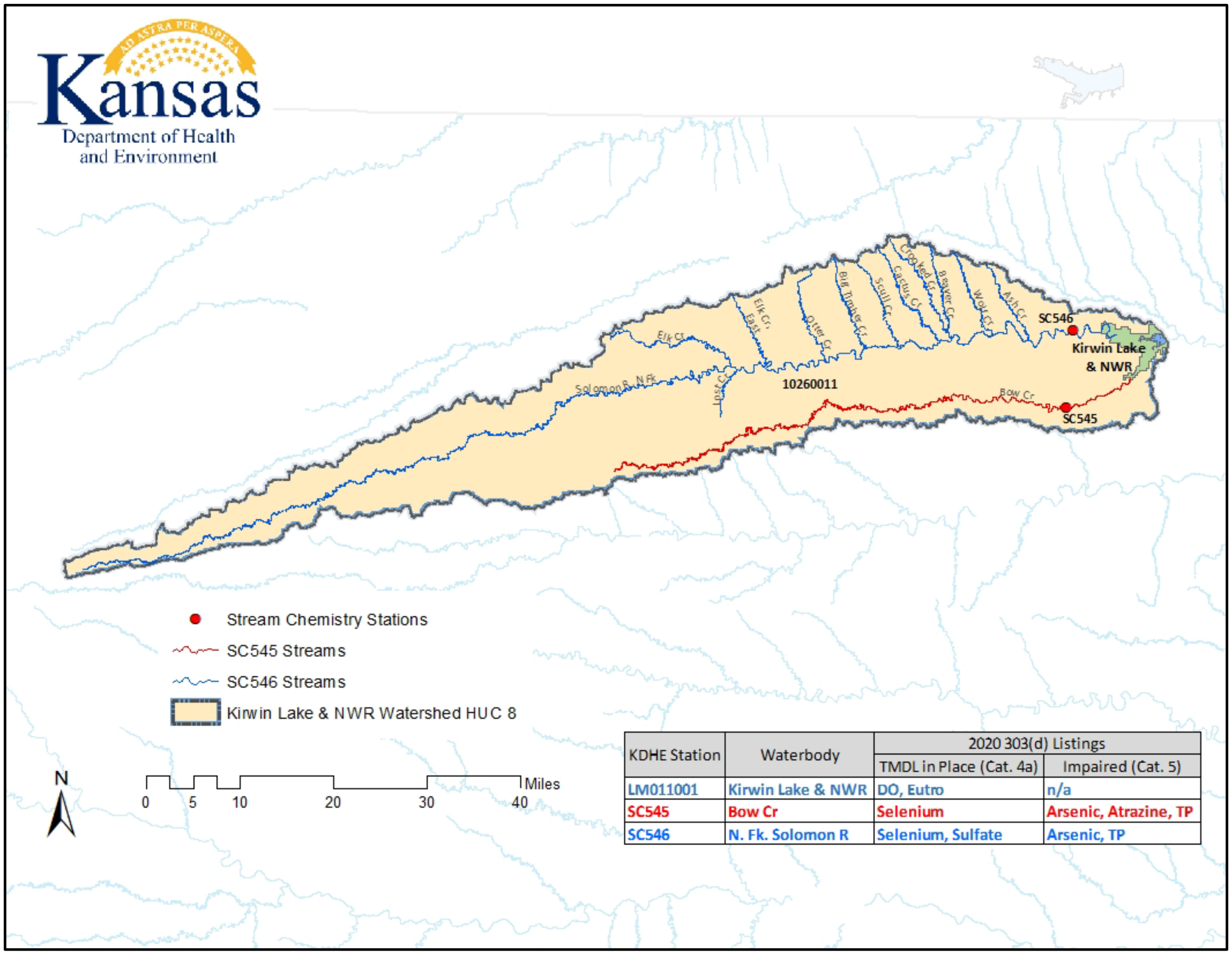


Figure 3-118. Kirwin Lake time series of daily water surface elevation and pool information. *Time series of daily water surface elevation, inflow, outflow, and conservation pool elevation for the period Jan. 2010 through Dec. 2019 from DSS data (HEC-DSSVue -Hydrologic Engineering Center Data Storage System Visual Utility Engine). Water quality sample dates are plotted corresponding with lake surface elevation for reference.*

Impairments

Impairments to Kirwin Lake and Upper North Fork of Solomon River are associated with nutrients and naturally occurring selenium in the watershed (Figure 3-119). The TMDL designated for accelerated eutrophication or enrichment from phosphorus is linked to increased aquatic plant growth as measured by average chlorophyll *a* concentration of 24 ug/L and total phosphorus of 0.132 mg/L (KDHE 2003c).

Kirwin Lake trophic state was classified as very eutrophic based on summer chlorophyll a concentration (KDHE 2003c, 2010). Selenium impairment affects upper lake areas and the river above Kirwin Lake with minimal effect on water quality near the dam.



KDHE Station	Waterbody	2020 303(d) Listings	
		TMDL in Place (Cat. 4a)	Impaired (Cat. 5)
LM011001	Kirwin Lake & NWR	DO, Eutro	n/a
SC545	Bow Cr	Selenium	Arsenic, Atrazine, TP
SC546	N. Fk. Solomon R	Selenium, Sulfate	Arsenic, TP

Figure 3-119. Kirwin Lake impaired waters and TMDLs. Impaired waters and TMDLs of Kirwin Lake and watershed from 2020 303(d) list (Courtesy of KDHE).

Field Measured Water Quality Data Summary

Physical water quality conditions for Kirwin Lake are provided in Table 3-33. Minimum dissolved oxygen value of 6.8 mg/L and maximum pH of 8.2 are acceptable values which represent the worst conditions for two physical analytes from surface samples which may degrade due to eutrophication. Median Secchi value 1.5 m. and median turbidity of 4.9 NTU provide for a functional photic zone and do not suggest light limitation to productivity similar to a previous water quality report for Kirwin Lake (KDHE 2012).

Temperature and dissolved oxygen profiles for 2018 and 2016 indicates very weak stratification with oxygen decline at depth (Figure 3-120). Weak thermal stratification occurs for short periods of time on many shallow Kansas lakes as frequent wind mixing frequently destabilizes thermocline formations. Biochemical oxygen demand resulting from high algae density are apparent as thermal variation is low and while dissolved oxygen declines gradually at depth (Figure 3-120).

Table 3-33. Physical water quality statistics from KDHE field measurements of Kirwin Lake from 2010-2019.

	Kirwin Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
D.O. mg/L	8	7.81	7.35	6.79	9.80	7.07	8.55	1.22	0.43
Temp °C	11	27.23	27.00	26.70	28.00	27.00	27.40	0.42	0.13
Secchi (m)	4	1.59	1.50	0.83	2.54	1.02	2.17	0.75	0.37
pH	8	7.94	7.95	7.70	8.20	7.75	8.10	0.20	0.07
Conductivity umho/cm	8	942.21	915.00	832.60	1100.00	842.55	1045.00	115.88	40.97
Turbidity NTU	8	5.57	4.98	3.20	9.70	3.45	7.40	2.55	0.90

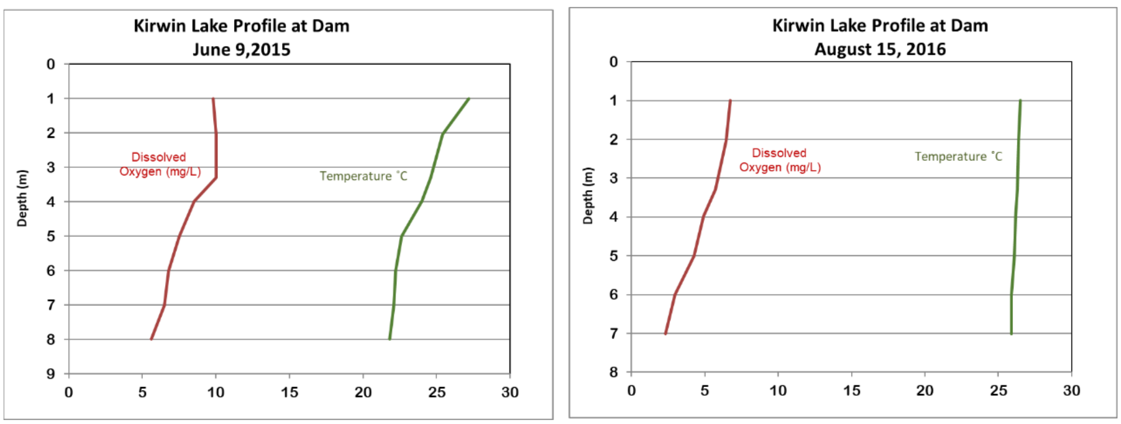


Figure 3-120. Kirwin Lake representative temperature and dissolved oxygen profiles 2014-2019. *Field data collected 2010-2019 provided courtesy of KDHE.*

Laboratory Water Quality Analysis

Water quality sample laboratory results from KDHE Monitoring and Analysis Unit are provided for Kirwin Lake in Table 3-34. Analytes measured below reporting limits in all samples (e.g., ammonia, orthophosphate, mercury) were omitted from results table.

Pesticide detections were infrequent and below KDHE surface water quality standards numeric criteria (KDHE 2018). Atrazine is the most common pesticide found in Kansas lakes. Maximum concentrations of atrazine did not exceed EPA drinking water criteria of 3 ug/L.

Total nitrogen mean value at Kirwin Lake was 0.8 mg/L is below average total nitrogen of USACE lakes (e.g., Tuttle Creek, Perry, and Milford lakes) (Figure 3-1) and exceeds EPA Ecoregional Recommended Criteria of 0.62 mg/L (EPA 2001).

Kirwin Lake total phosphorus mean of 0.06 mg/L is in the mesotrophic category (Carlson 1977) and less than half of the eutrophic conditions measured during TMDL period 1986-2001(KDHE 2003c). Mean chlorophyll concentration of 15 ug/L exceeds eutrophic threshold and TMDL endpoint of 12 ug/L (KDHE 2003c). Cyanobacteria is accounted for 92% of phytoplankton community in 2010 sample (KDHE 2012).

Cyanobacteria blooms have led to HAB Warnings due to toxic algae including the most recent public health warning lasting 3 weeks of the recreational season of 2017.

Total metals in Kirwin Lake surface samples did not exceed Kansas Surface Water Quality numeric criteria including Domestic Water Supply of 0.010 mg/L of total arsenic (KDHE 2018).

Table 3-34.Water quality chemistry statistics from KDHE surface samples of Kirwin Lake from 2010-2019.

	Kirwin Lake Descriptive Statistics-KDHE 2010-2019 Surface Samples								
Variable	Valid N	Mean	Median	Min.	Max.	Lower Quartile	Upper Quartile	Std.Dev.	Standard Error
Atrazine µg/L	4	0.828	0.845	0.420	1.200	0.630	1.025	0.319	0.160
TKN nitrogen mg/L	8	0.805	0.872	0.460	1.000	0.670	0.950	0.203	0.072
T. nitrogen mg/L	8	0.805	0.872	0.460	1.000	0.670	0.950	0.203	0.072
Chlorophyll a µg/L	8	15.021	13.780	4.730	27.480	9.290	20.910	8.557	3.025
Alkalinity mg CaCO3/L	8	155.38	158.70	130.00	170.00	147.84	165.00	13.91	4.92
Bromide mg/L	6	0.495	0.396	0.350	0.720	0.390	0.720	0.175	0.071
Chloride mg/L	8	65.147	63.854	50.000	83.000	50.236	80.000	16.041	5.671
Sulfate mg/L	8	222.98	218.74	180.00	280.00	188.20	255.00	39.81	14.07
Total organic carbon mg/L	8	8.609	8.413	7.500	10.000	7.972	9.300	0.931	0.329
Phosphorus mg/L	8	0.063	0.066	0.034	0.086	0.047	0.078	0.019	0.007
Arsenic mg/L	8	0.007	0.006	0.006	0.008	0.006	0.007	0.001	0.000
Boron mg/L	8	0.094	0.095	0.069	0.120	0.075	0.110	0.021	0.007
Copper mg/L	6	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.000
Iron mg/L	8	0.076	0.080	0.041	0.100	0.056	0.097	0.024	0.008
Magnesium mg/L	8	25.07	25.50	19.30	30.00	20.63	29.50	4.81	1.70
Manganese mg/L	6	0.045	0.037	0.028	0.069	0.029	0.068	0.019	0.008
Nickel mg/L	8	0.002	0.002	0.002	0.003	0.002	0.003	0.000	0.000
Selenium mg/L	8	0.003	0.003	0.002	0.004	0.003	0.004	0.001	0.000
Zinc mg/L	2	0.007	0.007	0.006	0.009	0.006	0.009	0.002	0.001
Strontium mg/L	8	0.947	0.941	0.810	1.100	0.842	1.050	0.119	0.042
Uranium mg/L	6	0.009	0.009	0.008	0.011	0.008	0.011	0.001	0.001

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FUTURE WITHOUT PROJECT CONDITIONS

1.0 FUTURE WITHOUT PROJECT: WATER QUALITY

Water Quality Summary

The availability of high-quality water for commercial, industrial and residential uses is vitally important for the water users of Kansas. Activities to further protect and improve the water quality of Kansas to avoid degradation of the State's water resources are imperative for current and future water users. State natural resource agencies have designated 16 of the 18 lakes in the Kansas River Basin as "impaired" from nutrient related impacts (e.g., excess nitrogen and/or phosphorus, general eutrophication, excess chlorophyll/algae measures, dissolved oxygen sags resulting from algae blooms) due in part to agricultural runoff. Inflow streams flowing into Basin lakes are frequently impaired from a range of pollutants including, but not limited to, fecal bacteria, herbicides like atrazine, and chemical contamination from naturally occurring compounds found in geological deposits (e.g., chloride and sulfate salts, selenium, and arsenic). Approximately 86% of the state's assessed stream miles are impaired for one of their uses and less than 5% of the state's assessed wetlands are able to support aquatic life and recreational uses (Kansas Water Office 2021a). Excess nutrients can promote Harmful Algal Blooms (HABs) under ideal growing conditions. HABs have impacted six lakes in the basin since 2011. Milford Lake has been the hardest hit, with HAB warnings impacting recreation 7 of the last 10 years. As accumulation of sediment reduces storage capacity of reservoirs, and internal nutrient loading increases, water quality problems are expected to intensify.

As water quality conditions degrade within a water body, use of water from that source as well as downstream uses can be negatively impacted. Negative impacts from degrading/poor water quality conditions can include increased costs to treat water for public water supply needs, decreased yields for agricultural producers, decreased recreational opportunities, fish consumption advisories, and diminished biological diversity in streams and lakes.

Reservoir Aging, Sedimentation, & Water Quality

The transport of sediment is a natural function in river ecosystems. Mass quantities and particle sizes transported depend upon watershed geology, topography, climate, land use/cover, and land management. Most natural river reaches are approximately balanced with respect to sediment inflow and outflow (Morris and Fan 1998). Storm events generating high run-off volumes transport the majority of sediment and nutrient loads. Sheet, rill, gully, and ephemeral gully erosion from hillslopes are major sources of most sediment introduced into stream channels. Other sources include landslides, debris flows, streambanks, irrigation, and roadsides (NRCS 2021). Functional riparian and aquatic habitats evolve in association with transported sediment quantity and composition (Hauer, et al. 2018).

Dam construction dramatically alters streamflow and sediment transport. Impounded stream and river segments result in lower flow velocities that efficiently trap sediment. Initial sediment trapping efficiency is often greater than 90% in large reservoirs (Juracek 2014) . As deposition occurs decreases in surface area, storage capacity, depth, and residence time affect physical, chemical, and biological components of reservoir ecosystems (Juracek 2014, Miranda 2017). Dammed reaches may again achieve an approximate sediment transport balance as impoundments fill with sediment and no longer provide water storage and other benefits. Declining storage reduces and eventually compromises the capacity for flow regulation, water supply, flood control benefits, hydropower, navigation, recreation, and environmental benefits that depend on releases from storage (Morris and Fan 1998). Despite increased demand for sustainable water supply, reservoir capacity is consistently diminishing due to sedimentation (George, Hotchkiss and Huffaker 2017).

Physical, chemical, and biological systems downstream of impoundments are also profoundly affected. Dams alter downstream flow rate, timing, duration, and volume. Water temperature, dissolved oxygen concentrations, transport of sediment, nutrients, and the mobility of resident and migratory species are affected. Seasonal flow patterns are altered, affecting life cycle requirements of native plant and animal species (IWR 2016, Juracek 2014). Altered downstream flow variability can impair or eliminate native fish and macroinvertebrate communities. Downstream of reservoirs, stream substrate changes from a mix of fine and course particles to exclusively course or armored substrate leading to significant ecological habitat effects (Juracek 2014, Miranda 2017, IWR 2016, Shelley, et al. 2016).

Reservoirs generally receive larger sediment loads than natural lakes because of larger contributing watersheds. The ratio of watershed area to water surface area is usually higher for reservoirs (Miranda and Bettoli 2010). Accumulation of sediment in reservoirs is accelerated by land use practices (tillage, grazing, development) in the watershed exposing vulnerable soils to precipitation runoff and erosion. Delivered sediment loads carry significant quantities of organic materials, nutrients, and contaminants. Most captured sediments in large reservoirs are fine-grained silts and clays affecting water clarity and capable of transporting nutrients and contaminants.

The progressive storage loss in reservoirs due to sedimentation is a fundamental aspect of reservoir aging, although all reservoirs do not age at the same rate. Climate, watershed geological characteristics, drainage network density, slope, land cover and land use, basin management, unique reservoir characteristics, and reservoir operational management practices play critical roles in the aging process. Within a single watershed, a small fraction of the landscape is usually responsible for a large percentage of the sediment yield and sediment transport may exhibit distinct seasonal variation due to timing of periods of precipitation and protective vegetative cover (Morris and Fan 1998). Reservoirs with watersheds dominated by cropland and/or urban development may exhibit hypereutrophic (highly productive) conditions, irrespective of chronological age (Carney 2009). Deposited and suspended sediments affect aquatic habitat and life contributing to reduced abundance and diversity via smothered spawning sites, inhospitable macroinvertebrate habitat, increased turbidity, reduced light availability, inhibited phytoplankton and macrophyte growth, diminished sight and filter-feeding, and water temperature effects. Elevated turbidity in surface waters impairs physical, chemical, and biological components of aquatic ecosystems, and leads to decreased aesthetic and recreational value. Turbidity can affect water temperature causing temperate reservoirs to warm more slowly in spring/summer, experience higher warm season surface temperatures, and cool more slowly in fall/winter. Alteration of heat budgets affects biotic and abiotic processes influencing growth rates, reaction rates, constituent solubility, and water density. Sediment accumulation enhances eutrophication and impairs water quality. Elevated levels of suspended matter increase the capacity for sorption and transport of nutrients, heavy metals, and organic compounds such as pesticides. High levels of suspended sediments may also result in limiting primary production despite high nutrient availability through diminished light availability. Fine sediment particles may remain in suspension for considerable periods of time affecting water clarity. Wind and wave action can resuspend fine sediments exacerbating water clarity and quality issues.

Dissolved oxygen concentrations affect rates of reduction of inorganic substances and the distribution of aerobic and anaerobic organisms. Higher water column oxygen demand is associated with turbid inflows and accompanying organic materials. Sediment oxygen demand, the rate of oxygen consumption by bacteria and other organisms metabolizing organic matter in the sediment, is often high in reservoir zones where sediment is deposited. Warm season water temperature increases, due to diminished reservoir depth and increased turbidity, results in lower water column dissolved oxygen concentrations. Dissolved oxygen concentration saturation decreases with increasing water temperature.

Sediment is a critical component of reservoir systems serving as habitat for benthic invertebrates, influencing macrophyte distribution, accumulating nutrients and regulating nutrient recycling, controlling concentrations of dissolved oxygen and other dissolved constituents, and accumulating contaminants (Miranda 2017). Interactions between mineral properties of sediment and water chemistry determine whether sediment becomes a source or a sink of nutrients or other contaminants. Under anoxic hypolimnetic conditions, desorption of nutrients and other contaminants from sediment into the water column can occur. As a reservoir loses storage to sediment accumulation, less ambient lake water is available for diluting incoming sediment, nutrient, and chemical loads, leading to higher turbidity and nutrient concentrations, and decreased chemical constituent buffering (Shelley, et al. 2016). The potential exists for naturally occurring (selenium, arsenic, sulfate, chloride, …) impairments to intensify and extend beyond lakes with reduced volume, reduced chemical buffering and attenuation.

Water quality discussions assessing future expectations in Kansas River Watershed lakes necessarily focus on the effects of water residence time, and the physical transport of constituents through a reservoir, on eutrophication, thermal stratification, chemical composition, heavy metal/nutrient accumulation, and primary production. Residence time has been described at the most important factor influencing water quality (Jørgensen 2003, 16-20) with water management inducing measurable effects influencing biogeochemical processes. Managed changes in residence time, and resulting relative strength of thermal stratification, are dynamic factors influencing nutrient and sediment transport that have been used to alter water quality with various levels of success (Olsson, et al. 2022, Jørgensen 2003). Similarly, temporal differences (i.e., annual, seasonal, diurnal...) in residence time influence the fate of constituents and processes affecting water quality (Rueda, Moreno-Ostos and Armgengol 2006) as well as phytoplankton community (Reynolds, et al. 2012).

With increases in available nutrients and increased warm-season water temperatures, phytoplankton may periodically proliferate (bloom) under specific environmental conditions. Proliferation and collapse of blooms can promote epilimnetic dissolved oxygen supersaturation and hypolimnetic anoxia. Cyanobacteria exhibit optimal growth rates at temperatures generally higher than eukaryotic primary producers. Many cyanophytes can regulate buoyancy and in stagnant waters rise to the surface and effectively shade out competitors. Some species of common cyanobacterial genera tolerate environmentally stressful conditions outcompeting other freshwater phytoplankton. Under climate change scenarios, the frequency of cyanobacterial harmful algal blooms (HABs) is likely to increase, primarily due to water temperature increases tempered by nutrient levels, and climatic impacts on hydrology that drive nutrient transport (Chapra, et al. 2017). Climate change is likely to affect patterns, intensities, and duration of precipitation and droughts and hydrologic changes may further enhance cyanobacterial dominance. Larger and more intense precipitation events can increase nutrient enrichment of water bodies from enhanced surface runoff and groundwater discharge. Accelerating anthropogenic nutrient loading, rising temperatures, enhanced vertical stratification, and increased atmospheric CO_2 supplies are likely to favor cyanobacterial dominance in a wide range of aquatic ecosystems (Paerl and Huisman 2009).

All reservoirs in the Kansas River Watershed will likely experience increasing effects of aging. Continued sediment loading will diminish storage capacity (KRRFSS Appendix D, Reservoir Sedimentation), deliver increased quantities of nutrients and pollutants, and compound effects of eutrophication. Continued and enhanced water quality impairment may be expected.

This analysis of potential future water quality conditions in the Kansas River Watershed is based on observed temporal trends of select water quality constituents, and estimation of constituent transport under climate change scenarios. Trend analyses elucidate what may be expected in the future based on what has been observed. Climate is a fundamental driver of nutrient and sediment transport and expected future climate conditions will directly impact transport from land surfaces to streams and reservoirs.

Trend analysis: Total Nitrogen, Total Phosphorus, and Total Suspended Solids

Temporal water quality data for seven USACE reservoirs within the Kansas River Watershed was provided by NWK. The maximum period of record included monthly (April through September) observations from 1996 through 2020. Data were available for Clinton Lake (CL), Harlan County Lake (HC), Kanopolis Lake (KA), Milford Lake (MI), Perry Lake (PE), Tuttle Creek Lake (TC), and Wilson Lake (WI). Data analyzed were restricted to in-lake dam site locations (surface (S) and bottom (B)) if available, and upstream in-flow sites if available. Trend analysis focused on total nitrogen (TN) and total phosphorus (TP) concentrations, the TN:TP ratio, and total suspended solids (TSS) concentrations. In-lake water quality data was supplemented with corresponding daily reservoir variables including inflow, outflow, storage, and pool elevation.

The Mann-Kendall (M-K) trend test is a nonparametric test which does not require the underlying data to follow a specific distribution. The M-K test can be used to determine increasing or decreasing trends in measurement values of a response variable observed during a certain time period. If an increasing trend in measurements exists, then the measurement taken first from any randomly selected pair of measurements should, on average, have a lower response (concentration or value) than the measurement collected at a later point (U.S. EPA 2015a).

The Theil-Sen (T-S) Line test represents a nonparametric version of the parametric Ordinary Least Squares (OLS) regression analysis and requires the values of the time variable at which the response measurements were collected. The T-S procedure does not require normally distributed trend residuals and responses as required by the OLS regression. Unlike the M-K test, actual concentration values are used in the computation of the slope estimate associated with the T-S trend test. The test is based upon the calculation of slope estimates for every pair of distinct measurements, and the median slope value is used as an estimate of the unknown population slope (U.S. EPA 2015a). The median slope value mitigates the influence of extreme (outlier) observations.

Water quality constituent concentration data often includes ‘censored’ data, where laboratory analysis results are not quantifiable (below the analysis method detection limit) and are reported as less than the method numeric limit of quantification. U.S. EPA’s ProUCL (U.S. EPA 2015b), and ‘R’ packages NADA (Lee 2020) and NADA2 (Julian and Helsel 2021) have been developed to analyze censored data.

Sampling dates were recorded with each water quality constituent concentration/value observation. Because the ProUCL program does not recognize dates, the time variable was derived as number of days since January 1, 1990. M-K trend and T-S line tests were performed with ProUCL. R packages NADA and NADA2 were used to further examine trends accounting for covariate influence (inflow, outflow, storage, and pool elevation) using the M-K trend test, and for seasonal (monthly) variation using the Seasonal Kendall trend test.

Results of the M-K trend and T-S line tests are presented in Table 1. Bold ‘Increasing’ and ‘Decreasing’ entries in the table indicate trend test p-value results less than 0.05. ‘No Trend’ entries indicate resulting p-values greater than 0.05. ‘NA’ table entries imply trend calculation is not applicable.

Noteworthy (p-value < 0.05) TN trends only occurred at dam site bottom locations at Harlan County Lake (HC-2B), Kanopolis Lake (KA-3B), and Milford Lake (MI-1B), and all were decreasing. TP trend analysis revealed increasing trends at five of the seven lakes at dam site surface locations (e.g., Figure 1 and Figure 2). Only two dam site bottom locations revealed TP trends, one increasing (MI-1B) and one decreasing (WI-15AB). Increasing inflow site TP concentration trends were reported at Clinton (CL-16), Milford (MI-24), and Perry (PE-41). One decreasing inflow site TP trend was noted at Wilson (WI-1).

All noteworthy TN:TP trends at dam site surface locations (five of the seven lakes) were decreasing. Example graphics are shown in Figure 3 and Figure 4. Inflow sites showed decreasing TN:TP trends at five of the seven lakes. TSS concentration trends were infrequent, but decreasing trends were noted at CL-16, MI-1S, and WI-15AS and B. The Wilson Lake inflow (WI-1) TSS concentration revealed an increasing trend.

Table 1. ***Results of M-K trend tests using ProUCL*** **(U.S. EPA 2015b).**

Lake	Site	TN (mg/l)	TP (mg/l)	TN:TP	TSS (mg/l)
Clinton	CL-2S (dam)	No Trend	**Increasing**	**Decreasing**	No Trend
	CL-2B (dam)	No Trend	No Trend	NA	No Trend
	CL-16 (inflow)	No Trend	**Increasing**	**Decreasing**	**Decreasing**
Harlan Co.	HC-2S (dam)	No Trend	**Increasing**	**Decreasing**	No Trend
	HC-2B (dam)	**Decreasing**	No Trend	NA	No Trend
	HC-8 (inflow)	No Trend	No Trend	**Decreasing**	No Trend
Kanopolis	KA-3S (dam)	No Trend	**Increasing**	**Decreasing**	No Trend
	KA-3B (dam)	**Decreasing**	No Trend	NA	No Trend
	KA-14 (inflow)	No Trend	No Trend	**Decreasing**	No Trend
Milford	MI-1S (dam)	No Trend	**Increasing**	**Decreasing**	**Decreasing**
	MI-1B (dam)	**Decreasing**	**Increasing**	NA	No Trend
	MI-24 (inflow)	No Trend	**Increasing**	**Decreasing**	No Trend
Perry	PE-2S (dam)	No Trend	No Trend	No Trend	No Trend
	PE-2B (dam)	No Trend	No Trend	NA	No Trend
	PE-17 (inflow)	No Trend	No Trend	No Trend	No Trend
	PE-29 (inflow)	No Trend	No Trend	No Trend	No Trend
	PE-41 (inflow)	No Trend	**Increasing**	No Trend	No Trend
Tuttle Creek	TC-3S (dam)	No Trend	**Increasing**	**Decreasing**	No Trend
	TC-30 (inflow)	No Trend	No Trend	**Decreasing**	No Trend
Wilson	WI-15AS (dam)	No Trend	No Trend	No Trend	**Decreasing**
	WI-15AB (dam)	No Trend	**Decreasing**	NA	**Decreasing**
	WI-1 (inflow)	No Trend	**Decreasing**	No Trend	**Increasing**

Increasing and **Decreasing** trends indicated by test p-values < 0.05; NA = not applicable/not calculated.

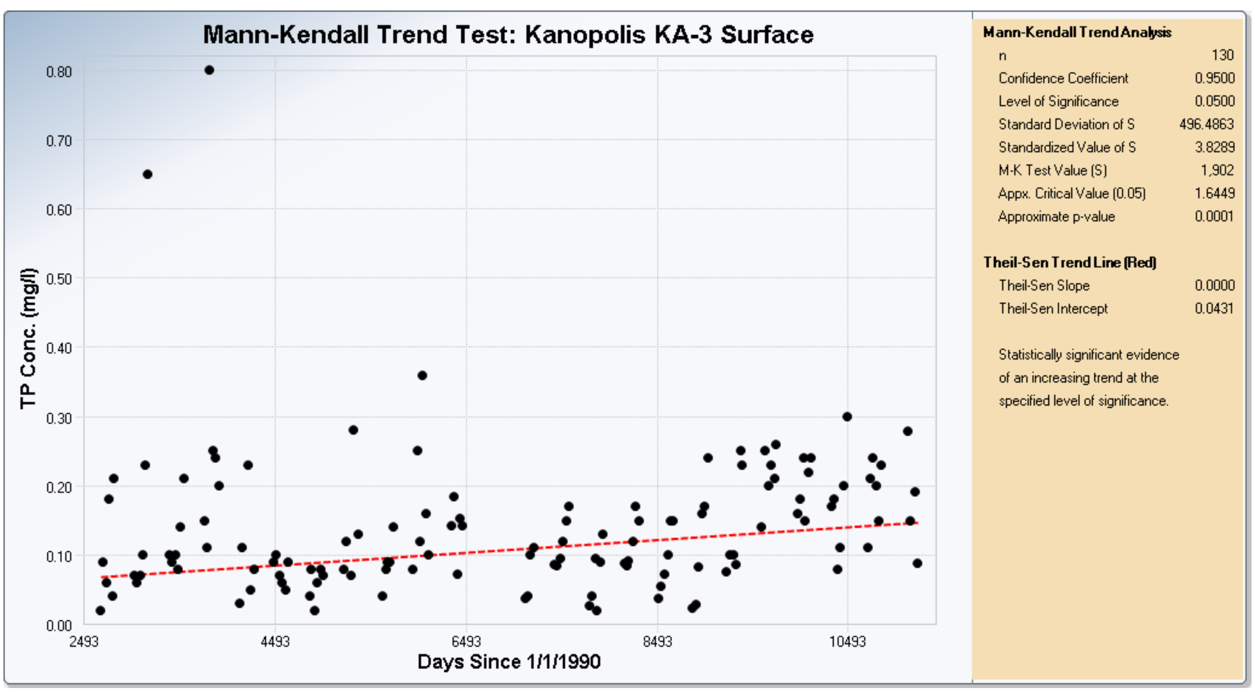

Figure 1. M-K trend test and T-S trend line for TP concentration at Kanopolis Lake (KA-3).

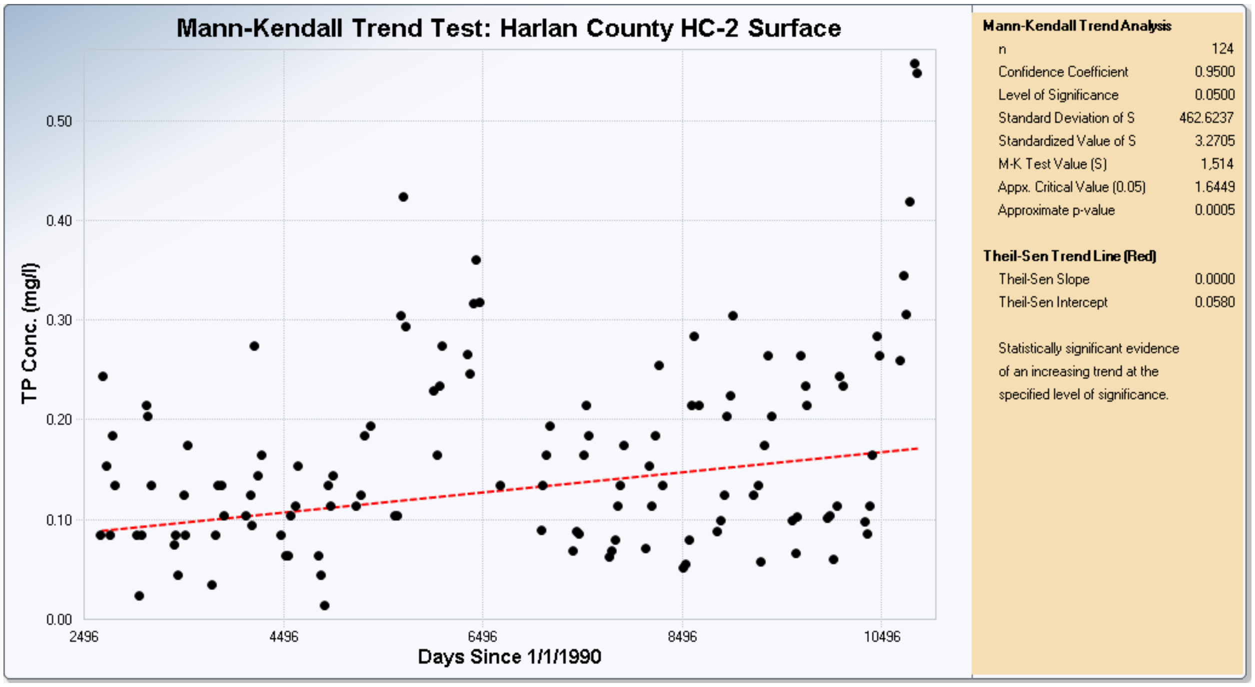

Figure 2. M-K trend test and T-S trend line for TP concentration at Harlan County Lake (HC-2).

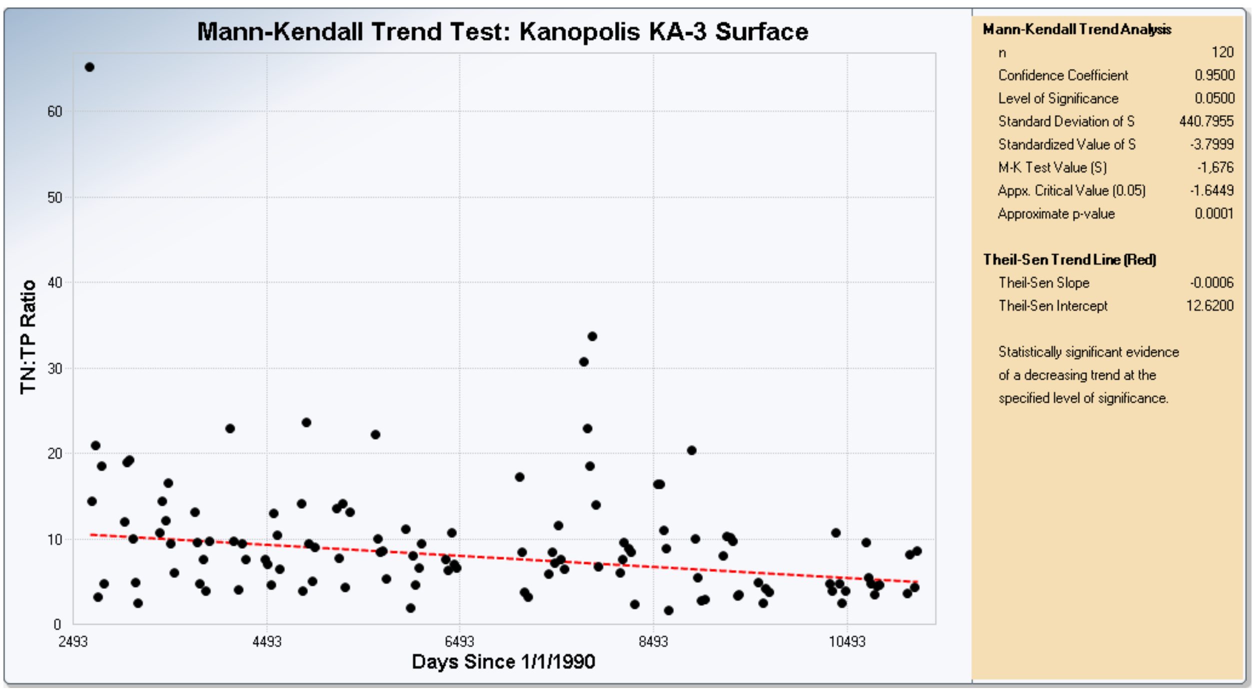

Figure 3. M-K trend test and T-S trend line for TN:TP ratio at Kanopolis Lake (KA-3).

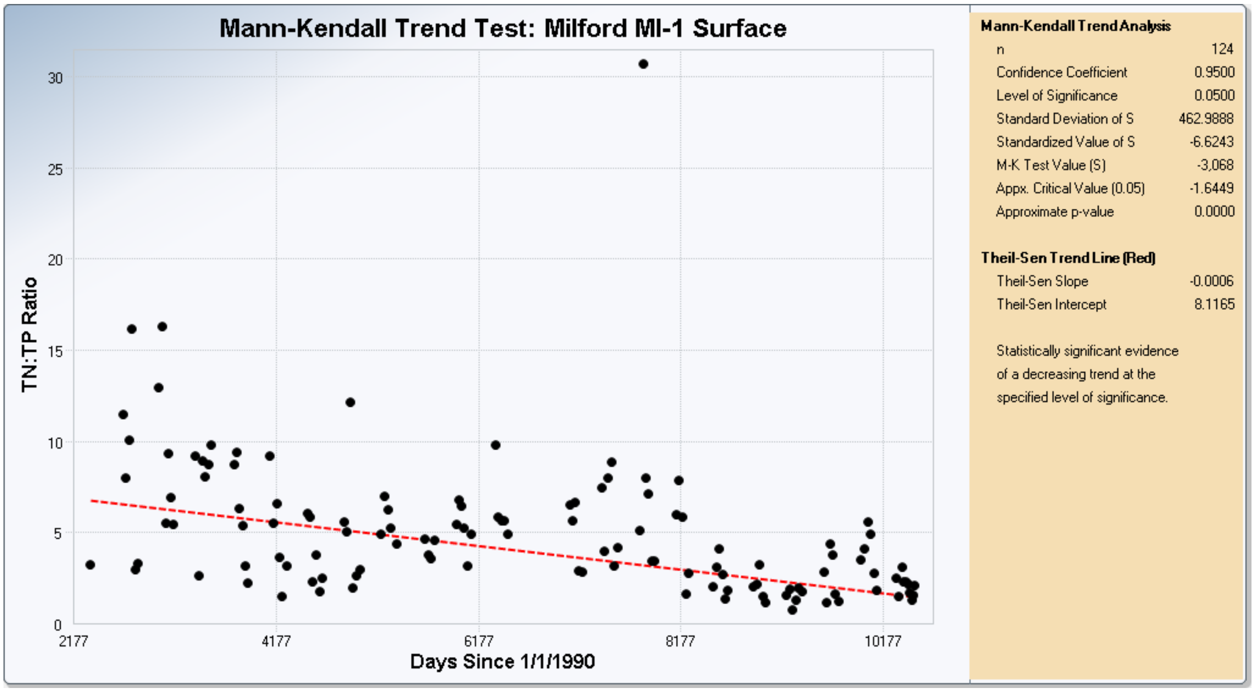

Figure 4. M-K trend test and T-S trend line for TN:TP ratio at Milford Lake (MI-1).

A temporal trend analysis of TN, TP, TN:TP, and TSS observations at dam site surface sites including daily corresponding reservoir attributes (flow in [cfs], flow out [cfs], storage [ac-ft], and pool elevation [ft]) as covariates was performed (Table 2). Incorporation of covariates in the trend analysis did not alter TN trend results; no noteworthy TN trends were revealed.

The Clinton Lake dam site surface location showed a significant increasing TP trend with no covariates included in the analysis, but with covariates no TP trend was revealed. Increasing TP trends with covariates included were noted at dam surface sites at Harlan Co., Kanopolis, Milford, and Tuttle Creek. At Harlan Co. Lake, site HC-2 (surface), inclusion of daily lake storage and pool elevation as covariates (separately) resulted in no significant trend. Corresponding to TP trend analysis without covariates, dam site surface locations at Perry (PE-2) and Wilson (WI-15A) revealed no TP trends with covariates.

Addition of covariates in analysis of TN:TP trends at dam surface sites resulted in fewer significant decreasing trends. Data available was insufficient to process information at Clinton, Kanopolis, Perry, and Wilson. Both Milford and Tuttle Creek revealed significant decreasing TN:TP trends with each covariate included.

Covariate inclusion in TSS trend analysis at dam surface sites revealed significant decreasing trends at Milford and Wilson, corresponding to analysis without covariates.

Table 2. ***Results of M-K trend tests with a covariate using NADA2*** **(Julian and Helsel 2021)** ***in R*** **(R Core Team 2020)*.***

Lake	**Site**	**Covariate**	**TN**	**TP**	**TN:TP**	**TSS**
Clinton	**CL-2**	Flow-In	No Trend	No Trend	NA	No Trend
		Flow-Out	No Trend	No Trend	NA	No Trend
		Storage	No Trend	No Trend	No Trend	No Trend
		Elev.	No Trend	No Trend	No Trend	No Trend
Harlan Co.	**HC-2**	Flow-In	No Trend	**Increasing**	No Trend	No Trend
		Flow-Out	No Trend	**Increasing**	No Trend	No Trend
		Storage	No Trend	No Trend	No Trend	No Trend
		Elev.	No Trend	No Trend	No Trend	No Trend
Kanopolis	**KA-3**	Flow-In	No Trend	**Increasing**	NA	NA
		Flow-Out	No Trend	**Increasing**	NA	NA
		Storage	No Trend	**Increasing**	NA	NA
		Elev.	No Trend	**Increasing**	NA	NA
Milford	**MI-1**	Flow-In	No Trend	**Increasing**	**Decreasing**	**Decreasing**
		Flow-Out	No Trend	**Increasing**	**Decreasing**	**Decreasing**
		Storage	No Trend	**Increasing**	**Decreasing**	**Decreasing**
		Elev.	No Trend	**Increasing**	**Decreasing**	**Decreasing**
Perry	**PE-2**	Flow-In	No Trend	No Trend	NA	No Trend
		Flow-Out	No Trend	No Trend	NA	No Trend
		Storage	No Trend	No Trend	NA	No Trend
		Elev.	No Trend	No Trend	NA	No Trend
Tuttle Creek	**TC-3**	Flow-In	No Trend	**Increasing**	**Decreasing**	No Trend
		Flow-Out	No Trend	**Increasing**	**Decreasing**	No Trend
		Storage	No Trend	**Increasing**	**Decreasing**	No Trend
		Elev.	No Trend	**Increasing**	**Decreasing**	No Trend
Wilson	**WI-15A**	Flow-In	No Trend	No Trend	NA	NA
		Flow-Out	No Trend	No Trend	NA	NA
		Storage	No Trend	No Trend	NA	**Decreasing**
		Elev.	No Trend	No Trend	NA	**Decreasing**

Increasing and **Decreasing** trends significant at $p < 0.05$; NA = sufficient data not available/not calculated.

TN, TP, TN:TP, and TSS dam site surface data at the seven lakes were evaluated for trends using the Seasonal Kendall (SK) test which performs the M-K calculations for each season, months in this application, and then combines the results. Constituent data available were from sampling efforts from April through September in most years. For monthly ‘seasons’, April observations are only compared to other April observations, etc. No comparisons are made across seasonal boundaries. The results of the analysis are found in Table 3.

No significant TN trends were revealed at any of the lake’s dam site surface locations. Significant increasing TP trends were noted at five of the seven lakes (not Perry and Wilson). Significant decreasing TN:TP trends were found at Clinton, Kanopolis, Milford Lakes, and Tuttle Creek. Two lakes, Milford and Wilson, revealed significant decreasing TSS trends.

Table 3. ***Results of Seasonal Kendall trend tests using NADA2* (Julian and Helsel 2021) *in R* (R Core Team 2020)*.***

Lake	Site	TN	TP	TN:TP	TSS
Clinton	**CL-2**	No trend	**Increasing**	**Decreasing**	No Trend
Harlan Co.	**HC-2**	No Trend	**Increasing**	No Trend	No Trend
Kanopolis	**KA-3**	No Trend	**Increasing**	**Decreasing**	No Trend
Milford	**MI-1**	No Trend	**Increasing**	**Decreasing**	**Decreasing**
Perry	**PE-2**	No Trend	No Trend	No Trend	No Trend
Tuttle Creek	**TC-3**	No Trend	**Increasing**	**Decreasing**	No Trend
Wilson	**WI-15A**	No Trend	No Trend	No Trend	**Decreasing**

Increasing and **Decreasing** trends significant at $p < 0.05$; NA = sufficient data not available/not calculated.

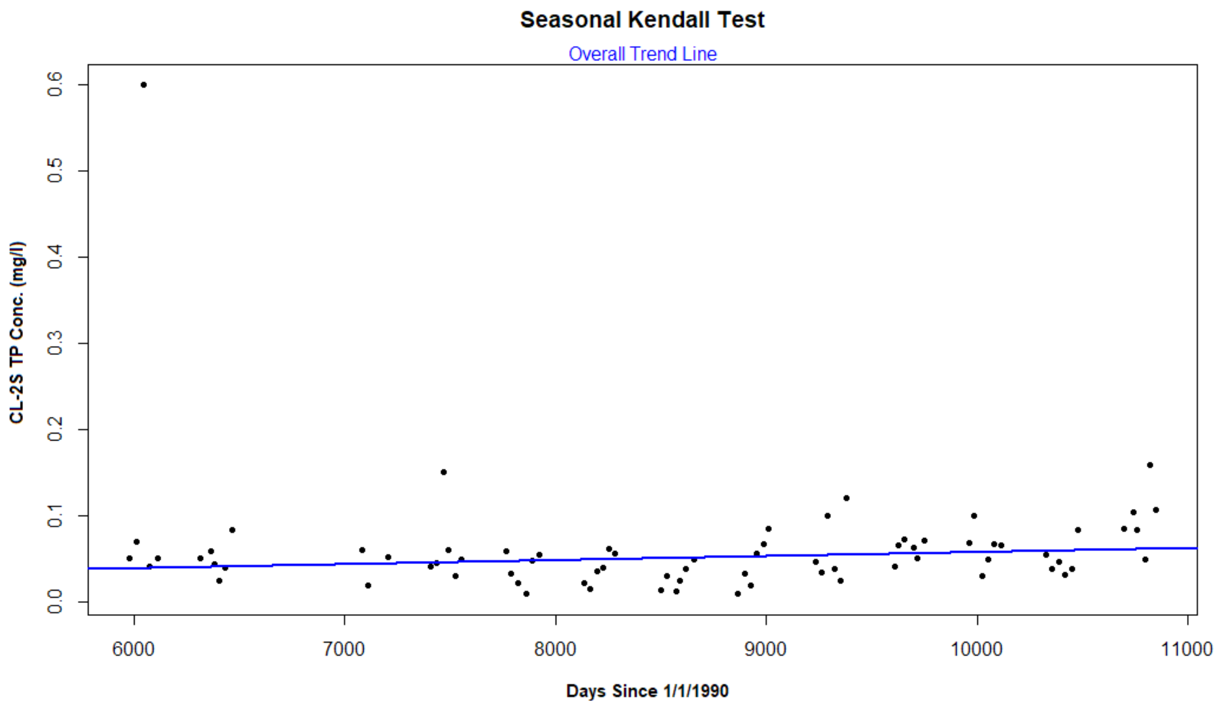

Figure 5. **SK trend test result ($p < 0.05$) for TP concentrations at Clinton Lake (CL-2S).**

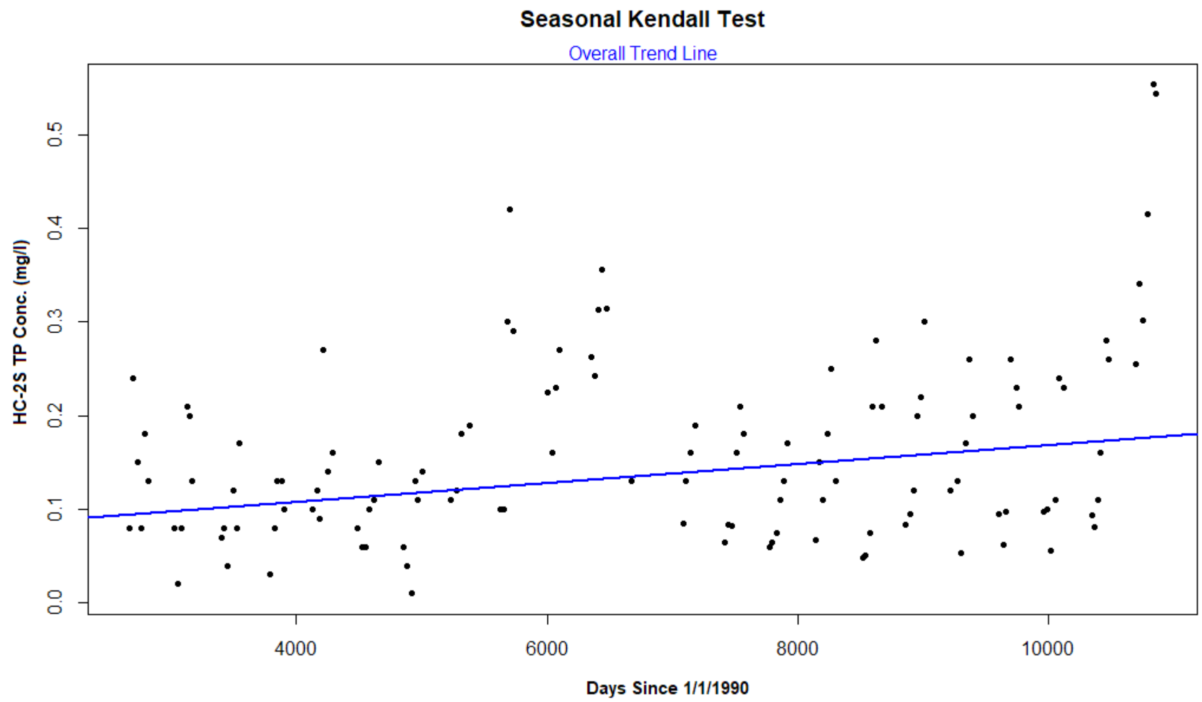

Figure 6. SK trend test result ($p < 0.05$) for TP concentrations at Harlan County Lake (HC-2S).

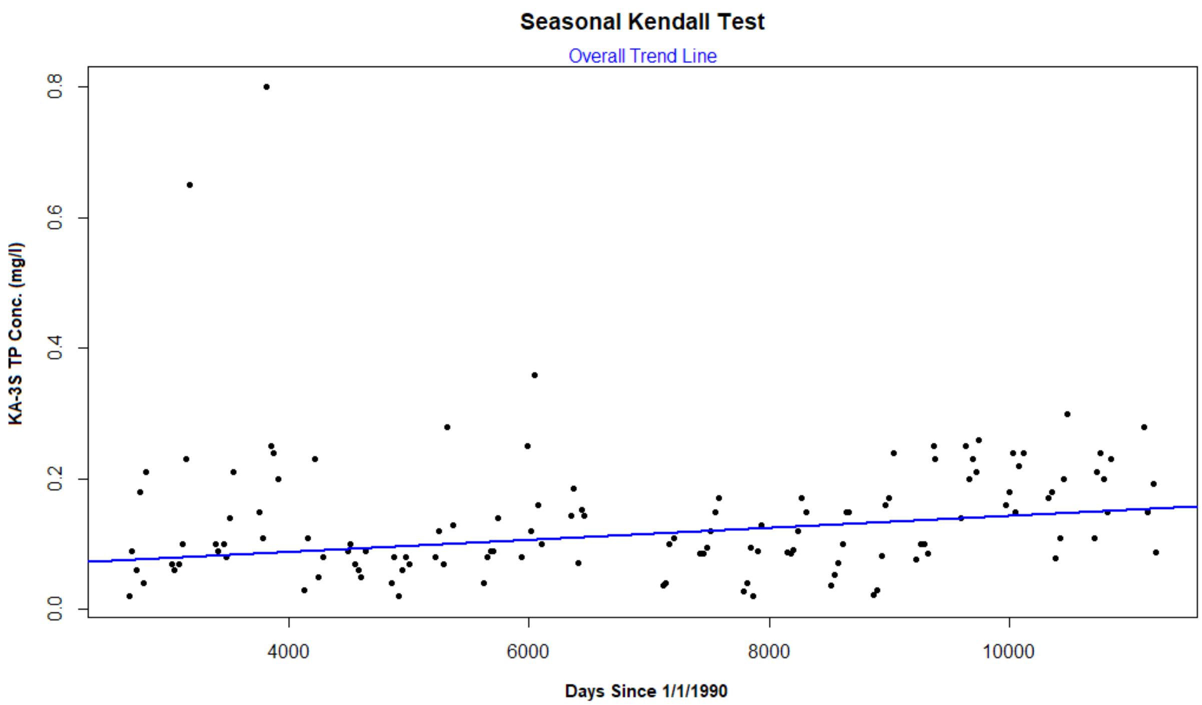

Figure 7. SK trend test result ($p < 0.05$) for TP concentrations at Kanopolis Lake (KA-3S).

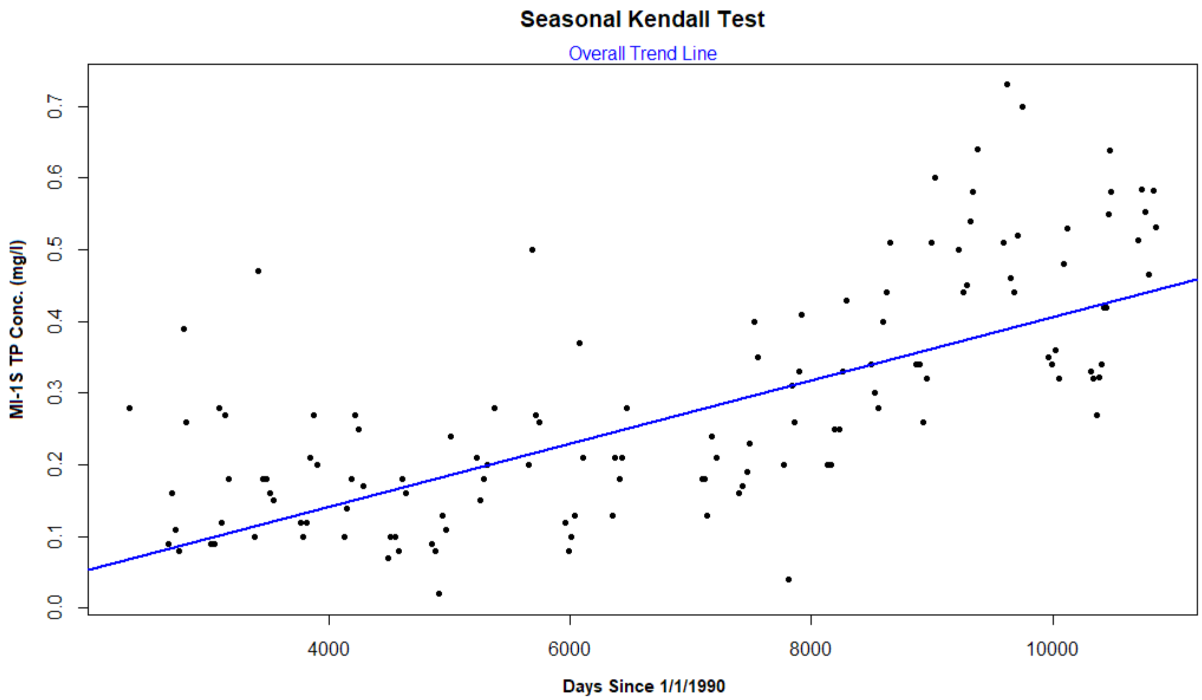

Figure 8. SK trend test result ($p < 0.05$) for TP concentrations at Milford Lake (MI-1S).

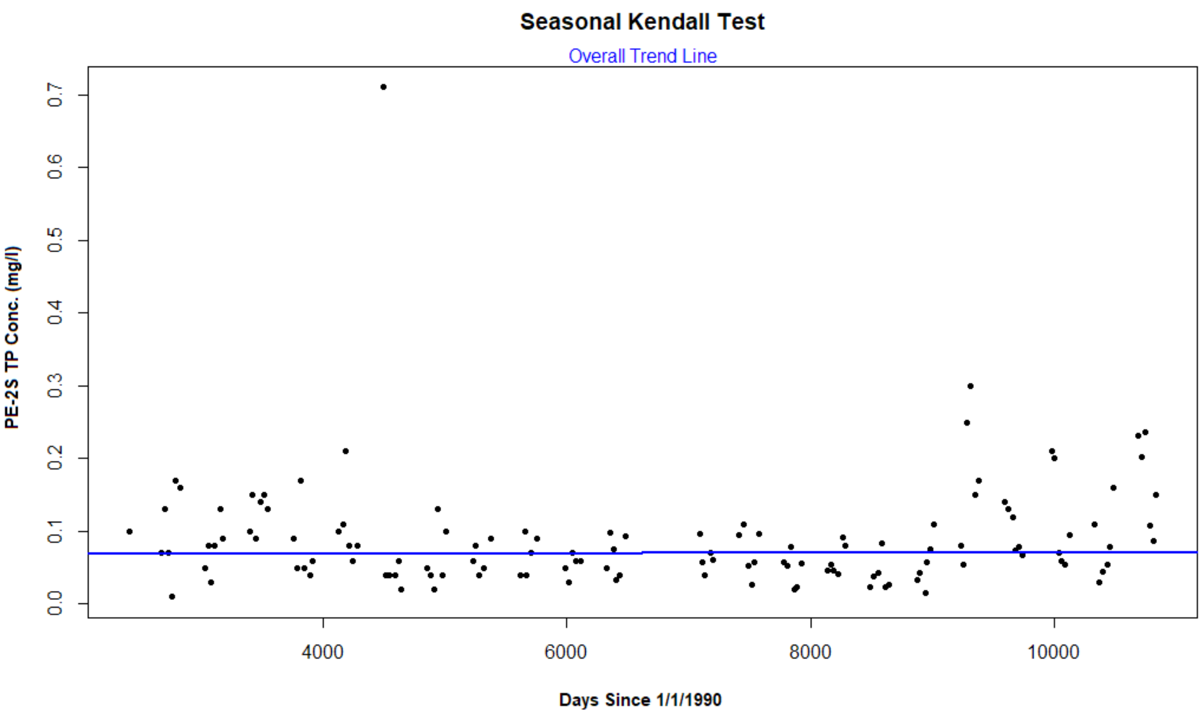

Figure 9. SK trend test result ($p > 0.05$) for TP concentrations at Perry Lake (PE-2S).

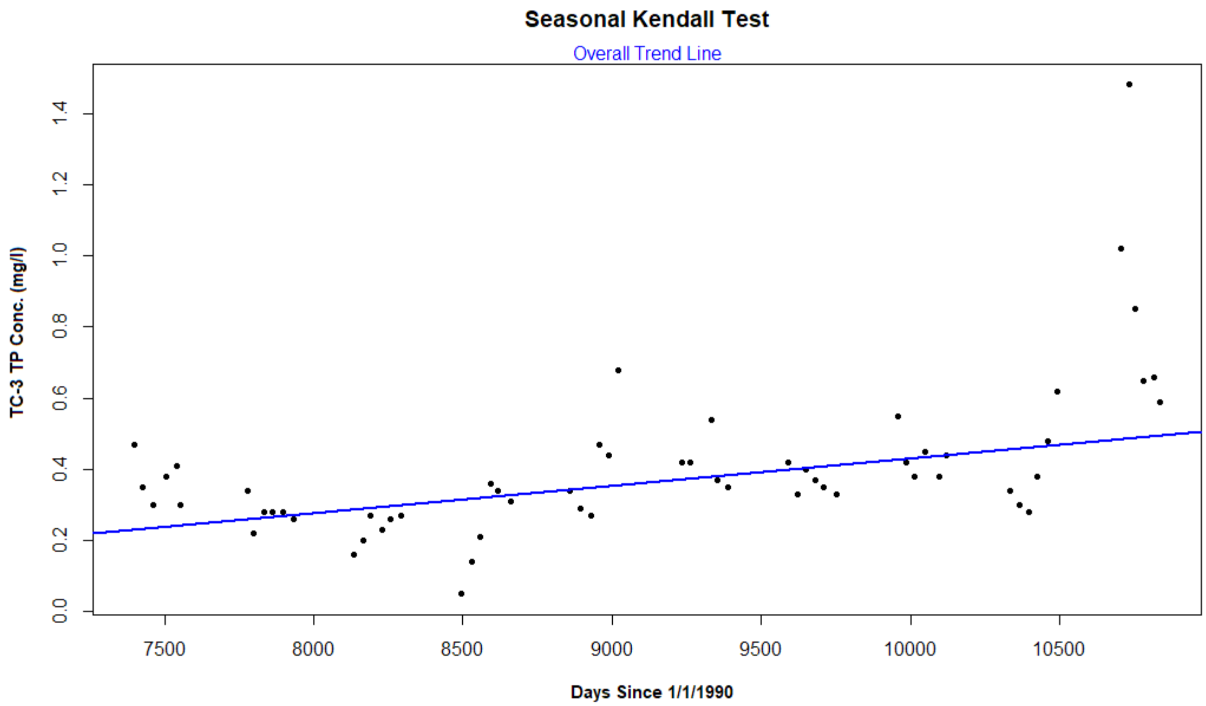

Figure 10. **SK trend test result ($p < 0.05$) for TP concentrations at Tuttle Creek Lake (TC-3).**

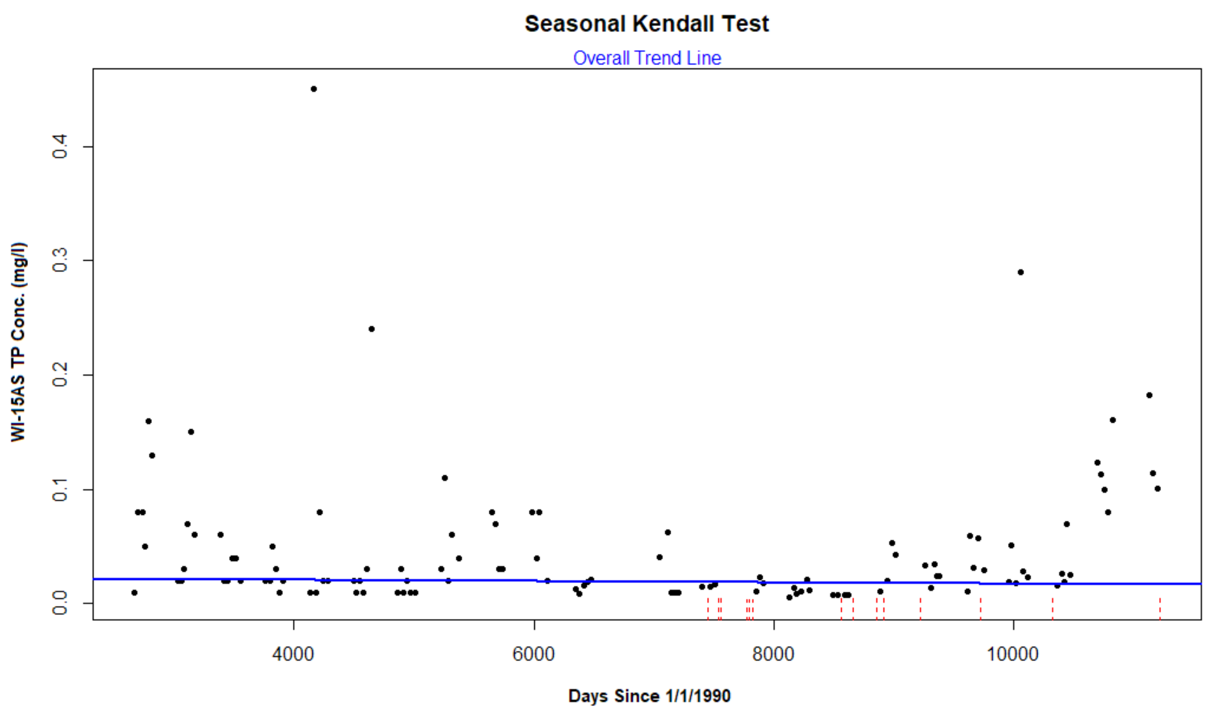

Figure 11. **SK trend test result ($p > 0.05$) for TP concentrations at Wilson Lake (WI-15AS).**

Trend Analysis Conclusions

The nutrients nitrogen and phosphorus are abundantly available throughout the Kansas River Watershed. A watershed-wide pattern of increasing in-lake TP concentrations suggests potential for continued eutrophication (high algal productivity) at Kansas Watershed reservoirs. Phosphorus is often considered a nutrient limiting primary productivity, although nutrient limitation of phytoplankton growth may vary temporally and geographically between phosphorus and nitrogen. Observed decreasing TN:TP ratios observed may indicate an enhanced opportunity for seasonal HAB issues as some flourish under conditions with elevated phosphorus availability and water temperature, with certain genera of cyanophytes capable of nitrogen fixation.

Future water quality within the Kansas River watershed lakes is dependent on multiple influencing factors, some of which are challenging to predict and/or estimate. Trends in land use and management can be monitored. As a significant portion of the total area of the watershed is currently classified as 'Cultivated Crops' (~51.5%), based on the 2016 National Land Cover Database (NLCD) (Yang, et al. 2018), it can be assumed that continued, and increasing (Figure 12), fertilizer use will continue to influence the water quality of runoff, groundwater, streams, and lakes. Additionally, the 2016 NLCD indicates ~40% of the total watershed area is classified as Grassland/Herbaceous and Pasture/Hay, much of which is used as rangeland/stock areas for livestock in the watershed. The Kansas Department of Agriculture (2021) publishes total numbers of livestock (cattle, sheep, hogs). Trending increasing numbers of animals require feed and produce increased quantities of manure (Figure 13).

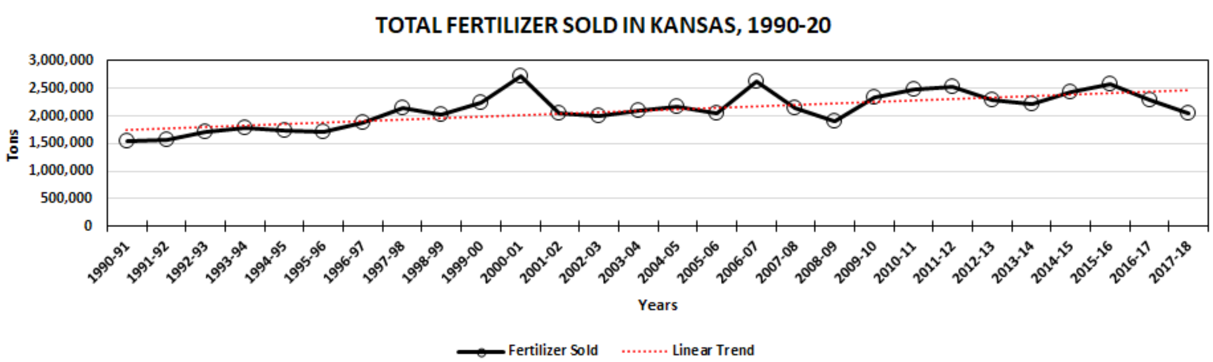

Figure 12. Total fertilizer sold in Kansas by fiscal year (Kansas Department of Agriculture 2021)

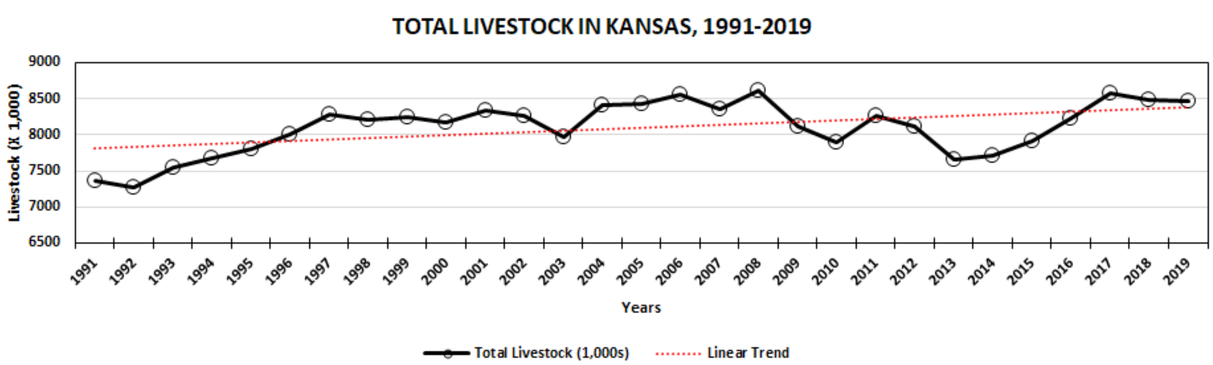

Figure 13. Total livestock in Kansas by year (Kansas Department of Agriculture 2021).

Climate Change and Streamflow Trends

Based on the USACE Climate Hydrology Assessment Tool (CHAT) (U. S. ACE 2021a) providing estimates of potential future hydrology for HUC-8 watersheds using climate models and scenarios from the Coupled Model Intercomparison Project Phase 5 (CMIP-5), future runoff trends can be estimated (Nguyen, et al. 2020). The CHAT utilizes 32 projected future Global Climate Model (GCM) simulations based on accelerated CO_2 levels for representative concentration pathways (RCPs) 4.5 and 8.5. RCP 4.5 represents rising radiative forcing stabilizing at 4.5 W/m^2 before 2100, and RCP 8.5 represents rising radiative forcing pathway leading to 8.5 W/m^2 in 2100, where radiative forcing expresses the change in energy in the atmosphere due to greenhouse gas emissions. CHAT options include evaluation of whether there is evidence of a statistically significant trend (defined as $p\text{-value} < 0.05$) in the mean of the 64 (32 for each RCP) simulated timeseries for both the historic simulation period (water years 1951-2005) and the projected future simulation period (water years 2006-2099). The Mann-Kendall test trend results were captured for this effort in evaluation of future runoff trends by HUC-8 within the three HUC-4 regions spanning the Kansas River Watershed. Results are presented below in Table 4. The generally increasing trends in streamflow across the watershed, due to future climate conditions with predicted regional future precipitation increases and the likelihood of increased frequency of extreme precipitation events, can be expected to transport increased quantities of sediment and nutrients.

Table 4. Results of M-K Test for Future Trends in Mean Annual Max of Average Monthly Streamflow at HUC-8 Watersheds in the Kansas River Watershed (U. S. ACE 2021a).

HUC-8	Name	States	Future (2006-2099) Streamflow Trend
10250001	Arikaree	CO, KS, NE	No Trend
10250002	North Fork Republican	CO, KS, NE	No Trend
10250003	South Fork Republican	CO, KS, NE	**Increasing**
10250004	Upper Republican	KS, NE	No Trend
10250005	Frenchman	CO, NE	**Increasing**
10250006	Stinking Water	CO, NE	NA
10250007	Red Willow	NE	**Increasing**
10250008	Medicine	NE	NA
10250009	Harlan County Reservoir	KS, NE	**Increasing**
10250010	Upper Sappa	KS	NA
10250011	Lower Sappa	KS, NE	**Increasing**
10250012	South Fork Beaver	CO, KS	NA
10250013	Little Beaver	CO, KS	NA
10250014	Beaver	KS, NE	**Increasing**
10250015	Prairie Dog	KS, NE	**Increasing**
10250016	Middle Republican	KS, NE	**Increasing**
10250017	Lower Republican	KS	**Increasing**
10260001	Smoky Hill Headwaters	CO, KS	NA
10260002	North Fork Smoky Hill	CO, KS	NA
10260003	Upper Smoky Hill	KS	**Increasing**
10260004	Ladder	CO, KS	NA
10260005	Hackberry	KS	NA
10260006	Middle Smoky Hill	KS	**Increasing**
10260007	Big	KS	**Increasing**
10260008	Lower Smoky Hill	KS	**Increasing**
10260009	Upper Saline	KS	**Increasing**
10260010	Lower Saline	KS	No Trend
10260011	Upper North Fork Solomon	KS	**Increasing**
10260012	Lower North Fork Solomon	KS, NE	**Increasing**
10260013	Upper South Fork Solomon	KS	**Increasing**
10260014	Lower South Fork Solomon	KS	**Increasing**
10260015	Solomon	KS	**Increasing**
10270101	Upper Kansas	KS	**Increasing**
10270102	Middle Kansas	KS	**Increasing**
10270103	Delaware	KS	**Increasing**
10270104	Lower Kansas, Kansas	KS, MO	**Increasing**
10270201	Upper Big Blue	NE	NA
10270202	Middle Big Blue	NE	**Increasing**
10270203	West Fork Big Blue	NE	**Increasing**
10270204	Turkey	NE	**Increasing**
10270205	Lower Big Blue	KS, NE	**Increasing**
10270206	Upper Little Blue	KS, NE	**Increasing**
10270207	Lower Little Blue	KS, NE	**Increasing**

Increasing trends using M-K test defined as p value < 0.05; NA = not available.

Projected Future Water Quality

HAWQS Methodology

The Hydrologic and Water Quality System (HAWQS) version 1.2 (HAWQS 2020) is a web-based interactive water quantity and quality modeling system that employs the Soil and Water Assessment Tool (SWAT) (Arnold, et al. 2013). SWAT is a basin-scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large watersheds with varying soils, land uses, and management conditions over time. The model is physically based in that it requires spatially referenced data describing weather, hydrology, soil types and attributes, topography, land use/cover, and land management. HAWQS provides users with interactive web interfaces and maps; pre-loaded input data; a user guide, and online development, execution, and storage of a user's modeling projects. The United States Environmental Protection Agency (U.S. EPA) Office of Water (OW) supports and provides project management and funding for HAWQS. The Texas A&M University Spatial Sciences Laboratory and EPA subject matter experts provide ongoing technical support including system design, modeling, and software development.

Historical weather data and future climate scenarios are available within HAWQS. Historical weather data available in HAWQS includes archived National Climate Data Center and National Weather Service precipitation and air temperature data (Menne, et al. 2012). Climate change scenarios are based on representative concentration pathways (RCPs) that capture a range of plausible greenhouse gas concentration futures approximating total radiative forcing in the year 2100. RCP4.5 scenarios, an intermediate scenario where greenhouse gas emissions peak approximately mid-century (2050) as a result of less stringent mitigation efforts, were used for modeling climate change effects in the Kansas River Watershed. Twelve Global Climate Models (GCMs) included in HAWQs provide a representative range of plausible projections across all of the U.S. EPA Regions. Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor, Stouffer and Meehl 2012) GCMs currently in HAWQS include CanESM2, CCSM4, GISS-E2-R, HadGEM2-ES, MIROC5, ACCESS1-3, GFDL-CM3, HadGEM2-CC, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM-CHEM, and MRICGCM3. Details with respect to future climate inputs in HAWQS are described in HAWQS (2017).

A model of the Kansas River Watershed was generated in HAWQS at the HUC-8 scale with base inputs including elevation (USGS 2010), 2006 land use/cover (Fry, et al. 2011) , soil types and attributes (Soil Survey Staff 2010), crop land management (USDA-NASS 2010), and historical weather information (Menne, et al. 2012). No modifications were made to adjust hydrologic output. The only alterations made to the default generated watershed model included addition of cropland fertilizer to replace crop nutrient uptake, and adjustments of reservoir size/volume attributes (U.S. ACE 2021b). A base scenario was run for a 50 year period (1966 through 2015).

Following the base run, climate change scenarios were run for a 50-year future period (2029 through 2078) under each available GCM. Climate change scenario results were aggregated in Excel (Microsoft Corporation 2020) and compared to the base run using spreadsheet analysis and GRASS GIS software (GRASS Development Team 2020). Qualitative graphic summaries of differences in average annual precipitation, air temperature, streamflow, and transport of sediment and nutrients (N and P) from subbasins (HUC 8) within the watershed were generated. These qualitative estimates represent potential hydrologic conditions and pollutant transport under a future without project activities.

The Kansas River Watershed exhibits a gradient of precipitation as it extends across the state, with average annual precipitation ranging from approximately 388 mm/year in the west (HUC 10250001) to approximately 921 mm/year in the east (HUC 10270104) over the 50-year period from 1966 through

2015 (Figure 14). Over the same period, average annual air temperature ranged from 5 to 11 degrees Celsius (Figure 15).

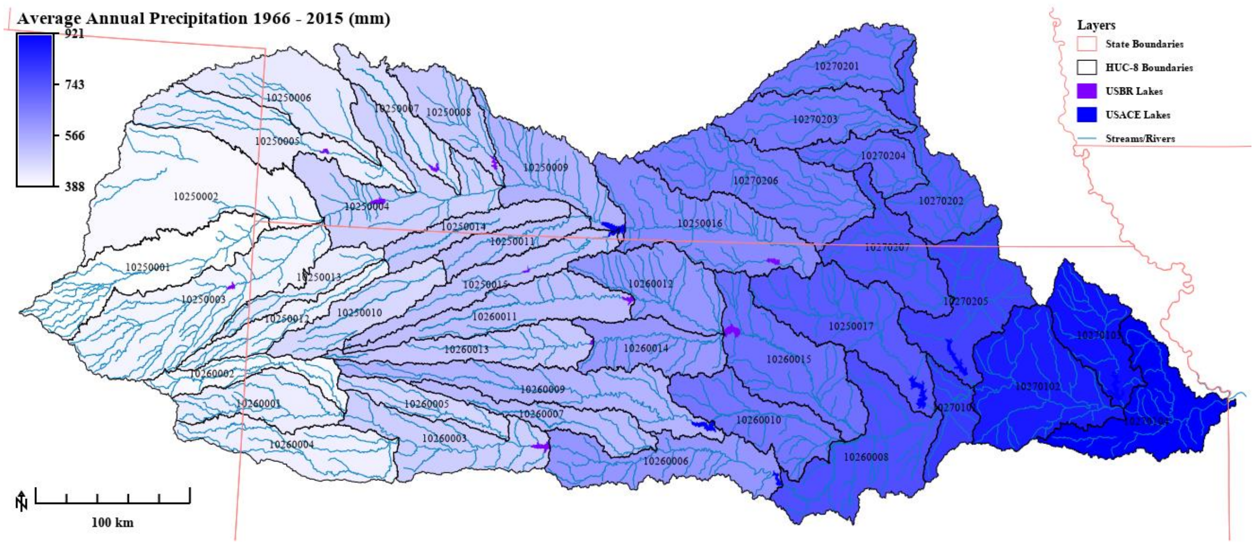

Figure 14. Modeled average annual precipitation by HUC-8 in the Kansas River Watershed (1966 – 2015).

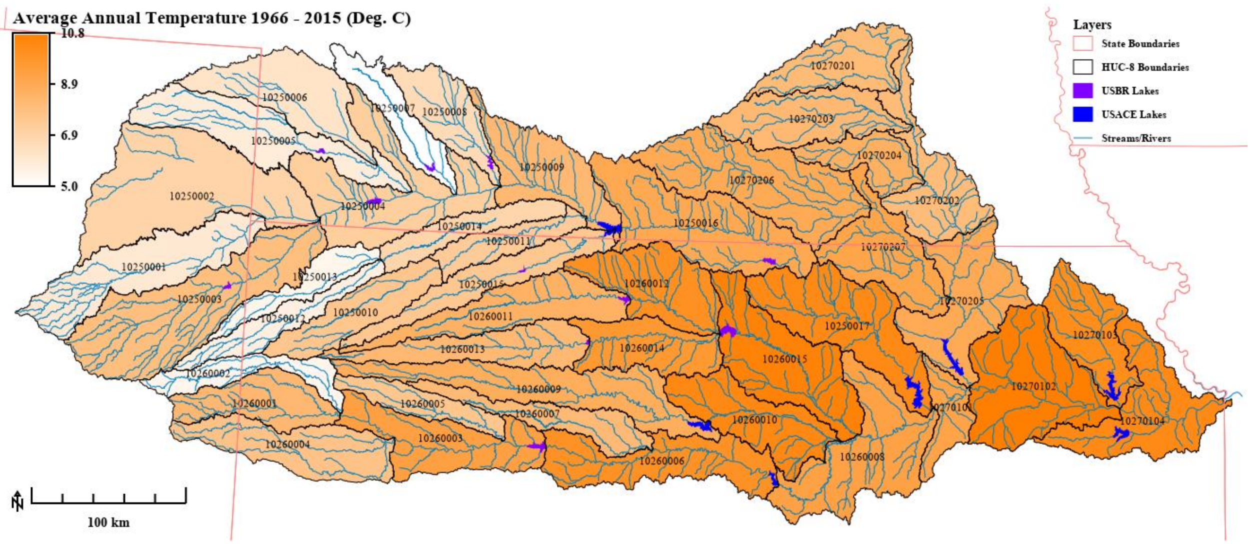

Figure 15. Modeled average annual temperature by HUC-8 in the Kansas River Watershed (1966 – 2015).

Aggregated output from modeled RCP4.5 GCMs, compared to output from the 1966 through 2015 period, indicate generally increasing precipitation across the watershed (Figure 16), and generally warmer average annual temperatures with greatest increases in the western half of the Kansas River watershed (Figure 17).

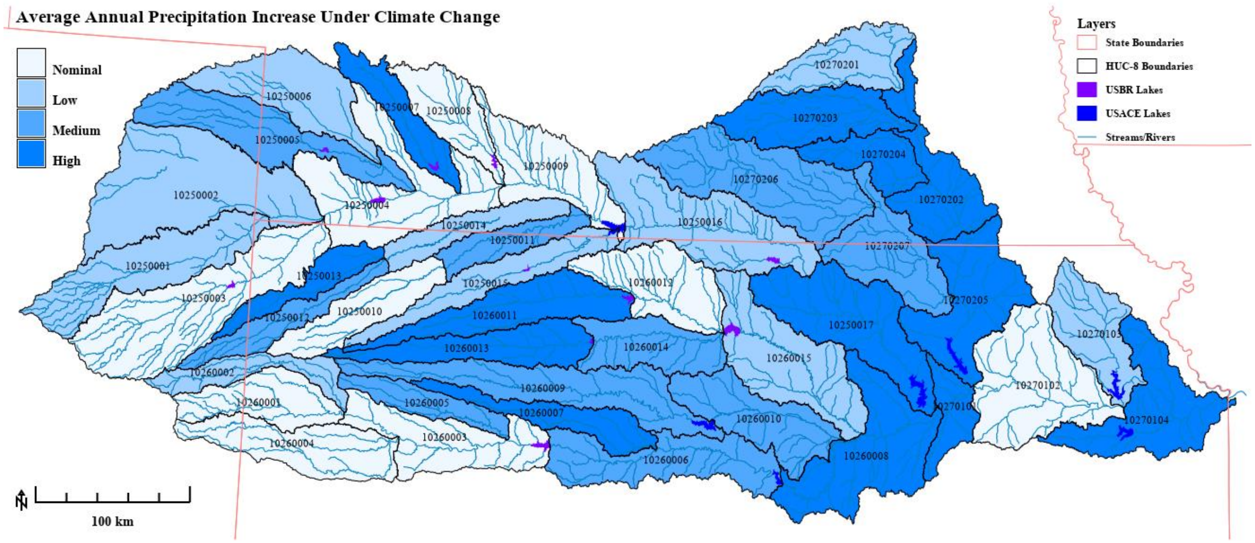

Figure 16. **Projected future (2029 - 2079) average annual precipitation increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).**

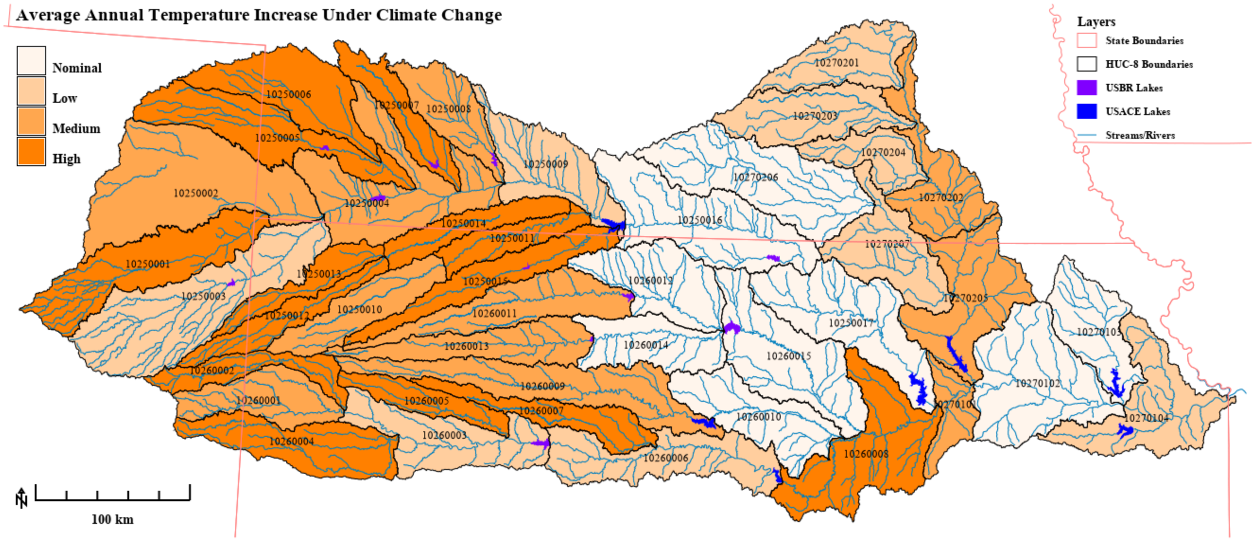

Figure 17. Projected future (2029 - 2079) average annual air temperature increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).

The RCP4.5 GCMs, input into the watershed SWAT models, collectively suggest generally increased average annual streamflow (Figure 18), especially in the eastern half of the watershed. Average annual streamflow increases under future climate conditions modeled in HAWQS (aggregated RCP4.5 GCMs) over significant portions of the Kansas River Watershed correspond with USACE CHAT (U. S. ACE 2021a) future streamflow predictions. The aggregate projected increases in average annual precipitation, air temperature, and streamflow contribute to higher (than 1966 - 2015) expected average annual sediment yield (Figure 19), total nitrogen yield (Figure 20), and total phosphorus yield (Figure 21).

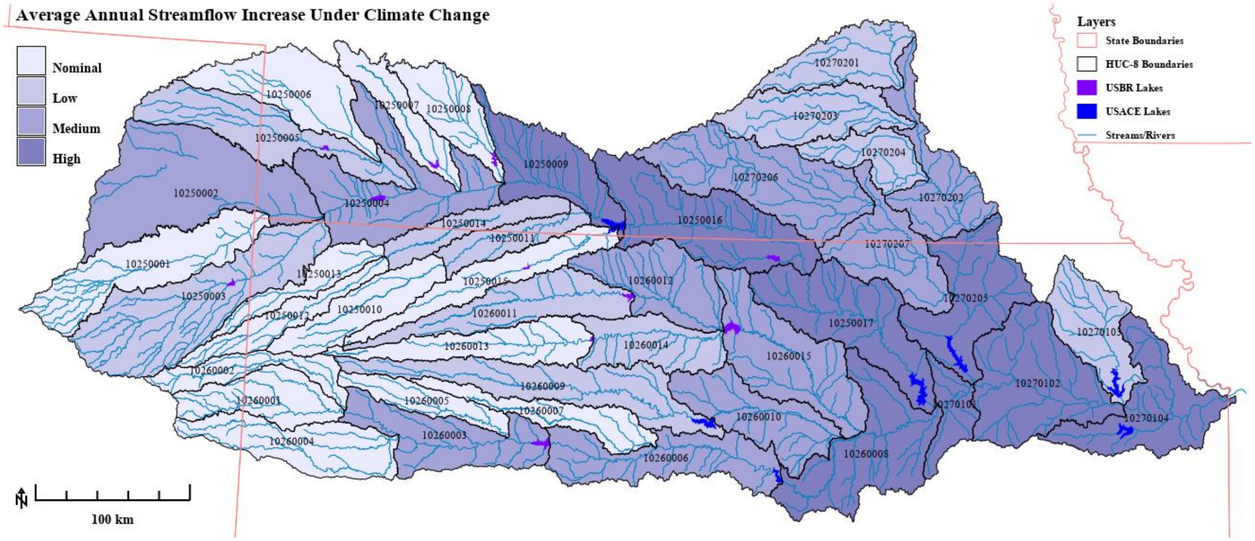

Figure 18. Projected future (2029 - 2079) average annual streamflow increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).

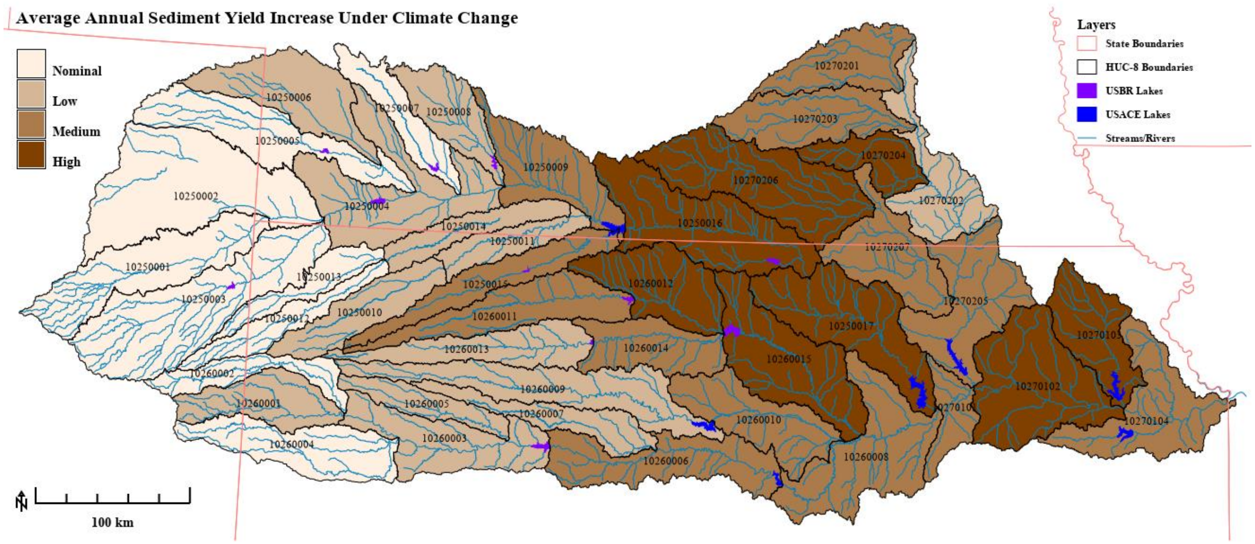

Figure 19. Projected future (2029 - 2079) average annual sediment yield increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).

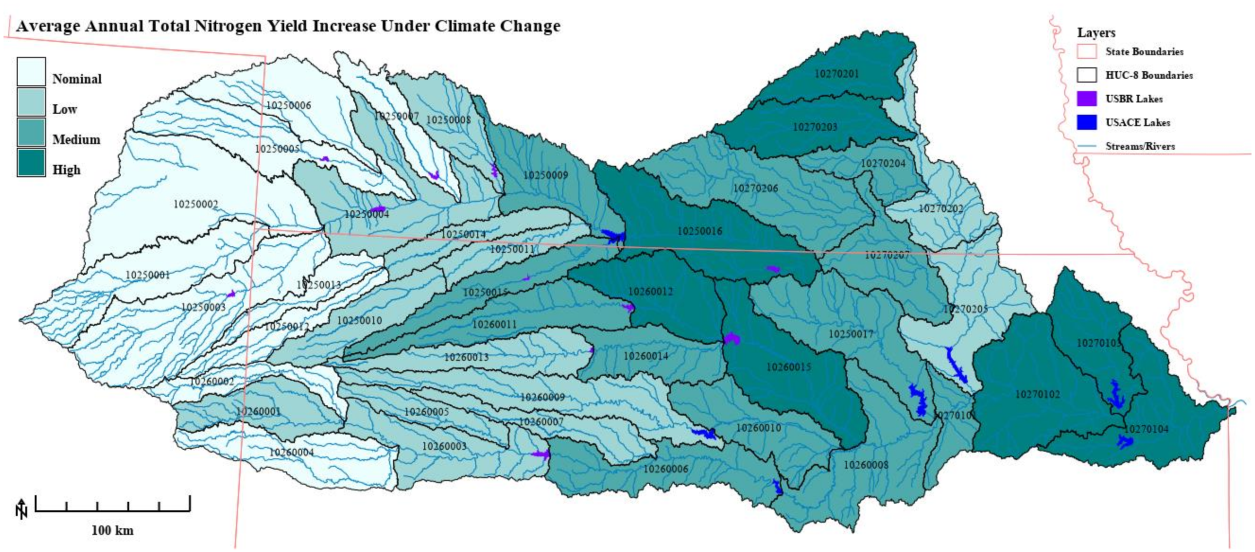

Figure 20. Projected future (2029 - 2079) average annual total nitrogen yield increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).

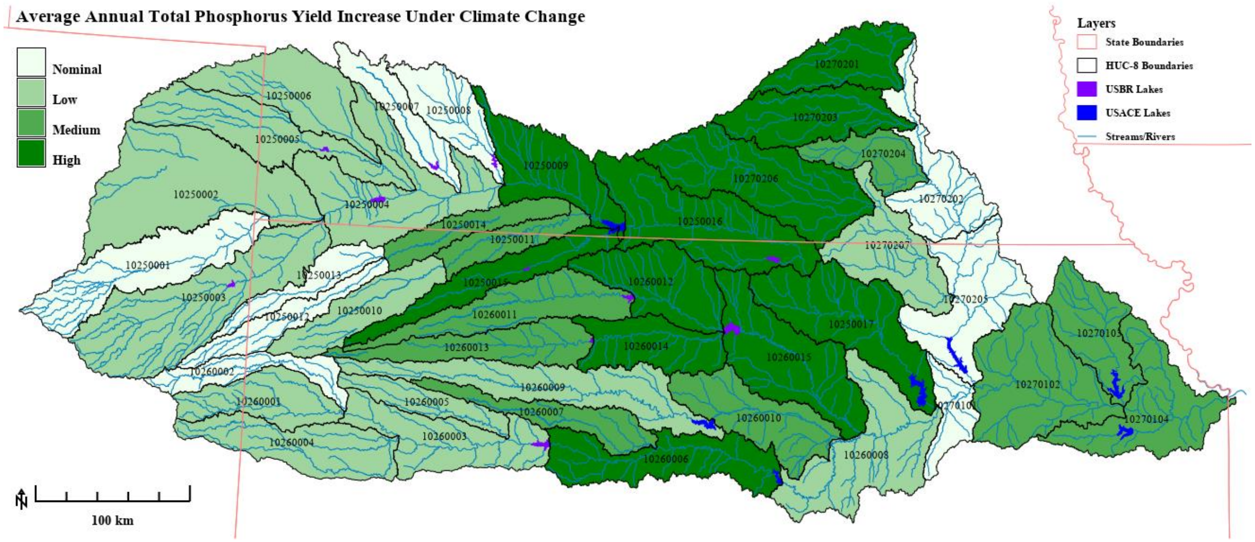

Figure 21. Projected future (2029 - 2079) average annual total phosphorus yield increases over the base period (1966 – 2015) under twelve aggregated RCP4.5 GCMs using HAWQS (SWAT).

Modeled anticipated average annual changes under aggregate GCMs for HUC8s containing USACE reservoirs are summarized in Table 5 below. Increases in future average annual precipitation generate increased average annual runoff carrying larger quantities of sediment and nutrients to reservoirs in the watershed. Higher delivered quantities of sediment and nutrients lead to increased rates of sedimentation, and increased levels of eutrophication.

Table 5. Summary of projected future climate (2029 - 2079) effects relative to base period (1966 – 2015) for HUC8s containing USACE reservoirs.

HUC8	Lake	Runoff/ Streamflow	Sediment Yield	TN Yield	TP Yield
10270104	Clinton	▲	▴	▲	▴
10250009	Harlan Co.	▲	▴	▴	▲
10250015		–	▴	▴	▲
10260006	Kanopolis	▴	▴	▴	▲
10250017	Milford	▲	▲	▴	▲
10270103	Perry	▴	▲	▲	▴

10270205	Tuttle Creek	▲	▲	▴	▬
10260009	Wilson	▴	▴	▴	▴

Change Indicators: ▬ = Nominal Change, ▴ = Low increase, ▲ = Medium Increase, ▲ = High Increase

Suggested increases in transport of sediment and nutrients under aggregated GCMs is due in part to the seasonal timing of precipitation. Modeled aggregate future climate scenarios suggest average annual precipitation increases (over historical quantities) in months of the year when vegetative cover is not present to mitigate surface runoff and sediment transport (Figure 22). Detail with respect to frequency, intensity, and duration of future precipitation events is uncertain, but modeled predictive scenarios, in aggregate, suggest increased precipitation quantities January through March, September, and November. Increased precipitation in these months translates to increases in runoff, transporting increased quantities of sediment, carrying increased quantities of soluble and sediment bound nutrients (nitrogen and phosphorus).

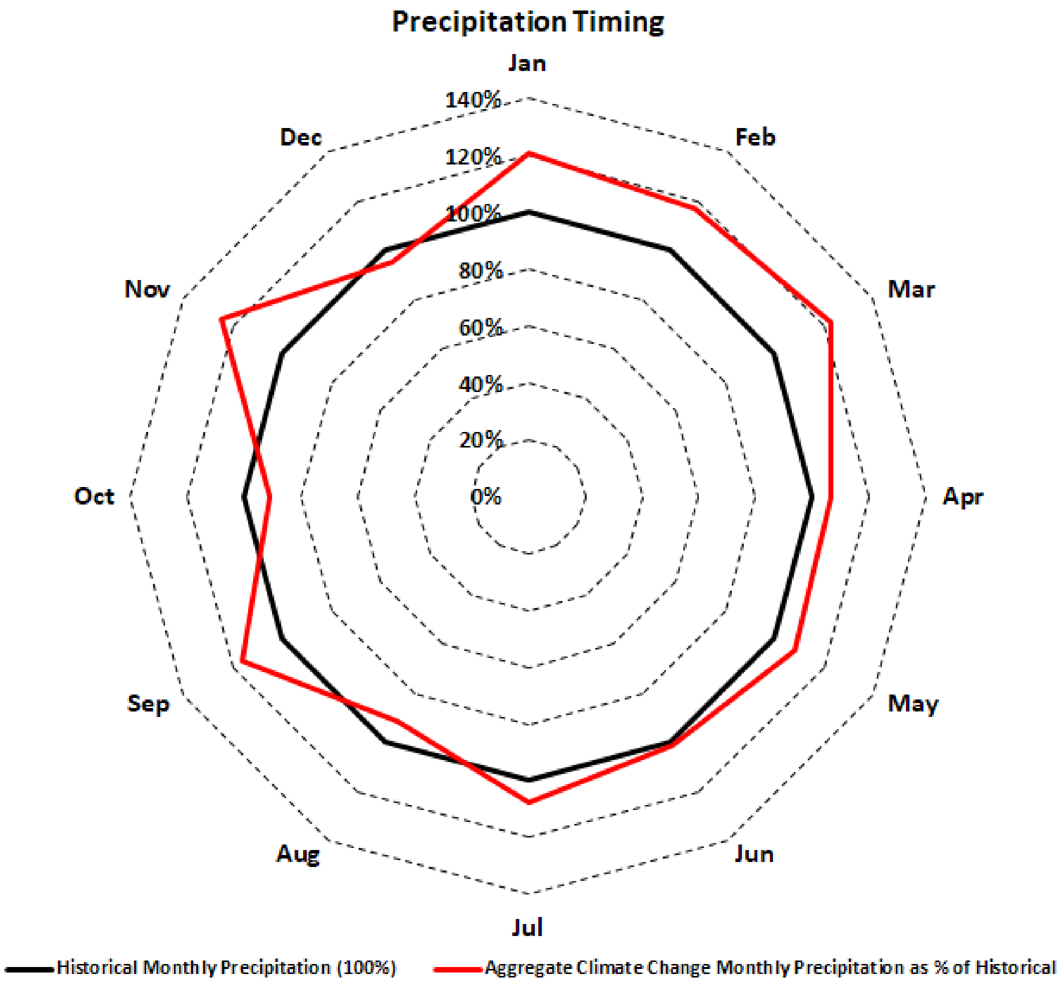

Figure 22. Modeled Kansas River Watershed historical (1966 – 2015) monthly average precipitation (black line) compared to twelve aggregated RCP4.5 GCMs monthly average precipitation (red line).

The strongest consensus amongst the literature supports a trend of increasing temperatures and precipitation in the region resulting in increased frequency in the occurrence of extreme storm events.

Extremes in climate will also magnify periods of wet and dry weather resulting in longer more severe droughts and larger more extensive storms (KRRFSS Appendix A-Climate Change Assessment). Future water quality of USACE reservoirs in the Kansas River Watershed will be impacted by these trends.

Kansas River Basin Residence Time

Water residence times at select influential reservoirs in the KS River watershed were estimated by CENWK-EDH-R for years 2024 and 2124 with models created using HEC-ResSim (Hydrologic Engineering Center – Reservoir System Simulation)(KRRFSS Appendix B-Water Management) and data set for the lower seven mainstem reservoirs on tributaries of the Kansas River. The 0-year FWOP (2024) scenario represents existing physical conditions. The second scenario, 100 yr FWOP (2124), represents change in reservoir storage over 100 years due to sediment deposition. Each scenario was modeled with historically observed average daily inflows over a 100-year timeframe. HEC-ResSim generated estimated lake storage, discharge, and evaporation from these simulations which were used in residence time calculation. The average residence time for lakes in each scenario was calculated and compared based on the residence time difference. Results reveal that the 100-year FWOP (2124) residence time decreases as lake storage diminishes due to sedimentation. Average residence times for select lakes likely to influence Kansas River water quality are presented in Table 7. Reduced residence time results in less time for nutrient and sediment constituent settling within reservoirs with decreased MPP volumes. Lakes with higher sedimentation rates (e.g., Tuttle Creek, Kanopolis, and Perry Lakes) are, as expected, those with the largest percent decrease in residence time in the 100-year comparison. A graphic representation of differences between 0-Year (2024) and estimated 100-Year (2124) residence time at Clinton Lake is shown in Figure 23 below. Figure 24 (Tuttle Creek Lake) and Figure 25 (Milford Lake), below, reveal the expected inverse relationship between annual average outflow and residence time.

Table 6. Average Lake Residence Time for select Kansas River Watershed Lakes.

Lake	Average Residence Time 0-year (2024) Existing Conditions (Months)	Average Residence Time 100-year FWOP (Months)	Average Residence Time Observed: 1990-2022 (Months)	Percent Decrease 0-year to 100-year
Clinton	9.0	7.0	9.0	22%
Kanopolis	2.7	1.2	4.5	56%
Milford	7.3	6.4	7.7	12%
Perry	5.0	3.0	5.6	40%
Tuttle Creek	2.4	0.8	3.0	67%
Waconda	11.2	8.5	10.3	24%
Wilson	24.7	20.9	n/a	15%

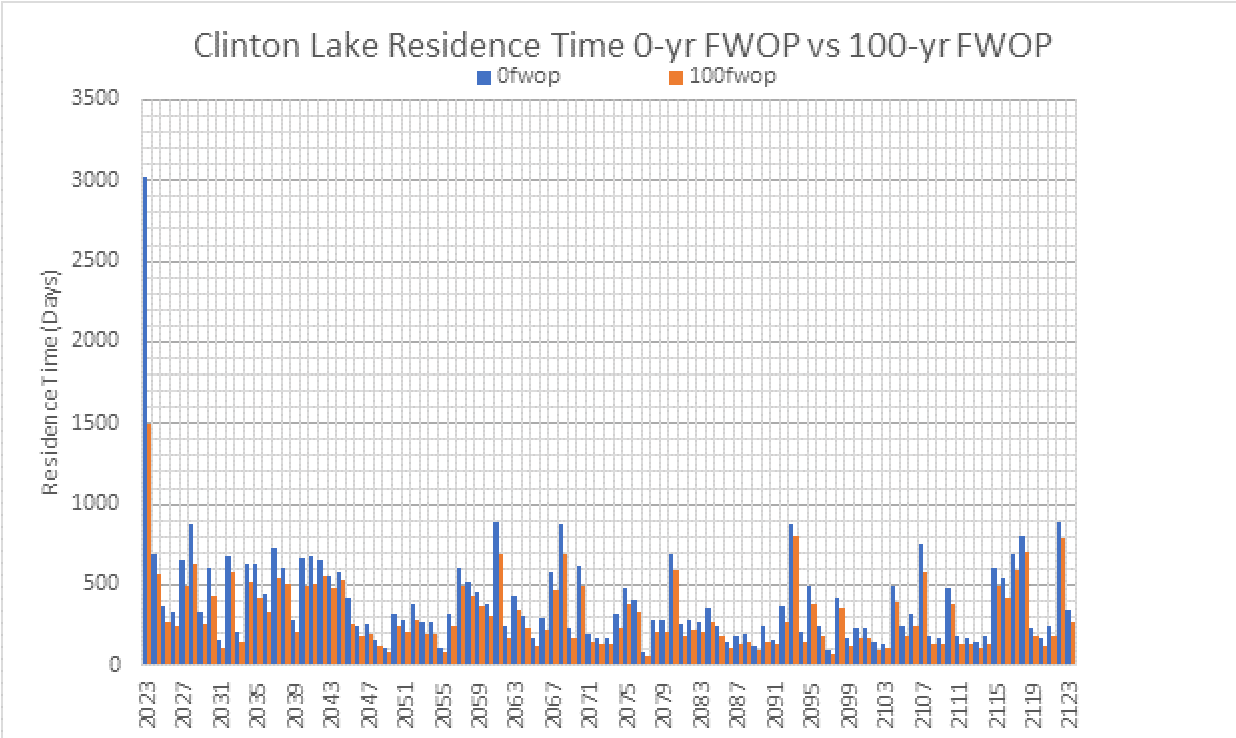

Figure 23. Clinton Lake residence time comparing 0-Year (2014, 0fwop) and 100-Year (2124, 100fwop) FWOP.

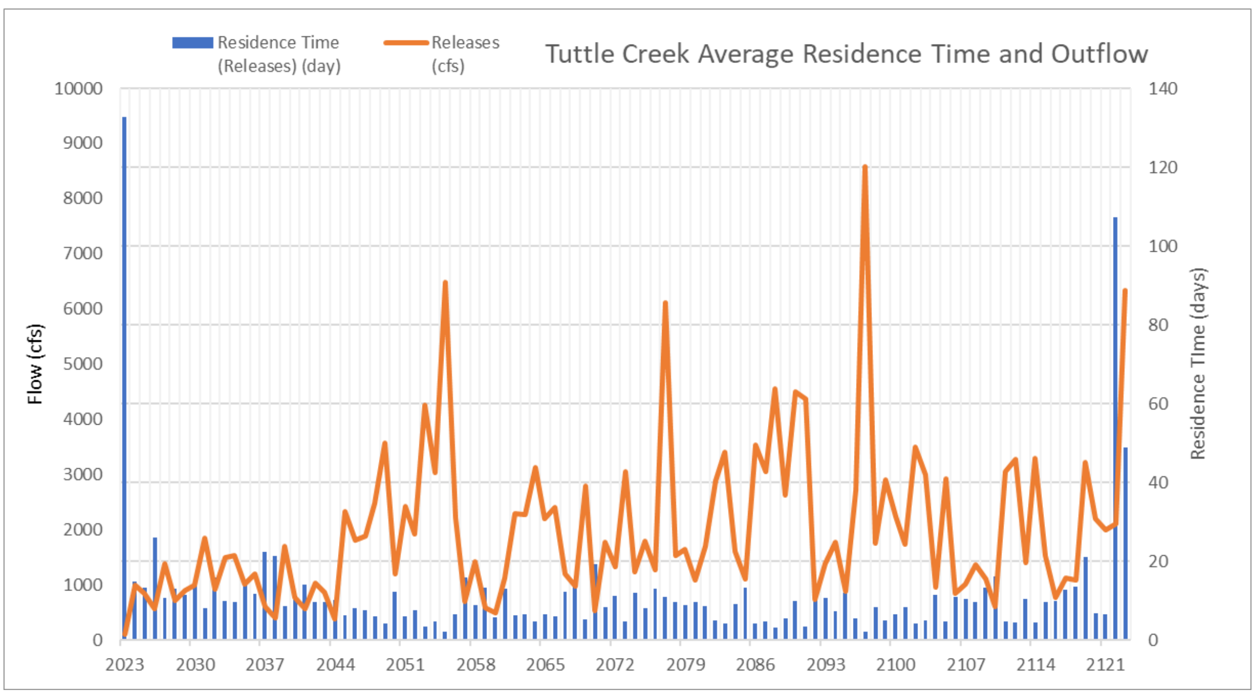

Figure 24. Tuttle Creek Lake annual average 0-Year residence time and annual average outflow.

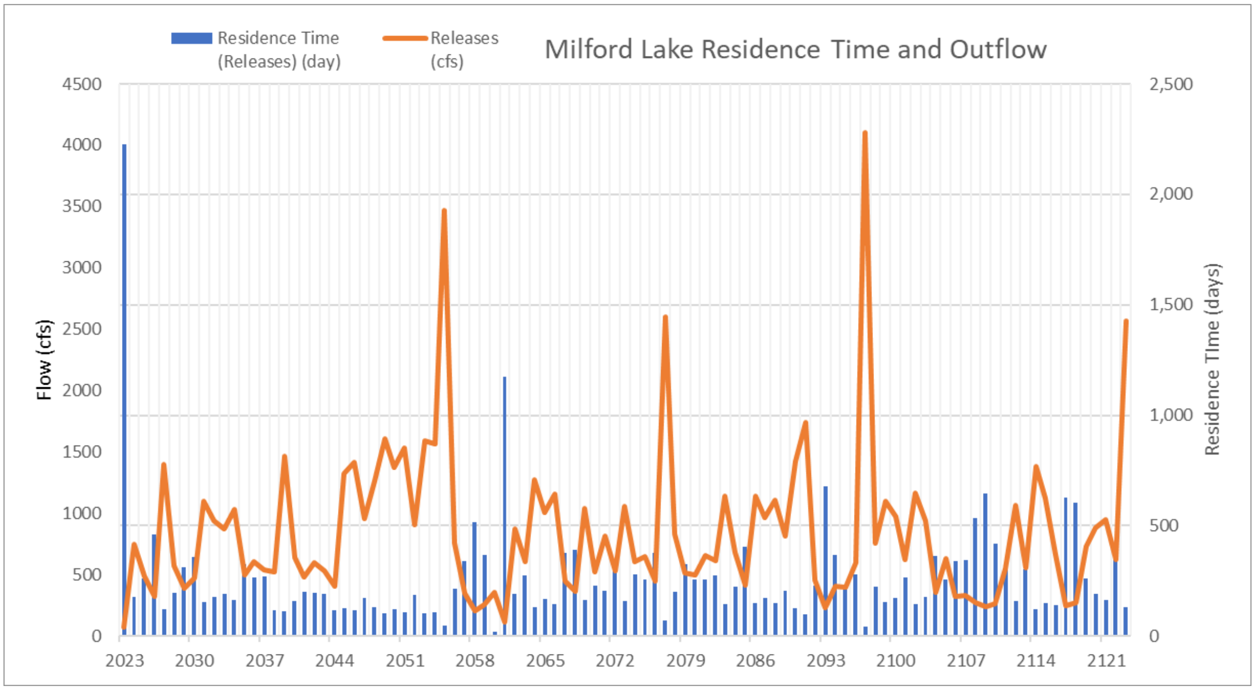

Figure 25. Milford Lake annual average 0-Year residence time and annual average outflow.

An additional residence time analysis was done for Clinton Lake and Tuttle Creek Lake using observed historic data from January 1990 to December 2022. The observed data included inflows, lake storage, releases, and evaporation. Cyclic analysis was performed describing the monthly trend of residence time based on percentiles and the average. The data reveals seasonality in residence time which decreases during the wetter periods and increases during the dry periods. Graphic examples are shown in Figure 26 for Clinton Lake and Figure 27 for Tuttle Creek Lake.

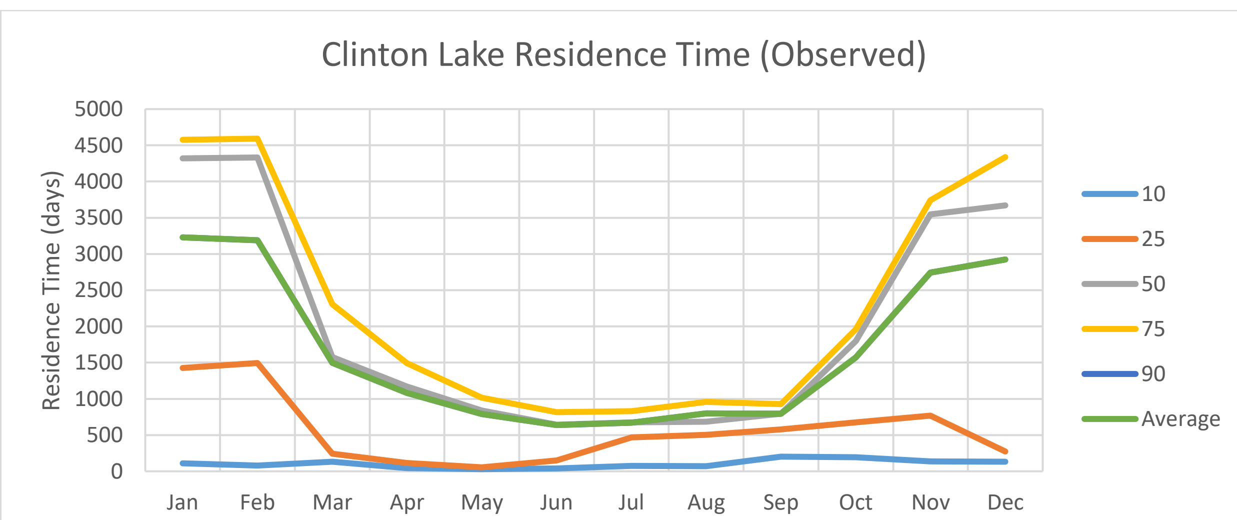

Figure 26. Clinton Lake monthly residence time calculated using observed (1990-2022) data.

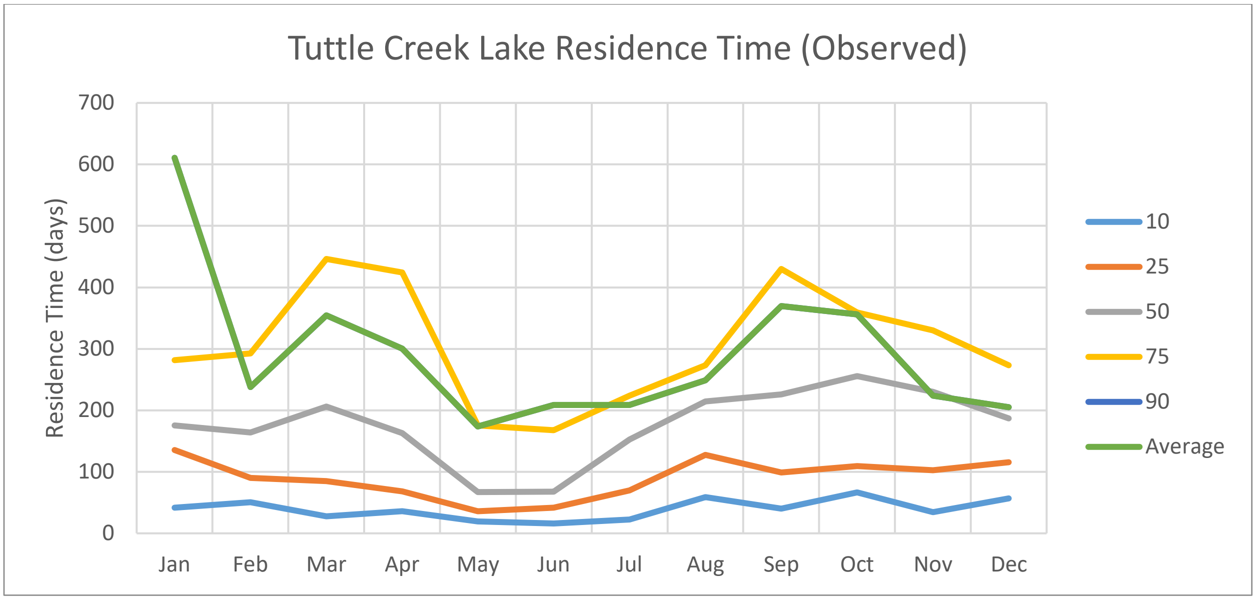

Figure 27. Tuttle Creek Lake monthly residence time calculated using observed (1990-2022) data.

Additional watershed (SWAT) simulations were run incorporating estimated volume change due to sedimentation at select reservoirs in the watershed estimated by CENWK-EDH-R for years 2024 (Year 0), 2049 (Year 25), 2074 (Year 50), and 2124 (Year 100). Estimated future multipurpose pool (MPP) volumes for USACE reservoirs in the watershed are listed in Table 7. Watershed simulations using historic climate inputs (1966 - 2015) were run with adjusted MPP volumes estimated for years 2024, 2049, 2074, and 2124 to aid quantifying potential sediment and nutrient transport changes due to diminishing pool volumes. The SWAT watershed model simulates lakes/reservoirs simplistically, tracking sediment and nutrients carried by water. Modeled in-reservoir transformation of nutrients is limited to removal by settling.

Table 7. Estimated Future Multipurpose Pool Volumes at Kansas River Watershed USACE reservoirs.

Lake	Year 0 (2024) Est. MPP Volume (ac-ft)	Year 25 (2049) Est. MPP Volume (ac-ft)	% 2024 Volume	Year 50 (2074) Est. MPP Volume (ac-ft)	% 2024 Volume	Year 100 (2124) Est. MPP Volume (ac-ft)	% 2024 Volume
Clinton	112,200	103,900	93%	96,700	86%	83,900	75%
Harlan Co.	309,400	304,000	98%	300,700	97%	291,100	94%
Kanopolis	43,300	34,800	80%	30,200	70%	18,300	42%
Milford	366,500	355,800	97%	349,900	95%	333,000	91%
Perry	182,900	159,400	87%	139,900	76%	105,200	58%
Tuttle	216,600	153,000	71%	106,500	49%	29,200	13%
Wilson	228,100	218,000	96%	209,000	92%	190,100	83%

For subbasins (HUC8s) containing reservoirs with diminishing MPP volume, simulations predicted nominally decreasing reservoir contributions to ground water due to increasingly smaller MPP volume and area. Predictably, model simulation revealed no significant changes in pollutant (sediment, TN, and TP) export rates from land surfaces to streams in subbasins with diminishing reservoir MPP volumes.

It is important to emphasize that estimates of transport of sediment and pollutants (TN and TP) for subbasins, reaches, and reservoirs, with future diminished storage volume in select reservoirs are based on annual averages of 50-year simulations driven by historic daily climate inputs (1966 – 2015). Precipitation and air temperature vary significantly from year to year (and day to day). Consequently, simulated annual average estimates of transport of sediment and pollutants are highly variable. For example, for the simulation with 2024 MPP volume estimates, standard errors of mean TN transported into the select reservoirs ranged from 11 to 24% of the mean. Similarly, standard errors of TN transported out of the same select reservoirs ranged from 14 to 28% of the mean. Standard errors of mean TP transported into and out of the reservoirs were marginally higher. Relative differences of annual average sediment and pollutant transport included in discussions below should be assessed considering this inherent variability.

For stream reaches in subbasins containing reservoirs with diminishing MPP volumes, simulations predicted nominal changes in sediment transport mass due to volume loss. Bulk quantities of sediment load transported from land surfaces to stream reaches deposits instream and at reservoir locations. Incrementally increasing annual average quantities of TN and TP are transported through reservoir reaches to reaches immediately downstream. This is primarily due to reduced water residence time within reservoirs as a function of reduced MPP volume.

For example, HUC8 10250016 (Middle Republican), the Republican River reach immediately below Harlan County Lake, receives and transports incrementally more TN and TP mass with decreasing Harlan County Lake volume. Simulations showed 2049 reservoir volume resulted in 0.2% more TN and TP mass in the reach over 2024 lake volume. 2074 volume resulted in 0.2 and 0.3% more TN and TP mass, respectively, over 2024. Estimated 2124 Harlan County Lake volume resulted in 0.4% more TN and TP mass in the reach over that transported in 2024.

HUC8 1026008 (Lower Smoky Hill) receiving flows below USACE reservoirs Kanopolis and Wilson shows increased transport of TN and TP mass with 2049 volumes (0.3 and 0.4%, respectively), 2074 volumes (0.6 and 0.7%, respectively), and 2124 volumes (1.1 and 1.4%, respectively) over modeled mass transported in 2024.

HUC8s 10270101 (Upper Kansas) below Milford Lake, and 10270102 (Middle Kansas) below both Milford and Tuttle Creek Reservoir revealed simulated increases in TN & TP mass transport over 2024. 2049 MPP volumes increased downstream TN and TP transport 0.3 and 0.4%, respectively, over 2024 for HUC 10270101; and 0.6 and 1.0%, respectively, for HUC 10270102. 2074 MPP volumes increased transport over 2024 by 0.5 and 0.7%, respectively, for HUC 10270101, and 0.9 and 1.7%, respectively, for HUC 10270102. Modeled 2124 MPP volumes increased TN and TP mass transport over 2024 MPP volumes by 1.0 and 1.3% in HUC10270101, and 1.4 and 2.7% in HUC10270102.

HUC8 10270104 (Lower Kansas) below Perry Lake and containing Clinton Lake showed similar modeled trends with TN and TP transport increases over 2024 MPP volumes of 0.5 and 0.9%, respectively, for 2049 volumes; 0.8 and 1.6% for 2074 volumes; and 1.2 and 2.4% for 2124 MPP volumes.

For reservoirs with diminishing MPP volume, model simulations related decreased volume (and area) to less annual average direct precipitation on the reservoir surfaces, less annual average evaporation from the reservoirs, and less seepage. Simulations revealed incrementally increasing annual average export of TN and TP from reservoirs with diminishing MPP volumes due to reduced settling time in reservoirs. Table 8. below shows comparison of simulated masses of TN and TP into and out of reservoirs with reduced MPP volume due to sedimentation relative to 2024. For each reservoir, simulations predicted incrementally increasing average annual nutrient mass exported, compared to 2024, with diminishing

MPP volumes. Milford Lake results indicate a unique trend where nutrient mass entering the reservoir during the years 2049, 2074, and 2124 increases due to higher incremental export from the upstream reservoir, Harlan County Lake. Concurrently, Milford Lake's estimated average residence time for 2124 (as shown in Table 6) reflects the smallest percentage decrease from the 2024 estimates, supporting the expectation of relatively minor changes in nutrient export. While the annual average flow into and out of the reservoirs remains relatively consistent across the simulations, the reduction in MPP volumes leads to a decrease in average annual residence time and the time available for nutrient settling.

Table 8. Comparison of simulated TN and TP mass into and out of Kansas River Watershed USACE reservoirs, relative to 2024, with decreasing future MPP volume.

Lake	Year	TN In % Change from 2024 (kg)	TN Out % Change from 2024 (kg)	TP In % Change from 2024 (kg)	TP Out % Change from 2024 (kg)
Clinton	2049	0.0	1.1	0.0	1.4
	2074	0.0	1.9	0.0	2.2
	2124	0.0	3.4	0.0	3.4
Harlan Co.	2049	0.0	0.4	0.0	0.4
	2074	0.0	0.5	0.0	0.7
	2124	0.0	0.8	0.0	1.1
Kanopolis	2049	0.0	1.4	0.0	1.8
	2074	0.0	2.2	0.0	2.9
	2124	0.0	4.4	0.0	5.9
Milford	2049	0.1	0.4	0.1	0.5
	2074	0.1	0.6	0.1	0.8
	2124	0.2	1.1	0.2	1.6
Perry	2049	0.0	3.3	0.0	4.4
	2074	0.0	6.3	0.0	8.3
	2124	0.0	12.0	0.0	16.3
Tuttle Creek	2049	0.0	1.1	0.0	1.7
	2074	0.0	1.8	0.0	3.0
	2124	0.0	3.2	0.0	5.2
Wilson	2049	0.0	0.7	0.0	0.9
	2074	0.0	1.3	0.0	1.7
	2124	0.0	2.5	0.0	3.4

Temporally decreasing MPP volume due to sedimentation in selected reservoirs, in combination with projected increases in runoff/streamflow and transport of sediment and nutrients under aggregate future GCMs suggests future decreases in retention time, and future decreases in trapping efficiency at those reservoirs with substantial volume loss. Lower reservoir retention time leads to higher quantities of sediment and especially nutrients (TN & TP) passed through reservoirs to downstream segments. Future climate projections suggesting increased runoff from land surfaces carrying increased sediment and nutrient loads may exacerbate sediment accumulation rates (volume loss) and nutrient enrichment.

As stated above, State natural resource agencies have designated 16 of the 18 lakes in the Kansas River Basin as “impaired” from nutrient related impacts (e.g., excess nitrogen and/or phosphorus, general eutrophication, excess chlorophyll/algae measures, dissolved oxygen sags resulting from algae blooms) due in part to agricultural runoff. Excess nutrients can promote Harmful Algal Blooms (HABs) under ideal growing conditions. As accumulation of sediment reduces storage capacity of reservoirs, and internal nutrient loading increases, water quality problems are expected to intensify.

Basic causes and drivers of algal blooms include excess nitrogen and phosphorus, warming temperatures, slow moving water, and sunlight. Management of reservoirs during extreme events directly impacts water quality conditions within reservoirs. Runoff from extreme rainfall events withheld in a reservoir to minimize downstream flooding, may lead to periods where the nutrient rich water, with sediment settling and warming conditions, could enhance conditions for epilimnetic algal blooms and hypolimnetic anoxia.

Watershed modeling results could be enhanced with the custom construction of a SWAT model of the Kansas River Watershed. Enhanced resolution and custom selection of subbasin outfall points would allow for more accurate simulation of stream reaches and reservoirs and provide the opportunity for a more robust calibration of overall watershed water, sediment, and nutrient transport and loading estimates.

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SALINITY AND DAM OPERATIONS AT WILSON AND KANOPOLIS LAKES

1.0 SALINITY AND DAM OPERATIONS AT WILSON AND KANOPOLIS LAKES

Executive Summary

This report analyzes the relationship between reservoir operations and chloride concentrations at Wilson Dam and Kanopolis Dam in Kansas, the primary purpose of both dams is flood risk reduction. However, their outflow impacts the taste and quality of downstream water supplies due to naturally occurring salinity in the basin's geographic formations. This study analyzes conceptual operation strategies aimed at decreasing the number of releases made in which the outflows chloride concentrations exceed threshold conditions (of 325 mg/L at Wilson and 200 mg/L at Kanopolis). These thresholds represent the approximate 70th percentile for outflow chloride concentrations in the baseline simulations using 100-years of historical data. We find two operational strategies capable of eliminating releases exceeding the chloride concentration thresholds, while also avoiding unsafe flood releases and storage conditions that drop into the inactive pool or encroach on surcharge space. The analysis makes use of limited water quality data, a simple 0-dimensional mass balance salinity model and simplistic reservoir operating rules. More work is required before these conceptual strategies could be considered viable alternatives, some next steps are suggested in the report's conclusions.

Introduction

This document analyzes the relationship between reservoir operation and chloride concentrations at Wilson Dam located in the Saline River Basin, and Kanopolis Dam located in the Smokey Hill River Basin in Kansas. Both dams are part of the larger Kansas River Watershed and Reservoir System and are operated primarily for flood risk management, though they also have ancillary recreation, wildlife management, and water supply functions. Importantly, elevated chloride concentrations in the dam's outflows impact the water quality at water treatment facilities serving the towns of Salina and Abilene; and further east they elevate the salinity of Kansas River, which provides municipal water supply for Junction City and beyond. Salinity in these basins is elevated due to naturally occurring mineral dissolution from sandstone, limestone, and chalk geologic formations leaching into the Saline River and Smokey Hill River baseflows (Bredehoeft, 1983; Knudsen, 2021; Whittemore, 1991). There is also significant salinity contribution from oil brine remaining in the groundwater after being used in industry (Whittemore, 1991). This study analyzes chloride concentration as a proxy for overall salinity due to data quality and "because it [chloride] is conservative, has low natural background levels, and is readily measured with adequate precision" (Chapra, 2009). Chlorides and other salt ions, accumulate in Wilson and Kanopolis Lake particularly during periods of low flow, and impact the taste and quality of the municipal water supplies. In this study the relationship between chloride concentration and reservoir operations is modeled, and alternative operational strategies are explored.

Study Location

The Saline River originates in northwest Kansas. It flows for 397 miles in an easterly direction before terminating at is confluence with the Smokey Hill River. In total, it drains an area of 3,419 square miles.

A little of half, 1,917 square miles, lie upstream of Wilson Lake which dams the river. The Saline River is generally slow moving and unnavigable. Outflows from Wilson Dam flow downstream to the lower reaches of the Saline River before its confluence with the Smokey Hill River, which originates directly to the south of the Saline River headwaters. Together the Saline, Smoky Hill and Solomon Rivers make up the Smoky Hill basin which drains 19,260 square miles of northwest Kansas before reaching its outlet at the confluence of the Smoky Hill River and Kansas River. Kanopolis Dam captures the flow from a 2,330 square mile catchment of the Smoky Hill River upstream of its confluence with the Saline River. Thus, Kanopolis and Wilson operate in parallel.

The Kanopolis Dam was built first and began impounding water in 1948. Wilson Dam began operations, almost two decades later, in 1964. Both operate primarily for flood control purposes. Wilson Dam was originally designed for irrigated water supply and navigation purposes. However, the salinity and shallow nature of the Saline River flows make its use for irrigation and navigation unfeasible.

Methods and Data

The primary source of input data for this investigation comes from the United States Army Corps of Engineers (USACE) Kansas River Reservoirs Flood and Sediment, Watershed Study and its Hydrologic Engineering Center Reservoir Simulation (HEC-RESSIM) models and data. This data includes reconstructed daily inflows from the period of 23 July 1918 to 01 February 2020 at Kanopolis Lake, and 30 August 1919 to 30 April 2020 at Wilson Lake. The data was reconstructed by the USACE Kansas City District (NWK) based on a record of changes in reservoir stage and an evaluation of reservoir releases, evapotranspiration, and wind effect on stage measurements (Twombly, B., 2022).

Chloride concentration data collected between 1990 and 2020 was provided by the Kansas Department of Health and Environment (KDHE). These samples were collected near USGS gage locations, allowing the discharge data from the USGS gages to be linked to the chloride data by date. Figures 1 and 2 mark the key sample locations.

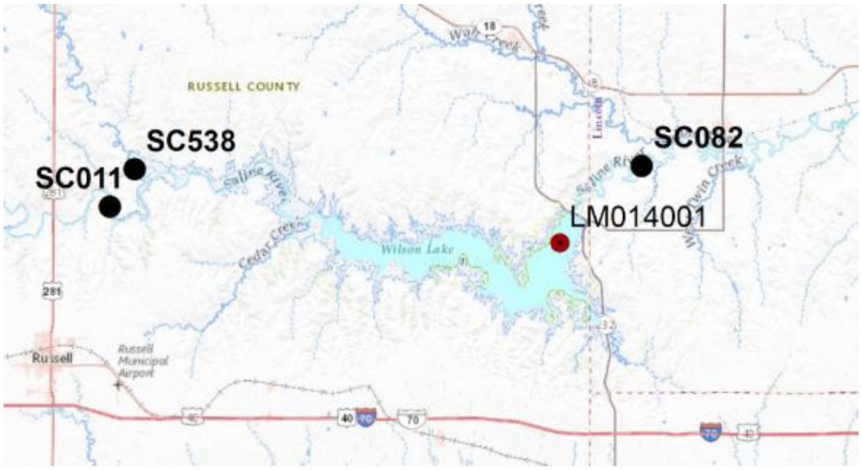

Figure 1. Wilson Reservoir KDHE sample locations

(SC011 and SC538 are used in this study, both are upstream of Wilson Lake)

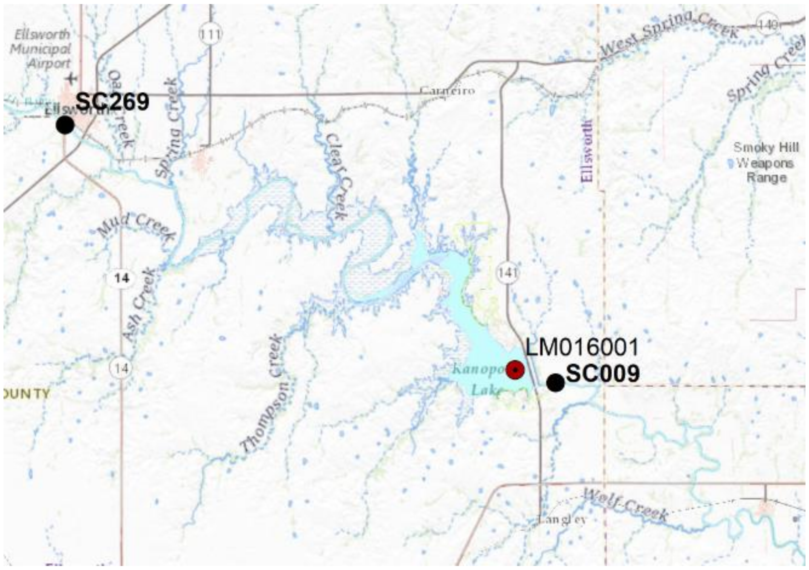

Figure 2. Kanopolis Reservoir KDHE sample locations
(SC269 is used in this study, which is upstream of Kanopolis Lake)

The KDHE and USGS data were analyzed to estimate chloride concentration as a function of inflow. Any distance between KDHE sample stations and USGS gages is assumed to be negligible for the purpose of this analysis. USGS discharge data is collected every 15 minutes. This study used the 12:00 PM discharge readings to approximate daily discharge. The method of estimating concentration based on inflow is described further in the **Chloride Model** section of this report.

Table 1. KDHE and USGS data summary

Sampling Station	KDHE Chloride Concentration Date Range (number of samples with corresponding flow data)	USGS Discharge Date Range (station name, proximity to KDHE station)
SC011	3/26/1990-12/16/2020 (169)	10/1/1990-3/7/2022 (Russell, 06867000, 4.5 mi upstream of SC011)
SC538	3/26/1990-12/16/2020 (25)	8/21/2014-3/7/2022 (Paradise, 06867500, co-located)
SC269	3/19/1990-1/11/2021 (161)	10/1/1990-3/7/2022 (Smoky Hill, 6864500, co-located)

Table 2. Inflow locations descriptive statistics

Variable	Max	Min	Mean	Median
Wilson Inflows (cfs)	49300	0	141.4	41
Kanopolis Inflows (cfs)	27507	0	277.5	76
Russell Gage (SC011, cfs)	8060	.25	95.3	38.1
Paradise Gage (SC538, cfs)	2740	0	36.5	3.33
Smoky Hill Gage (SC269, cfs)	27507	0	283.3	90
Chloride Concentrations (mg/L)				
SC011	3400	29	957	492
SC0538	2000	8	924	750
SC269	601	18	341	359

Figures 3 and 4 show the flow record time series for both Wilson and Kanopolis, red line are used to mark the range of dates over which chloride data is also available.

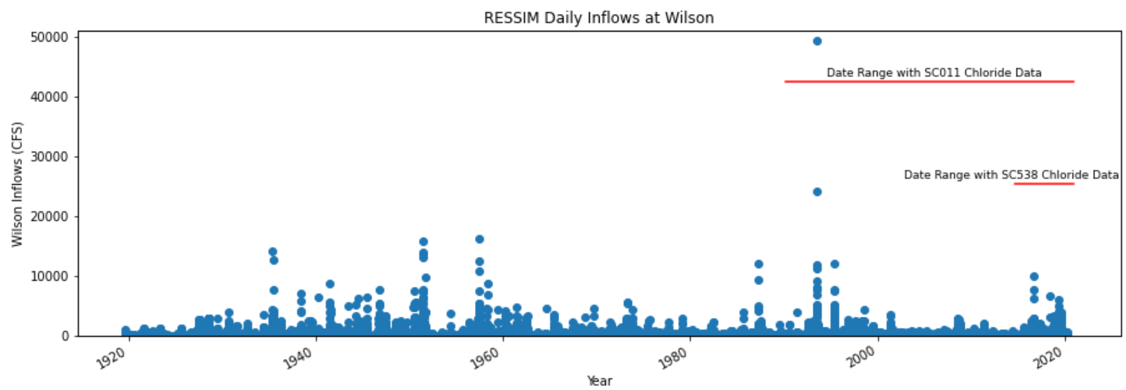

Figure 3. Wilson Lake inflow timeseries with chloride observational period marked in red

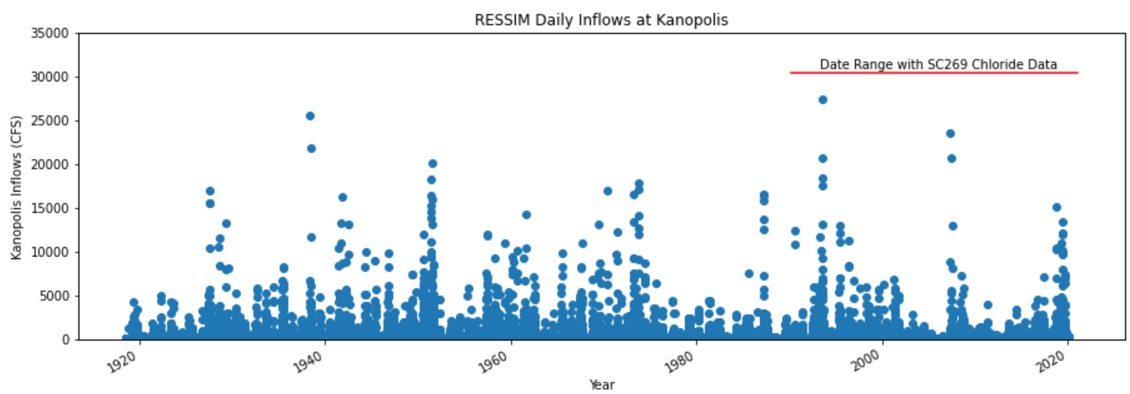

Figure 4. Kanopolis Lake inflow time series with chloride observational period marked in red

At the SC011 and SC269 gauge locations, the chloride and USGS discharge data overlap across approximately 30% of the inflow timeseries used by the model. At the SC538 gauge location, approximately 6% of the inflow timeseries has associated chloride-discharge data.

Chloride data is available over the 0.030 to 0.996 Wilson inflow quantiles, and 0.000 to 0.999 Kanopolis inflow quantiles. Figures 5-7 shows a bar chart of the available chloride data observations by quantile of flow.

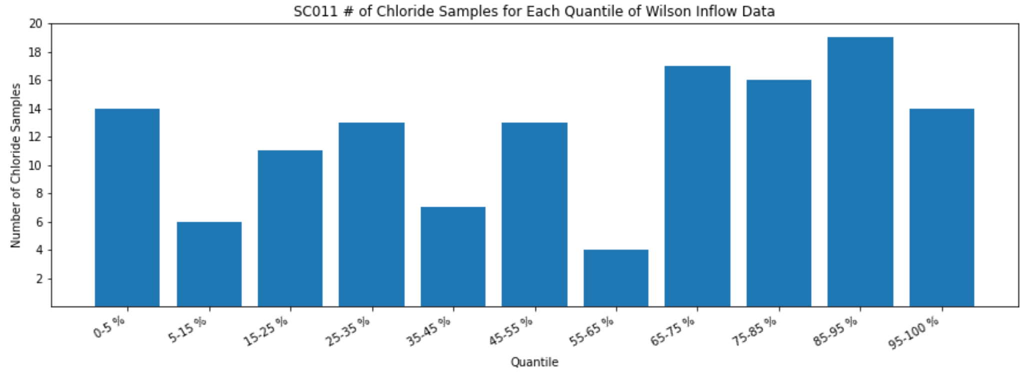

Figure 5. Count of chloride samples at SC011 location by quantile bin of Wilson Lake inflows

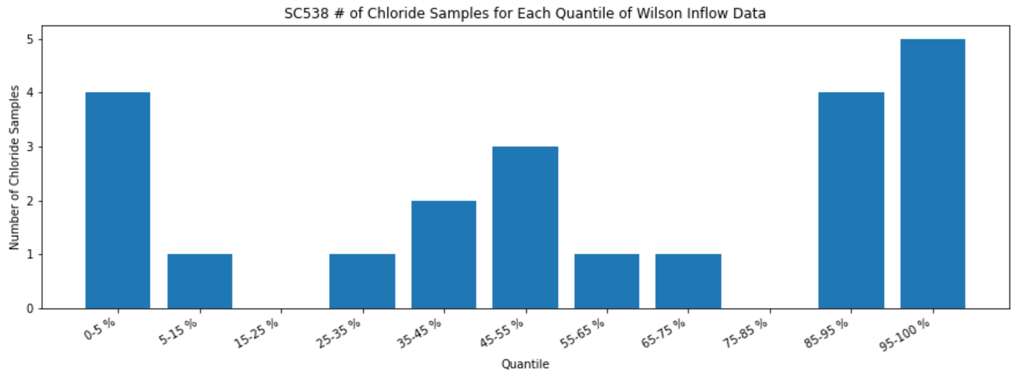

Figure 6. Count of chloride samples at SC538 location by quantile bin of Wilson Lake inflows

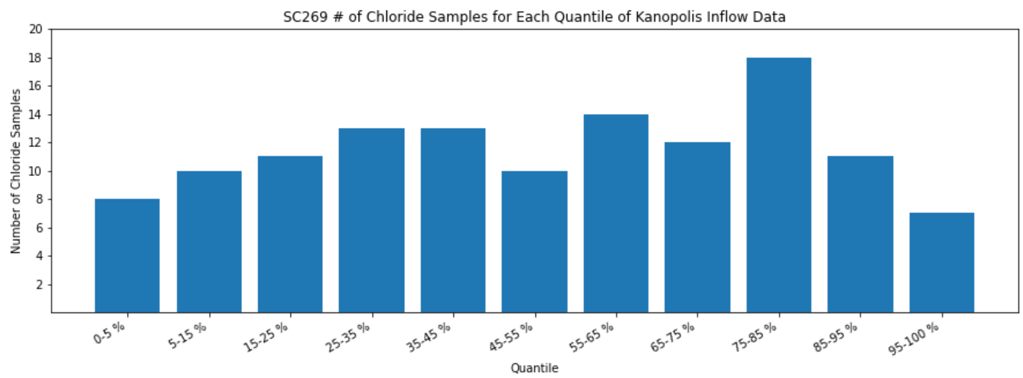

Figure 7. Count of chloride samples at SC269 location by quantile of Kanopolis inflows

This analysis uses the *Canteen* reservoir operations model. This model integrates other models, in this case a simple mass balance salinity model, into its operations though a plug-in interface. Future studies may upgrade the water quality model, used in this analysis by integrating a higher fidelity water quality model, fit to better water quality data. For instance, the KDHE data could be augmented with the USACE sampling and gage monitoring programs data. This dataset contains fewer observations but includes measurements at various depths in the reservoirs. This could be useful in calibrating future hydrologic, water quality, and/or hydrodynamic models to improve the accuracy of the analysis.

The Watershed Study models created using HEC-ResSim (Hydrologic Engineering Center – Reservoir System Simulation)(KRRFSS Appendix B-Water Management) Kanopolis and Wilson were used to parameterize the Canteen reservoir operations model. Specifically, volume-elevation relationships at the reservoirs (see Figures 8 and 9), pool elevations, gate locations (see Figure 10), maximum outflow from each outlet structure by pool elevation, and operating rules were taken from these models. These operations are briefly reviewed below.

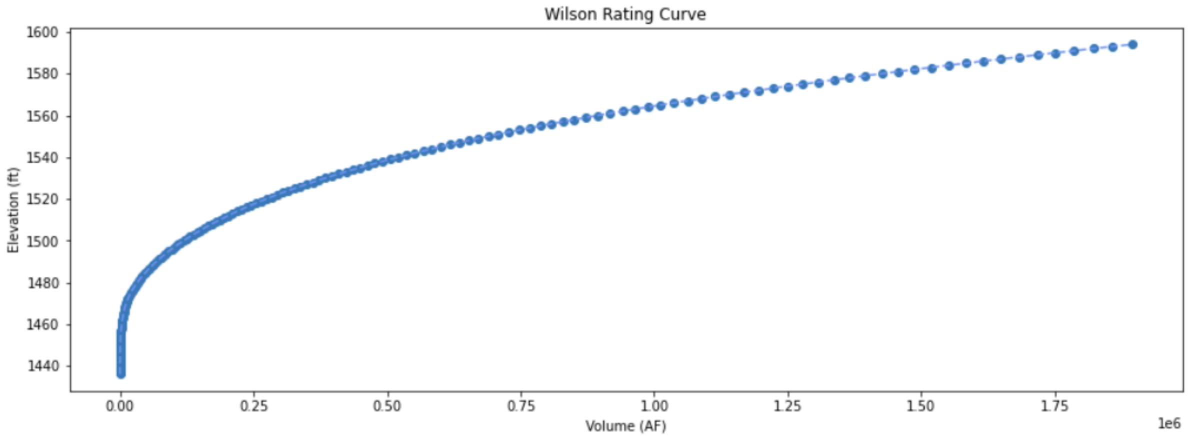

Figure 8. Wilson Lake rating curve

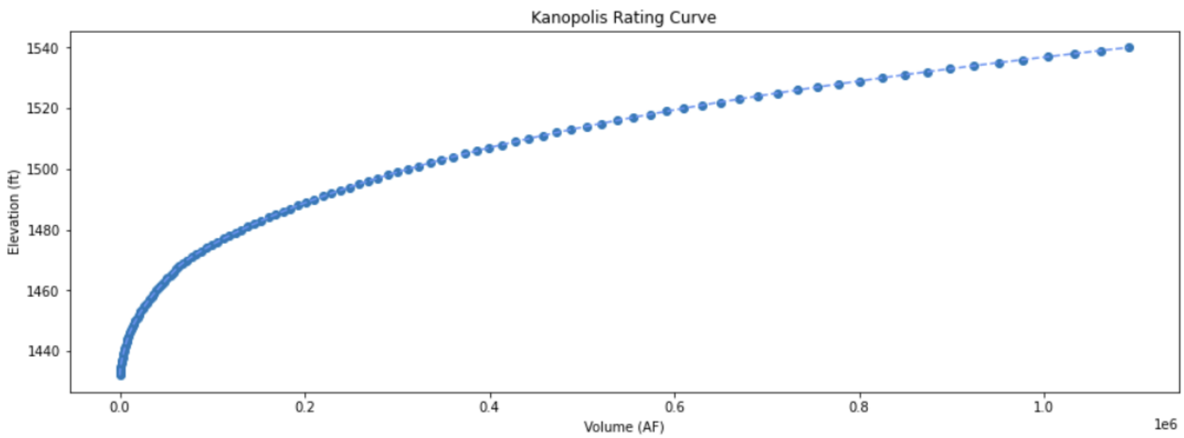

Figure 9. Kanopolis Lake rating curve

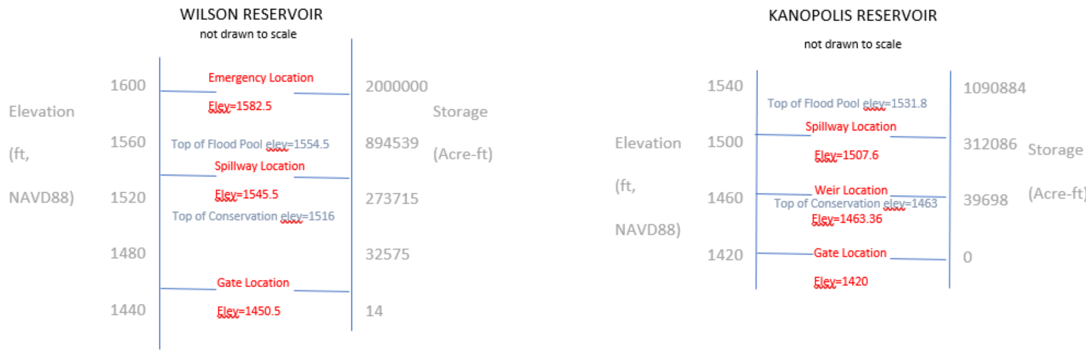

Figure 10. Wilson and Kanopolis Lakes pool and outlet locations

Reservoir Operations

The existing Wilson and Kanopolis reservoirs operating rules are based primarily on the stored water volume. Each reservoir contains inactive, conservation, flood, and surcharge storage pools and unique set of rules govern the releases from these pools. More specifically:

- *Inactive pool*: no releases are made from the reservoirs' inactive pools. This water is inaccessible to the reservoirs' outlet structures.
- *Conservation pool*: gated releases are made from the reservoirs' conservation pools. These releases follow seasonally variable volumetric daily targets.
- *Flood pool*: inflows in the flood pool are managed with the goal of maintaining an empty flood pool. Releases are constrained by a maximum allowable release, which increases as the volume of water being stored in the flood pool increases.
- *Surcharge pool*: Releases from the surcharge space are mostly uncontrolled, the volume of these releases are determined by the spillway design and storage behind the dam.

Figures 11 and 12 show the storage-release (blue) and elevation-release (red) relationships at both dams. Pool and outlet elevations are marked on the plots.

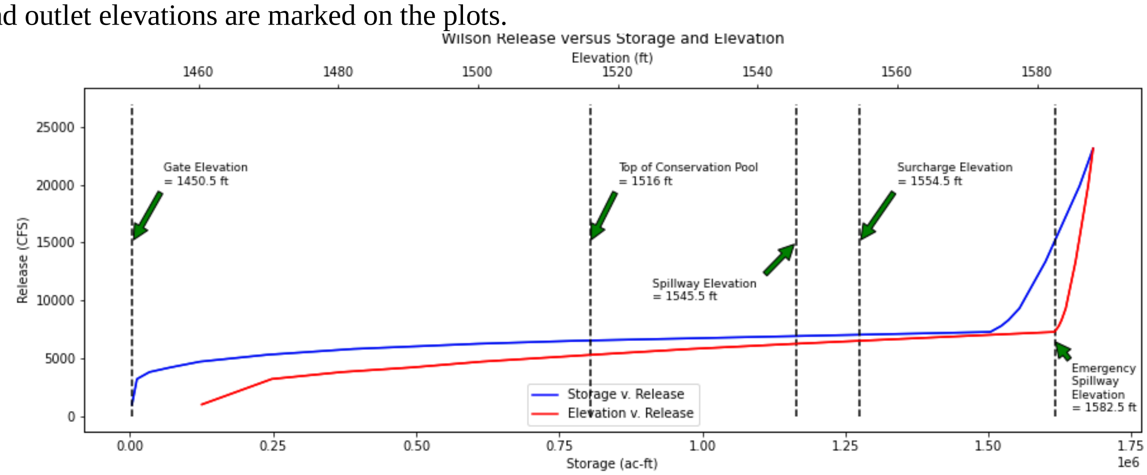

Figure 11. Wilson Dam release schedule

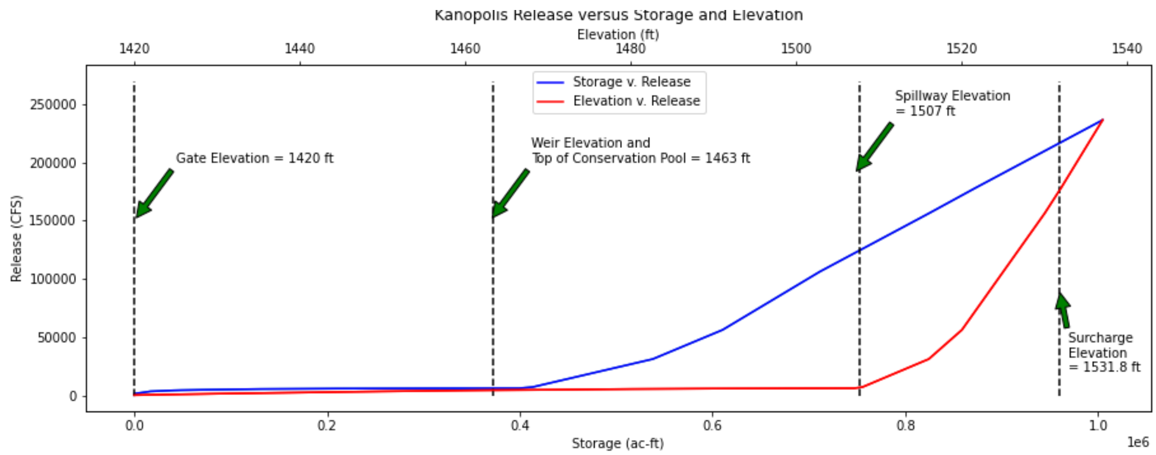

Figure 12. Kanopolis Dam release schedule

Chloride Model

The chloride model at each reservoir is a simple, zero-dimensional, conservation of mass model. The model starts with the single inflow input provided by USACE-NWK. Flow and chloride contributions from the upstream tributaries are estimated and recombined to provide the reservoir operation model with a flow-weighted average inflow and chloride concentration. The concentrations of chloride in the tributary flows are modeled by a rational decay function fit to the KDHE chloride versus USGS flow data. This function is in the form:

$$[Cl^-] = \frac{1}{(max\,[Cl^-] + decay * Qin)} \qquad (1)$$

where decay and max chloride are constants fit to the observational record, and Qin is the independent variable, describing the volume of inflow.

These functions were visually compared to the KDHE chloride versus USGS discharge data, over a range of decay values until a best fit was approximated. This curve relates chloride concentration to reservoir inflow, with higher chloride concentrations being associated with lower flows. A more thorough curve fitting process would accompany a more detailed chloride model (Yobbi, 1989).

The percent of total inflow from the USGS-gaged tributaries were estimated by comparing the USGS discharge to the USACE-NWK total reservoir inflow on a daily interval. At Wilson, the Saline River was estimated to contribute 70% of the USACE-NWK inflow, with Paradise Creek contributed an additional 5% and the remainder of local inflows contributing 25%. Chloride concentration functions for the Saline River and Paradise Creek were estimated from those rivers' chloride and flows gauge observations. The remaining inflows used the Paradise Creek curve to estimate chloride concentrations. The model splits the USACE-NWK total inflow into Saline River (70%), Paradise Creek (5%), and local flow (25%) portions. The chloride contributions from each source are computed using their respective chloride concentration functions. Finally, a total chloride concentration is computed as a flow-weighted average from the three sources. This method was used because the Saline River is known to have higher chloride concentrations than other tributaries.

At Kanopolis, the USGS discharge data on the Smoky Hill River at Ellsworth is typically higher than the USACE-NWK calculated inflow. This data suggests that the Smoky Hill River is the dominant inflow source at Kanopolis and the correlation curve from the Smoky Hill River data pairs was used exclusively to estimate chloride concentration for inflows into the dam. Thus, no weighted average of tributary flows was used at Kanopolis.

More detailed analyses on salinity-flow relationships in rivers have been performed in Florida by the USGS, and in Colorado by the Bureau of Reclamation, and would likely inform the next steps in analyzing this data (Yobbi, 1989; Prairie, 2005).

Figures 13-15 plot the KDHE-USGS data and show the fit of the data to the estimated salinity function.

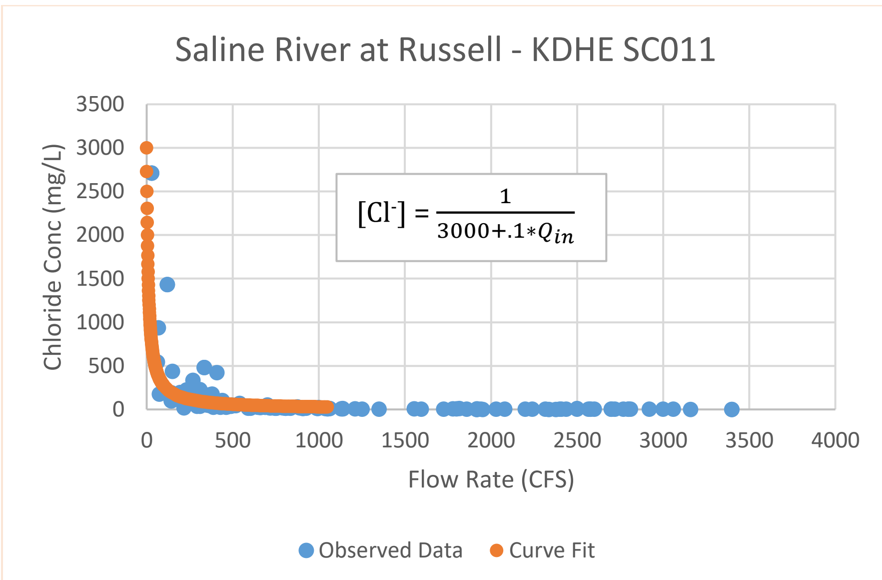

Figure 13. Saline River at Russell, KS (SC011) location

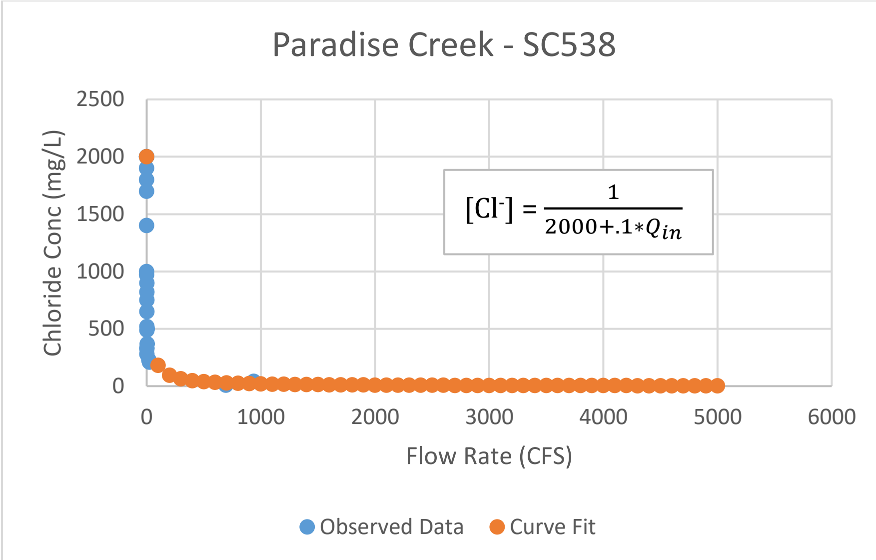

Figure 14. Paradise Creek at Paradise, KS (SC538) location

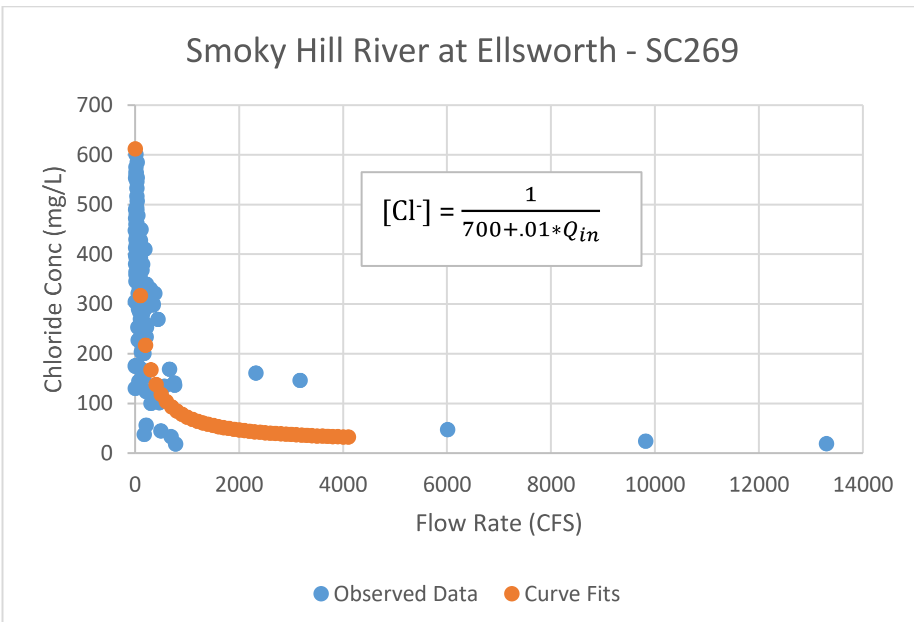

Figure 15. Smoky Hill at Ellsworth, KS (SC269) location

After the inflow chloride concentrations are computed, the inflow flow volume and concentration are averaged with the storage volume and reservoir concentration from the previously modeled time step. The resulting concentration reflects the reservoir and outflow concentration in the model. The concentration in reservoir release is the primary metric of interest, in the analysis of reservoir operations.

$$Reservoir\ [Cl^-]_t = \frac{Q_{in,t} * [Cl^-]_{in,t} + Storage\ Volume_{t-1} * [Cl^-]_{res,t-1}}{Storage\ Volume_t} \qquad (2)$$

This is an oversimplified approach and could be improved in future versions of the model. For instance, future salinity models might consider the natural stratification of saline water due to differences in density and hydrodynamic transport more generally.

Scenario Analysis and Optimization

An analysis of few conceptual operating strategies, and a multi-objective optimization model were used to explore the impacts of operations on salinity in the reservoir and its outflows. The optimization model referred to as the Policy Tree Optimization links indicator variables, in this case: inflow, salinity, and reservoir storage to operational policies in the form of a binary tree, given an objective function (Herman and Guiliani, 2018). It does so by identifying thresholds for the indicator variables that trigger specific actions, such as a particular reservoir release. The algorithm explores a range of operating policies, in search of those that minimize an objective or penalty function. The objective function used in this application sums equally weighted binary penalties for: (1) reservoir releases that may result in downstream flooding (i.e., Wilson outflows > 2,250cfs), (2) reservoir releases that exceeded a salinity concentration threshold (i.e., 325 mg/L), and (3) storage volumes that fall below the conservation pool elevation (e.g., into the inactive pool) or exceed the top of the flood pool elevation (e.g., encroach into the surcharge space). A continuous penalty, (4) representing the outflow concentration quantile, based on the baseline distribution was also added to the objective function.

Policies that increased or decreased the status quo reservoir releases by a discrete factor were considered. In other words, the optimization model searched for new policies that (a) avoided high salinity release, (b) minimized downstream flood risk, and (c) maximized operational control at the reservoir, so long as they continued to follow the existing storage pool based operational strategy.

Results

The model outputs a daily timeseries simulation that tracks inflow, storage, outflows, reservoir and outflow salinity concentrations, outflow concentration quantile, and binary variables indicating if the flood, operational control, or salinity thresholds (used by the optimization model) are exceeded. The results presented in this section show the model output with an initial storage equal to the top of conservation pool elevation. The initial chloride concentration are set equal to the median concentration over the baseline simulation.

Baseline Simulation

The output timeseries’ for each dam is displayed in figures 16 and 17 over the 100-year simulation period.

Figure 16. Wilson Lake baseline simulation results

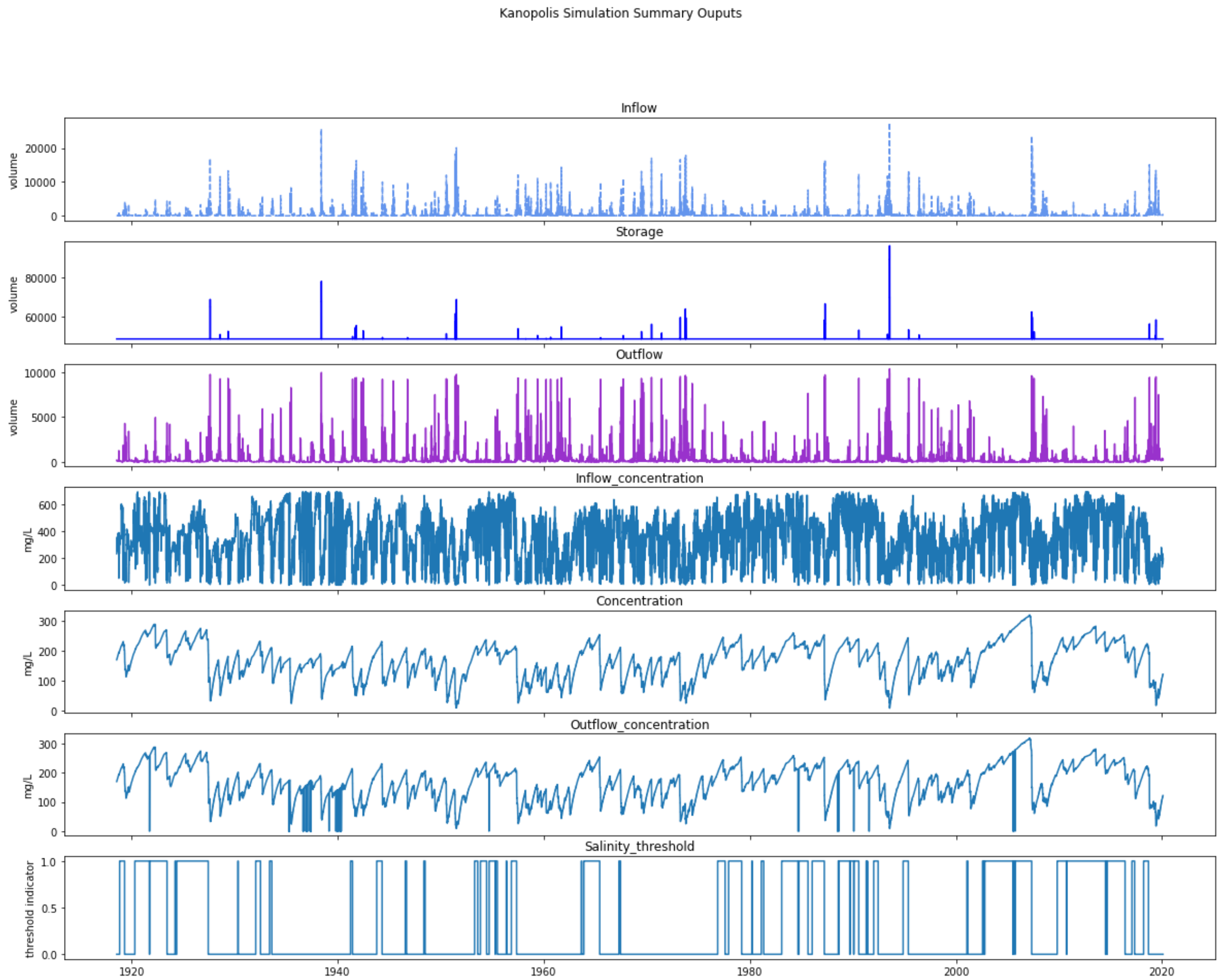

Figure 17. Kanopolis Lake baseline simulation results

At Wilson Lake inflow chloride concentrations range between 0 and 2000 mg/L. However, the highest concentrations correspond with the lowest flow volumes. Therefore, this range is muted by the reservoir, with lake concentrations ranging between 100 and 400 mg/L. Figure 18 below, displays patterns in the inflow hydrology and corresponding patterns in the chloride concentrations in the inflow, lake, and outflows. Inflow chloride concentration is negatively correlated with inflow volume (a result of equation 1). During dry months with low flows (i.e., October -March) salinity in the lake builds. However, the salinity threshold of 325 mg/L is generally only surpassed when these dry periods extend over multiple years (as shown in figure 16). Large volume flood flows are low in chloride. As a result, periods of above average inflow, in many cases even a single large event punctuate rising chloride levels. Outflow concentrations in this model match the concentrations in Wilson Lake. Since no consideration is given to water quality in the baseline reservoir operations, in total the outflow salinity threshold of 325 mg/L is surpassed on 12,964 days in the 100-year period simulation.

Patterns in chloride concentrations and hydrology at Wilson Lake are also evident in Kanopolis Lake (see figure 19), and simulation results at Kanopolis (see figure 17) mirror those at Wilson Dam. The most notable difference is that the salinity concentrations are generally lower at Kanopolis, with inflow concentration ranging between 0 and 700 mg/L and reservoir concentrations ranging between near 0 and 300 mg/L. The relationship between inflow hydrology and reservoir salinity at both lakes is explored in the context of several events in the Supplemental Materials provided at the end of this report.

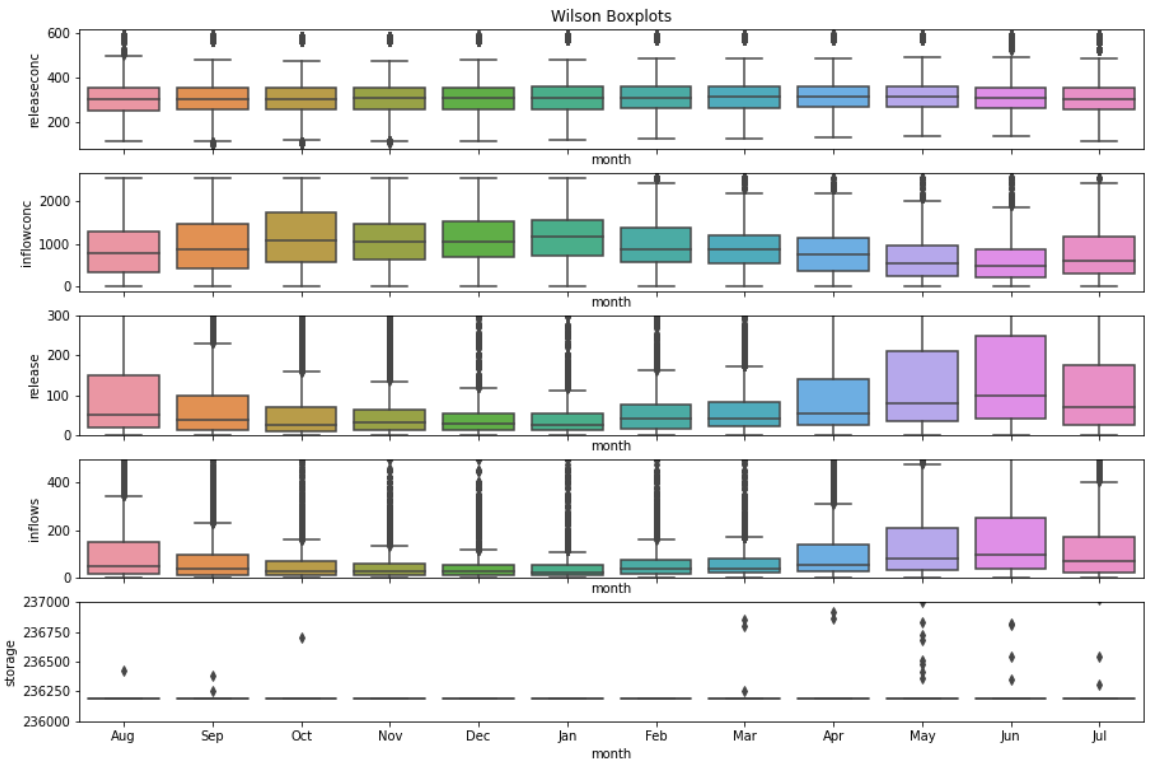

Figure 18. Boxplot of salinity concentrations, inflow, storage, and outflow statistics at Wilson Dam

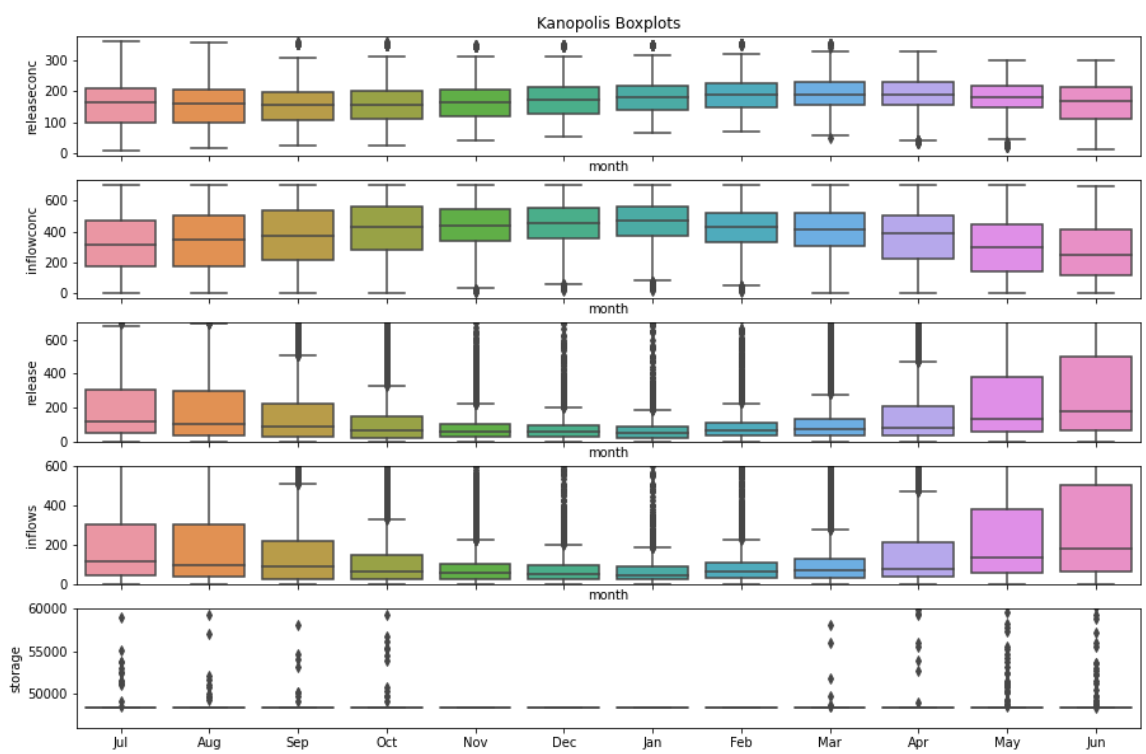

Figure 19. Boxplot of salinity concentrations, inflow, storage, and outflow statistics at Kanopolis Dam

Chloride concentration thresholds for the scenario and optimization analysis are set based on the distribution of outflow concentration, at each of the reservoirs in the baseline analysis. These distributions are show in figure 20 and 21 below. The probability density function (PDF) displays two peaks of density centered around approximately 200 mg/L and 300 mg/L, with more observations under the higher concentration peak. This is logical since salinity builds up in the lake over long low-flow periods, which are punctuated by large-short duration high flows.

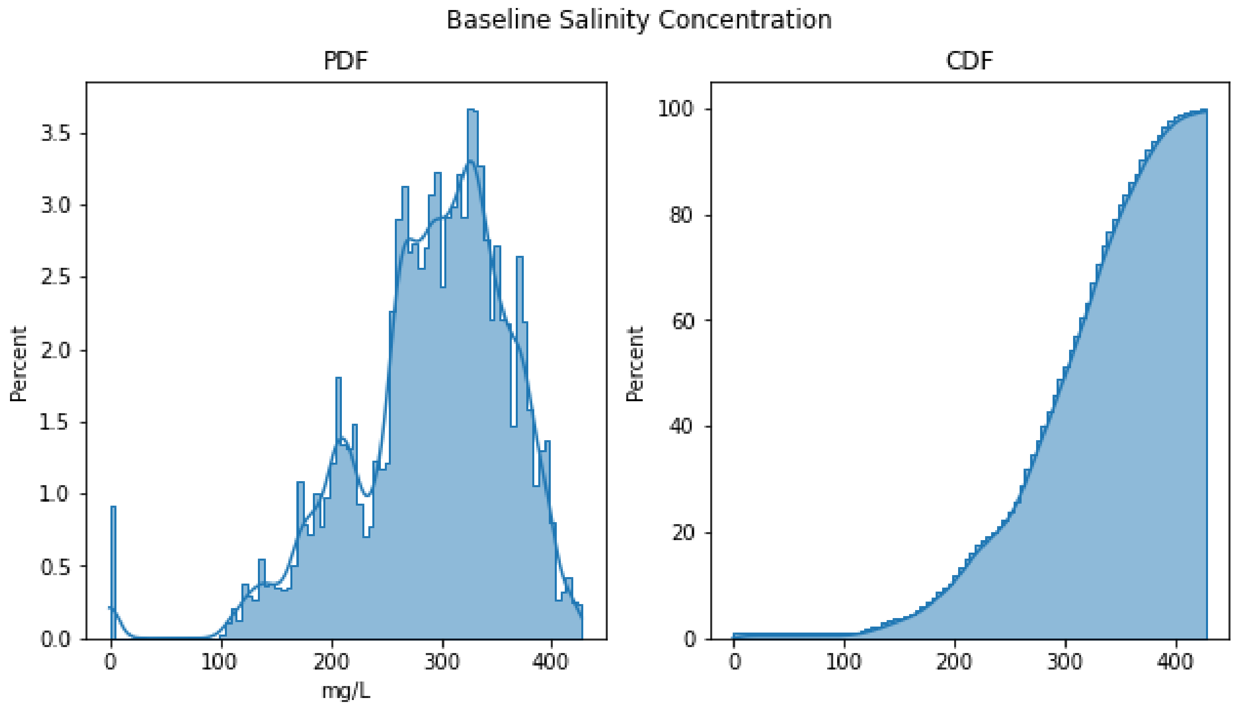

Figure 20. Wilson Lake chloride concentration distribution

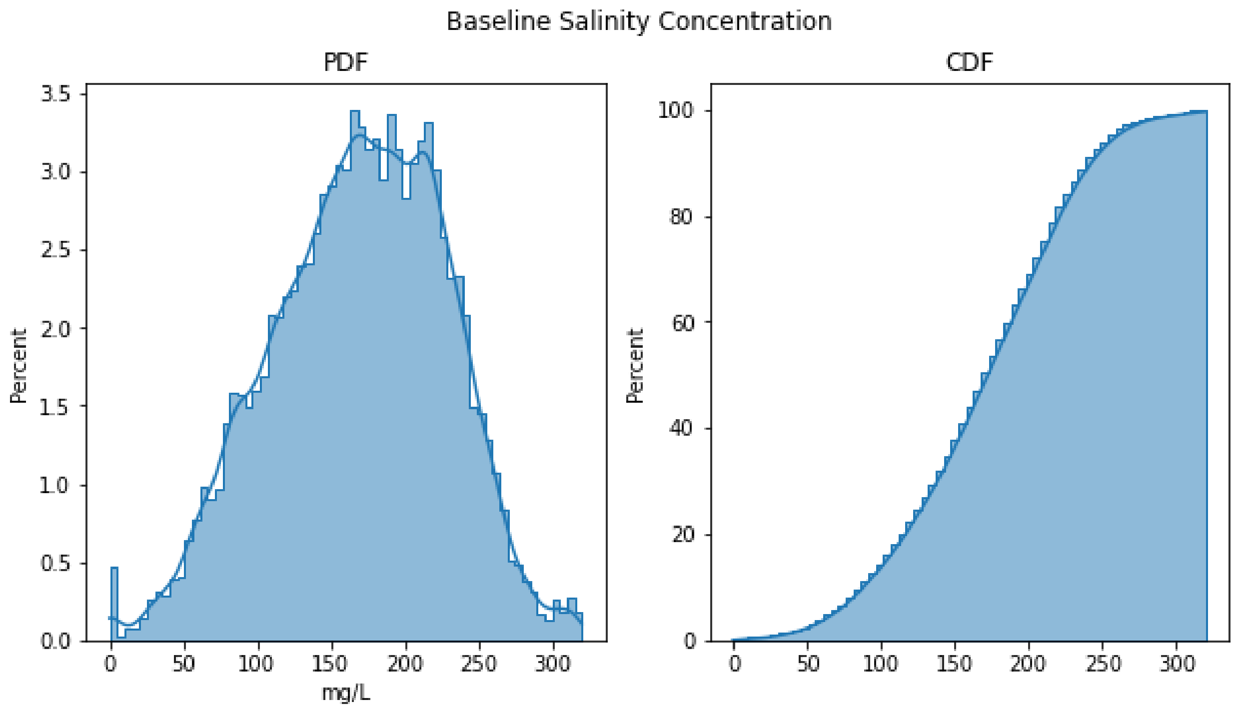

Figure 21. Kanopolis Lake chloride concentration distribution

Operational Scenarios

The salinity model in this study is a mass balance model. As a conservative constituent, the volume of chloride in the reservoir inflows over 100 years will be (approximately) equal to the volume of chloride in the outflows. For instance, in Wilson Dam, the average chloride concentration over the 100-year simulation volume is 258 mg/L. An outflow with less than this average concentration must be balanced by outflow more than this average concentration. This mass balance framing bounds the analysis. A reservoir with a storage capacity equal to the 100-year simulation period inflows could avoid ever making a release that exceeds this concentration (but could not lower them further without exceeding the concentration at a different time). The goal of the operational rules evaluated in this report are to minimize the number of releases exceeding a threshold concentration of 325 mg/L at Wilson Dam and 200 mg/L at Kanopolis Dam. These concentrations represent the approximate 70th percentile in the baseline simulation outflows.

Two conceptual operational strategies are explored. First a simple strategy, was explored that modifies the Wilson and Kanopolis dam operations to make no releases, provided that the reservoir storage volume does not encroach into surcharge space, during periods in which the chloride concentration exceeded the 325 mg/L threshold. During the simulation period this strategy succeeds in avoiding all 3 binary penalties discussed in the method section, e.g., the reservoir never falls into the inactive pool or encroaches on surcharge space; the maximum safe release is never exceeded; and no releases are made during period in which the chloride concentration exceeds its threshold value. Simulation results for this operational strategy are displayed below.

Figure 22. Wilson "simple" conceptual operational strategy simulation results

(this strategy avoids releases during periods in which the chloride concentration exceed 325 mg/L, but otherwise preserves status quo reservoir operations)

Figure 23. Kanopolis "simple" conceptual operational strategy simulation results
(this strategy avoids releases during periods in which the chloride concentration exceed 325 mg/L, but otherwise preserves status quo reservoir operations)

Finally, a more aggressive operational strategy permits encroachment into the conservation space in order to create storage for high chloride concentration inflows is explored in the two plots below. Like the simple strategy, this conceptual strategy also succeeds in avoiding penalties associated with encroaching in the inactive or surcharge space, making unsafe flood releases or making releases during periods in which the chloride concentration exceeds the threshold limit.

Figure 24. Wilson Lake "aggressive" conceptual operational scenario simulation results
(this operational strategy is similar to the simple strategy displayed and discussed above except that it permits greater encroachment in the conservation pool to store inflows with chloride concentration > 325 mg/L)

Figure 25. Kanopolis Lake "aggressive" operational scenario simulation results

(this operational strategy is similar to the simple strategy displayed and discussed above except that it permits greater encroachment in the conservation pool to store inflows with chloride concentration > 200 mg/L)

Conclusions And Future Work

Neither of the conceptual operational scenarios explored above are likely to be viable operational alternatives. However, they demonstrate the capacity for Wilson and Kanopolis reservoir operations to be modified to improve the salinity of downstream drinking water supplies. This study would benefit from the following next steps: (1) construction of an improved salinity model that integrates data from existing sources (this may or may not be possible with existing datasets), (2) exploration of the operational scenarios explored above and optimization routines using stochastically generated streamflow data, to avoid an overfit operational alternative, (3) inclusion of additional indicator variables in the exploration of conceptual alternatives including day of year and other hydrologic and water quality parameters. Initial investigation of more detailed operational alternatives that take future reservoir conditions into account, including notably decreasing storage space due to sedimentation.

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SUPPLEMENTAL INFORMATION

Event Analysis

The figures below show a snapshot of periods selected from the simulated timeseries that are indicative of periods in which the inflow hydrology strongly influences the salinity concentration in the reservoir storage and reservoir outflows.

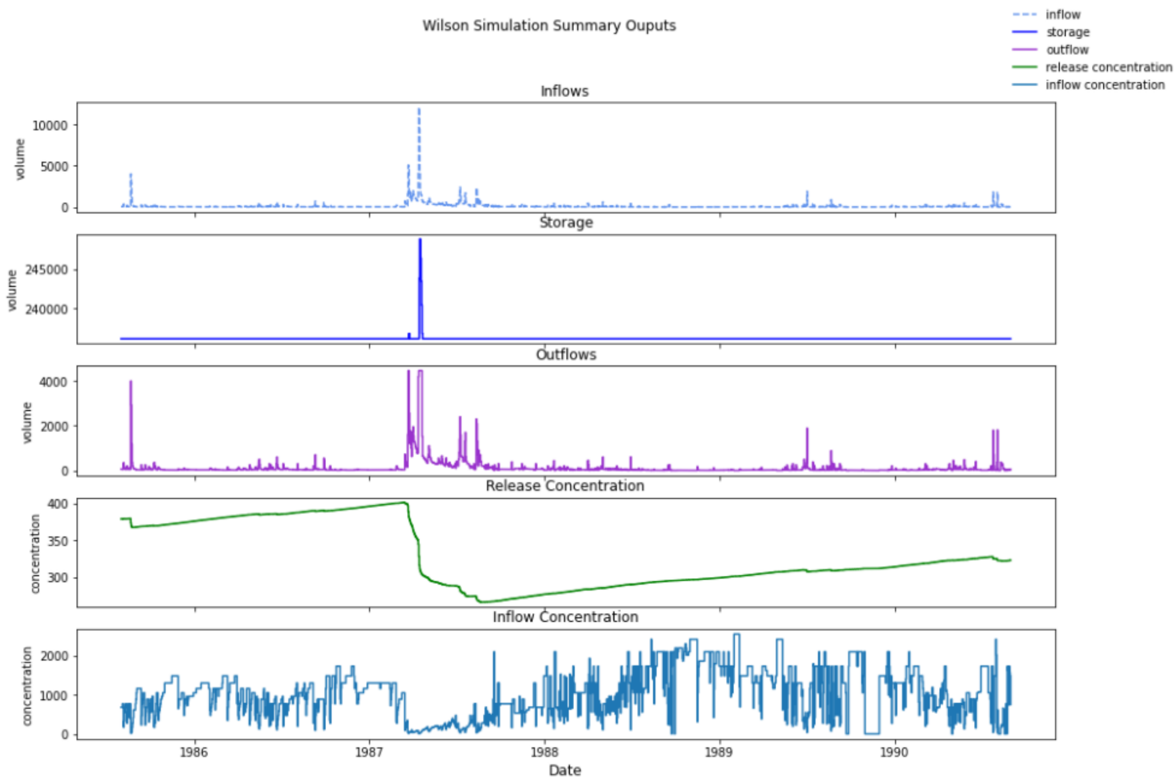


Figure S1: Wilson 1986-1991

The event above shows a dry period of approximately 2 years, in which the reservoir concentration exceeds in 90th percentile value. This is punctuated by an extreme inflow in early 1987, and 99th percentile reservoir release. The combination of these two factors, large low concentration inflows and large high concentration outflows, substantially reduce the concentration in the reservoir. However, they also represent a bad outcome from a water quality perspective: a sustained period of small high concentration releases followed by a set of large, high concentration releases.

The figure below shows a similar period for Kanopolis reservoir. The early portion of the simulation between 1985 through early 1987 is characterized by low inflows and increasing salinity concentrations in the reservoir this is punctuated by the large inflow in 1987 (the same event as in the Wilson example above). Afterwards, the salinity concentration rises again between 1987 and late 1990 during an extended period of low flows, again this is punctuated in late 1990 by a large inflow.

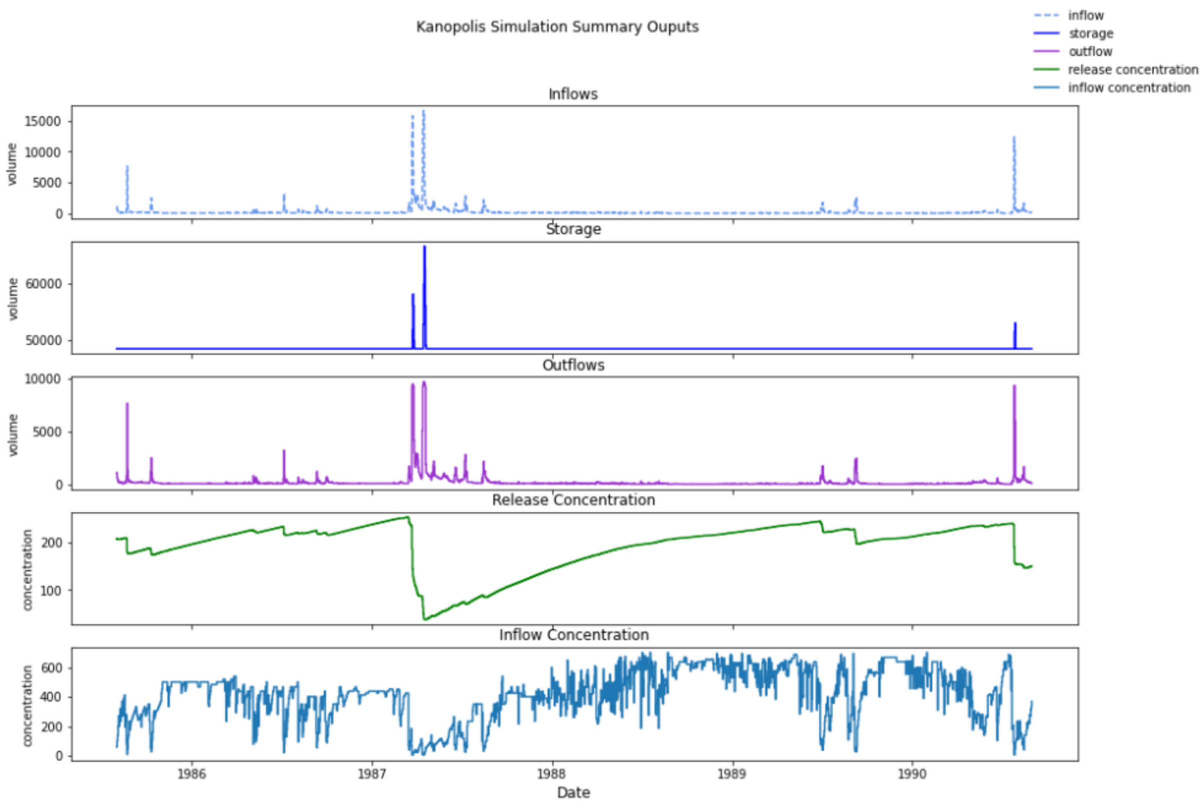


Figure S2. Kanopolis 1985 – 1987 and 1987 -1990

The Wilson event from the late 1980s show a peak reservoir concentration quantile near 90%, followed by a release above the 99-percentile outflow. This is a bad scenario for the water intakes downstream. The other images show other scenarios, which can be put into context with the quantile tables.

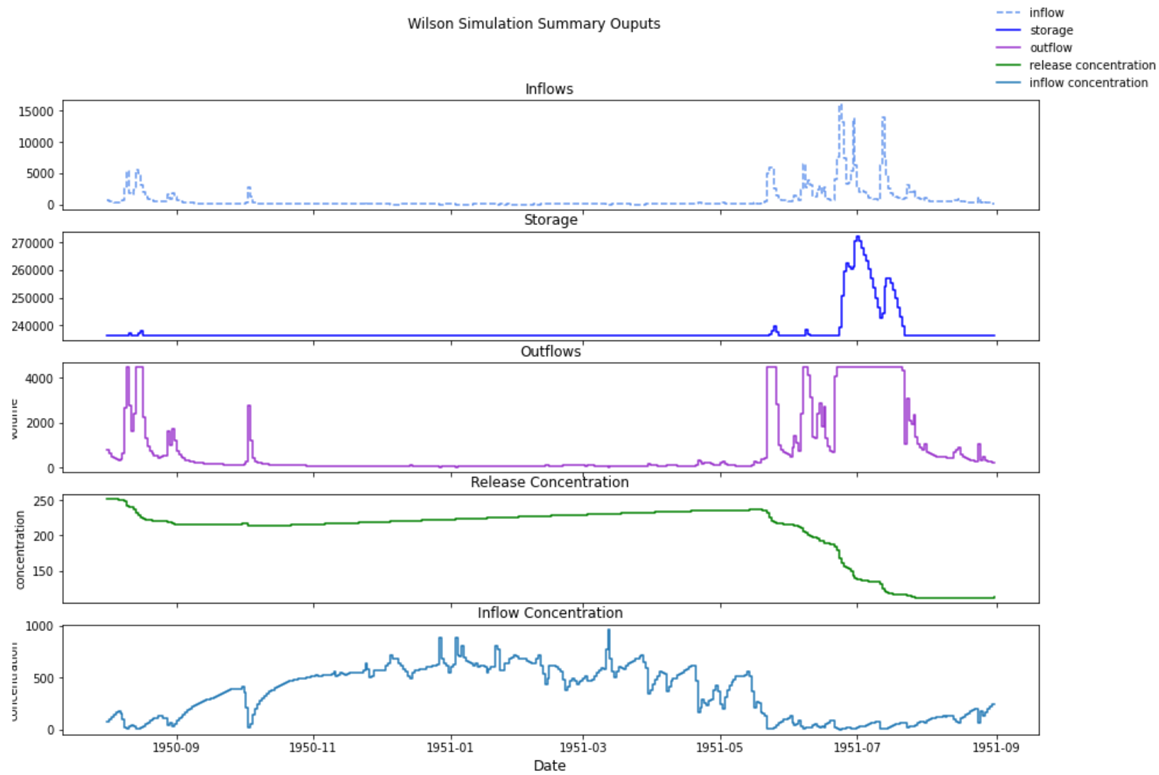
Wilson Quantiles

Quantiles	Reservoir Cl Quantile	Inflow Cl Quantile	Inflow Quantile	Outflow Quantile
0.09	196.227280	185.769915	6.0	6.000000
0.19	237.534950	345.014711	14.0	14.000000
0.29	267.096669	510.482904	20.0	20.000000
0.39	288.544186	665.672736	30.0	30.000000
0.49	306.950987	822.950867	40.0	40.000000
0.59	322.685526	1012.132822	57.0	57.000000
0.69	339.068161	1185.367804	80.0	80.000000
0.79	371.370263	1481.049863	130.0	130.000000
0.89	407.614789	1730.532213	250.0	250.000000
0.99	585.562880	2549.924188	1800.0	2178.061157

Kanopolis Quantiles

Quantiles	Reservoir Cl Quantile	Inflow Cl Quantile	Inflow Quantile	Outflow Quantile
0.090000	85.702296	103.703704	14.000000	14.000000
0.190000	115.195837	200.000000	26.000000	26.000000
0.290000	137.741730	280.000000	40.000000	40.000000
0.390000	155.512735	341.463415	57.000000	57.000000
0.490000	171.086422	388.888889	75.000000	75.000000
0.590000	187.205797	437.500000	100.000000	100.000000
0.690000	204.000791	486.111111	140.000000	140.000000
0.790000	220.169662	538.461538	220.000000	220.000000
0.890000	241.071431	608.695652	475.000000	475.000000
0.990000	312.884073	686.274510	3940.000000	4334.850000

Finally, a shorter event between 1950 and 1951 is shown below. A single dry year slowly increases the reservoir salinity, despite the high inflow concentrations the low volumes of water associated with these flows prevents a dramatic rise in the salinity between September 1950 and June of 1951. A period of above large inflows between June and August 1951 brings the salinity concentration in the lake down by about half over the span of two months.


Wilson Simulation Summary Ouputs
inflow
storage
outflow
release concentration
inflow concentration
Inflows
15000
10000
5000
0
Storage
270000
260000
250000
240000
Outflows
4000
2000
0
Release Concentration
concentration
250
200
150
Inflow Concentration
1000
500
0
1950-09
1950-11
1951-01
1951-03
1951-05
1951-07
1951-09
Date

Q-Q Plots

The Q-Q plots below show a roughly linear relationship between the inflow and outflow concentration. The linearity of this relationship demonstrates the reservoirs attenuation of the exponential inflow-concentration relationship. The shallow slope of the line (in comparison to the 1:1 line) is indicative of the large operational storage-to-inflow relationship.

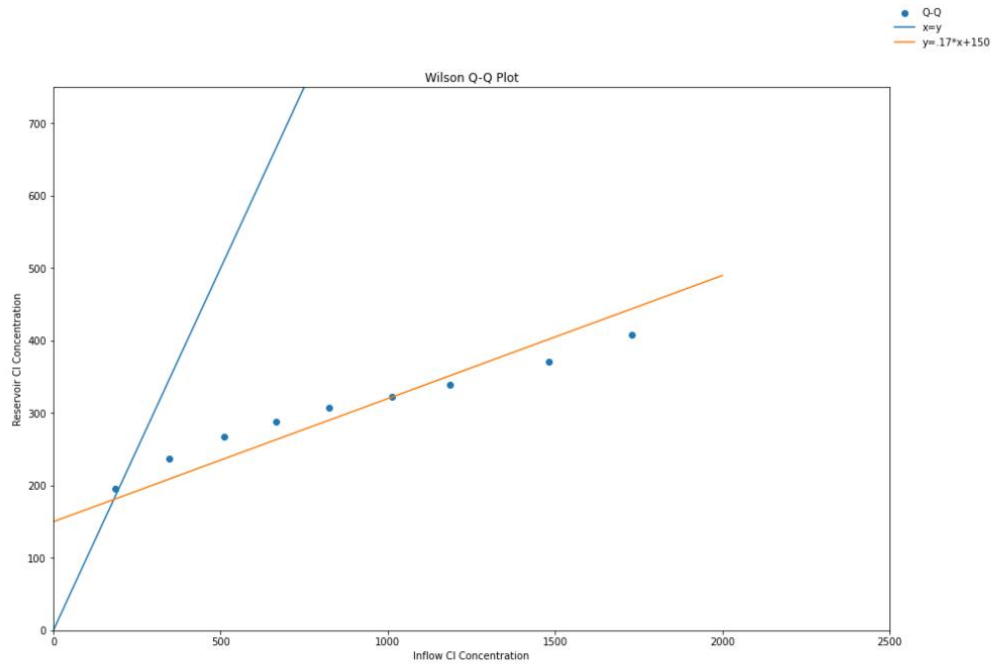


Figure 22: Wilson Q-Q Plot