Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

Baseflow Water Quality Monitoring of the Lake Taneycomo-White River Watershed (HUC-1101000301)

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FINAL

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SCOPE AND OBJECTIVES

Water quality of lakes and reservoirs in the Missouri Ozarks is a concern for local communities as these impoundments are important components of the area's economy. Lake Taneycomo is a 2,080-acre reservoir built in 1913 on the White River downstream of Table Rock Lake near the tourist town of Branson, Missouri (Bayless and Vitello, 2002). Since the completion of Table Rock Dam in 1959, Lake Taneycomo receives cold water from the bottom of Table Rock Lake, which has created a popular recreational trout fishery (Weithman and Haas, 2009). However, the water being released into Lake Taneycomo has low dissolved oxygen (DO) levels that are below Missouri standards for a cold-water fishery. Further, Lake Taneycomo has also had a history of increased sedimentation in tributary coves and algal blooms during periods of reduced hydroelectric power generation (Berkas, 1987; Knowlton and Jones, 1990). Excess nutrients and sedimentation can make the low DO problem worse in the lake by increasing the biological oxygen demand in the reservoir (MDNR, 2010).

In 1994, Lake Taneycomo was placed on the State of Missouri 303d impairment list for not meeting the minimum DO water quality criterion of 6.0 mg/L required for its designated use as a cold-water fishery and a Total Maximum Daily Load (TMDL) was approved in 2010 (MDNR, 2010). The TMDL identified the release of oxygen deprived cold water resulting from the thermal stratification of Table Rock Dam as the cause of low DO in Lake Taneycomo. The nutrients and other organic materials from the contributing watershed area delivered to the lake during runoff events can also lower DO concentrations in impoundments. Rising urban populations has been identified within the TMDL as a potential source of nutrients and other oxygen-consuming substances entering Lake Taneycomo during runoff events contributing to the low DO in the lake. Reducing the amount of nutrients entering the lake from rural and urban nonpoint sources can have a positive effect on DO conditions in Lake Taneycomo and can be an important step toward improving water quality.

Through a contract agreement with the Missouri Department of Natural Resources (MoDNR), the Ozarks Environmental and Water Resources Institute (OEWRI) at Missouri State University (MSU), in partnership with H_2Ozarks, is assisting with the development of a watershed management plan for the Lake Taneycomo-White River watershed (HUC-1101000301) that includes the contributing area to the lake below Table Rock Dam. As a part of this project, OEWRI conducted a baseflow water quality assessment that examines the spatial distribution of nutrients, bacteria, and other typical water quality indicators within the Lake Taneycomo-White River watershed. The specific objectives of the water quality monitoring assessment are:

1. Establish a baseflow monitoring network near the outlet of 10, HUC 12 subbasins within the Lake Taneycomo-White River watershed and collect water quality sample seasonally for one year,

2. Monitor the water quality of the Lake Taneycomo reservoir at three sampling sites seasonally for one year,

3. Interpret water quality trends and assess the spatial variability of water quality within the Lake Taneycomo-White River watershed.

This report summarizes and organizes data collected for this project and interprets the water quality for Lake Taneycomo and its contributing recharge areas and analyzes water quality trends.

STUDY AREA

Physical Setting

The Lake Taneycomo-White River watershed (871 km^2) is in southwest Missouri and is a sub-watershed of the larger White River Basin. Most of the watershed lies within the Salem Plateau physiographic section of the Ozark Plateaus of the United States Interior Highlands (Adamski et al. 1995). The underlying geology is Mississippian age Limestone and Ordovician age dolomite with lesser amounts of sandstone. Karst features, such as caves, sinkholes, and springs are common. The typical soils in the watershed are formed from limestone and dolomite residuum and a thin layer of loess in the uplands (Dodd and Dettman, 1996). Land use within the watershed is 70.0% forest, 17.1% agriculture, and 10.2% urban (Figure 1). This mixed-use watershed includes the City of Branson, multiple golf courses, public forest land, and cattle grazing operations. Major tributaries to Lake Taneycomo include Bull Creek, Fall Creek, Turkey Creek, and Roark Creek.

Sample Sites

There are ten HUC12 watersheds within the larger HUC10 watershed which range in size from 46.2-146.6 km^2 (Table 1). Forest land cover is the highest category by percentage for all 10 HUC12 watersheds, with four having more agricultural land use and 6 having more urban land use. Within the 10 HUC12 watershed there were 13 sampling sites established, with 10 located along streams and three along Lake Taneycomo. These sites were chosen for this project based on the following criteria: 1) road access; 2) proximity to a major road crossing; 3) public access; and 4) reservoir accessibility. Of the 13 sampling sites, one site was assigned to each of the ten

HUC12 watersheds draining into the reservoir, and three of the sample sites were assigned to different portions of the reservoir itself (Figure 2).

METHODS

This section describes methods used for water quality sample collection and water quality analysis. For more details on these methods the approved Quality Assurance Project Plan (QAPP) and all Standard Operating Procedures (SOPs) for this project are available on the OEWRI website: https://oewri.missouristate.edu/.

Sample Collection

Water samples were collected for analysis including field-measured water chemistry at 13 sites in the Lake Taneycomo-White River watershed and reservoir from September 2020 through September 2021 according to the approved QAPP (Arceneaux et al., 2020). Sampling occurred at baseflow conditions four times per year to assess seasonal variability. Water chemistry was measured in the field using a YSI Professional Plus Handheld Multi-Parameter Meter including temperature (T), dissolved oxygen (DO), specific conductivity (SC), and pH. Grab samples for nutrients, total suspended solids (TSS), and chloride (Cl) were collected at each site in 500 mL plastic containers, placed on ice, and transported to the laboratory. Sample splits to be analyzed for nutrients were preserved to a pH of 2.0 and all samples were placed in a refrigerator. Bacteria samples were collected in sterilized shrink-banded vessels and placed on ice for transport.

Laboratory Analysis

All nutrients, TSS, Cl, and bacteria analytical methods were completed according to the approved QAPP (Arceneaux et al., 2020). Nutrient samples were analyzed at Consulting Analytical Services International (CASI) in Springfield, MO for total phosphorus (TP), nitrite plus nitrate (N+N), and total kjeldahl nitrogen (TKN) using standard methods. Values for TKN and N+N were summed to get total nitrogen (TN). Values for TSS, Cl, and bacteria were measured at the OEWRI Water and Sediment Quality Laboratory. For measured values equal to, or below, the detection limit, ½ the detection limit was used for analysis.

RESULTS

A total of 52 samples were collected over the sampling period from the 13 sites within the Lake Taneycomo-White River watershed. Individual sampling runs were completed on September

10, 2020; December 10, 2020; June 14, 2021; and September 14, 2021. This section describes the sampling period hydrology and water quality analytical results by site.

Monitoring Period Hydrology

The monitoring period of this study (2020-2021) was wetter compared to the 30-year average as total runoff and typical baseflow discharge was elevated. The average annual rainfall for 2020-2021 was 148.7 cm, which is 30.1 cm higher than the 30-year annual average of 118.6 cm. Generally, spring and early summer seasons were relatively wet, and late summer and fall were relatively dry (Figure 3). Over the 13-month sampling period, seven of those months had rainfall at or above the monthly average. Three of those months, October 2020, March 2021, and May 2021, had rainfall >5 cm over the monthly average. This led to an elevated baseflow discharge that lasted from roughly November 2020 to July 2021 at the USGS gaging station located on Bull Creek near Walnut Shade (Figure 4). In September and October 2020, discharge was near 10 ft^3/s (0.28 m^3/s) and again in late August and September 2021. However, between November 2020-July 2021 was closer to 90 ft^3/s (2.5 m^3/s). Annual average discharge for Water Year (WY) 2020 at this gage was >2 times higher than the overall average discharge from 1995-2021 and 33% higher in WY2021. Average annual discharge from 1995-2021 is 6.8 m^3/s (240 ft^3/s) at this gage (Table 2). Average discharge for WY2020 (October 2019-September 2020) was 15.3 m^3/s (540 ft^3/s) and 9.1 m^3/s (321 ft^3/s) in WY2021 (October 2020-September 2021). While these rainfall and runoff patterns are high compared to the long-term average, recent studies suggest this may be a new normal as the frequency of high intensity rainfall events has increased since the early 2000s in the Ozarks (Foreman, 2014; Pavlowsky et al., 2016).

Physical Water Parameters

Physical water parameters measured during sampling were generally lower and less variable at the lake sites compared to the stream sites. Average temperature for the stream sites ranged from 15.6-20.7 °C and 13.0-15.2 °C for the lake sites (Table 3, Figure 5). Mean pH ranged from 7.6-8.0 at stream sites and 7.3-7.5 at lake sites. Average SC ranged from 267-492 µS/cm at stream sites and 231-240 µS/cm at lake sites. Mean DO ranged from 6.6-9.4 mg/L at stream sites and 6.8-7.6 mg/L for the lake sites. While average DO readings were above the 6.0 mg/L limit for cold water fisheries, there were times in the summer and fall when DO was lower than 6.0 mg/L in streams and the lake. The low variability at the lake sites is due to the relatively consistent inflow from Table Rock Dam that moderates these readings.

Nutrients, Chloride, Suspended Solids, and *E. Coli*

<u>Total Phosphorus</u>

Three of the stream sites and one of the lake sites had average TP concentrations higher than local water quality criteria over the sampling period. For streams, sites 5 (Roark Creek), 8 (Lower Bull Creek), and 9 (Turkey Creek) had average values greater than 0.075 mg/L, which is the eutrophic threshold established in the James River TMDL (MDNR, 2001). The James River is a major tributary of Table Rock Lake, and the watershed is located just west of the Lake Taneycomo-White River watershed over the divide. Average TP concentration for site 5 was 0.08 mg/L, site 8 was 0.09 mg/L, and site 9 was 0.16 mg/L (Table 4, Figure 6A). While these watersheds contain significant urban land use (15.2-19.8%), other watersheds have higher percentages (>25%) of urban land use but have lower average TP concentrations. This suggests other factors may be contributing to the high TP values. For instance, site 9 (Turkey Creek) has the highest average concentration (0.16 mg/L) and is also downstream of the Hollister wastewater treatment plant. However, the source of higher TP concentrations at the other locations is unknown. Two of the three lake sites had average TP concentrations greater than the nutrient criteria screening value for Ozark Highland lakes, which is 0.016 mg/L (MDNR 2019). Site 11 (Silver Lake) had an average concentration of 0.02 mg/L and Site 12 (Coon Creek) had an average concentration 0.03 mg/L. However, both sites are downstream of the confluence with Turkey Creek, which had the highest TP concentrations from all the sites in this study and is influenced by a wastewater treatment plant.

<u>Total Nitrogen</u>

One of the stream sites and all three of the lake sites had average TN concentrations higher than local water quality criteria over the sampling period. Among stream locations, site 6 (Silver Creek) had an average value of 1.55 mg/L and is the only site with an average value greater than 1.5 mg/L, which is the eutrophic threshold established in the James River TMDL (Table 4, Figure 6B, MDNR, 2001). All three lake sites had average TN concentrations greater than the nutrient criteria screening value for Ozark Highland lakes, which is 0.4 mg/L (MDNR 2019). Concentrations increased from upstream to downstream. Average TN concentration for site 11 (Silver Lake) was 1.43 mg/L, site 12 (Coon Creek) 1.25 mg/L, and site 13 (Fall Creek) 1.13 mg/L. Rainfall over the monitoring period was higher compared to the long-term average and may be partially responsible for higher TN values.

<u>Chloride</u>

Chloride can be introduced into aquatic systems naturally and through anthropogenic influences. Elevated concentrations of chloride in streams can be an indicator of wastewater pollution and road salt applications in winter which can be toxic to aquatic life (Amick and

Burgess, 2000; Huggins et al., 2005). Most of the sites sampled had average Cl concentrations less than 10 mg/L (Table 4, Figure 6C). However, site 8 (Roark Creek), site 9 (Turkey Creek), and site 10 (Fall Creek) had elevated Cl concentrations with average concentrations >10 mg/L. Elevated concentrations at sites 8 and 10 could be an indicator of leaking wastewater infrastructure or domestic water lines and is typical of ageing urban areas (Owen et al., 2017; Owen et al. 2018; Owen et al., 2019). Site 9 is downstream of the Hollister wastewater treatment plant and has the highest average concentration of any site in the study at 27.2 mg/L. While this is elevated, it is not near toxic levels for aquatic organisms, which is 230 mg/L (Benoit and Stephan, 1988).

<u>Total Suspended Solids</u>

High concentrations of TSS in water can negatively impact the health of streams and aquatic life and is typically very low at baseflow in Ozarks streams (Hutchison 2010). Only site 9 (Turkey Creek) had an average TSS values >5 mg/L (Table 4, Figure 6D). Site 9, which is downstream of a wastewater treatment plant outflow, had the highest average concentration of 15.3 mg/L and the highest sampled concentration of 30.0 mg/L.

<u>*E. coli*</u>

The presence of *E. coli* bacteria is an indicator of fecal contamination by warm-blooded animals, including humans, and identifying bacteria sources are important for focusing management efforts that could ultimately reduce *E. coli* concentrations and potential waterborne diseases (Davis et al., 2005; Gentry et al., 2006; MSS, 2022). The State of Missouri has two *E. coli* concentration criteria for waters designated for whole body contact. Class A streams are designated recreational specifically for swimming, while Class B streams as designated for recreation but not specifically for swimming. The criteria value for Class A streams is 126 colony forming units (CFUs)/100 mL and 206 CFUs/100 mL for Class B streams as a geometric mean over the recreational season, which is April 1st-October 30th. Lake Taneycomo, Roark Creek, Bear Creek, and Bull Creek are Class A streams and Fall Creek, Turkey Creek, Silver Creek, and Coon Creek are Class B streams. Also, the IDEXX method used for this study reports as Most Probable Number (MPN)/100 mL and is interchangeable with CFUs for water quality comparisons at the screening level (Buckalew et al. 2006).

E. coli results show that only one site, site 10 (Fall Creek), does not meet the state whole-body contact criteria, but higher levels of bacteria can be found in the urban areas of the watershed, but these higher levels do not appear to extend into the lake. For 11 of the 13 sites the average *E. coli* concentrations were <100 MPN/100 mL for the entire year (Table 4 and Figure 7A). Site 8 (Roark Creek) had an average of 187 MPN/100 mL and site 10 (Fall Creek) had an average of 736 MPN/100 mL over samples collected throughout the year. However, over the recreational season, only Site 10 exceeded the whole-body contact criteria with a geometric mean of 455 MPN/100 mL. The sites within the reservoir had much lower *E. coli* values compared to the tributary sites suggesting the lake dilutes the inputs from the tributaries.

CONCLUSIONS

Lake Taneycomo is on the state of Missouri's impairment list for low DO and a TMDL has been developed to address the problem. While releases from Table Rock Dam are the main cause of low DO in the lake, the TMDL also suggests reduction of nutrients and sediment entering the lake from the portion of the watershed below Table Rock Dam would also help in improving the water quality in the lake. As part of the development of a watershed management plan designed to address nonpoint contributions of nutrients and sediment, a baseflow water quality monitoring study was conducted to assess the spatial distribution of nutrients, bacteria, and other typical water quality indicators within the watershed. A water quality monitoring network was established within the Lake Taneycomo-White River watershed and sampled seasonally over a 1-year timeframe. A total of 52 samples were collected over the sampling period from the 13 sites within the Lake Taneycomo-White River watershed. Stream sites are located near the outlet of the 10, HUC12 sub-watersheds within the larger HUC10 watershed. There are also three sites located on Lake Taneycomo. There are five main conclusions of this study:

1. **Rainfall over the monitoring period (2020-2021) was wetter compared to the 30-year average and total runoff and typical baseflow discharge was also elevated.** The average annual rainfall was 30.1 cm higher than the 30-year annual average that came mostly in the spring and early summer. This led to an elevated baseflow discharge that lasted from roughly November 2020 to July 2021. Annual average discharge for Water Year (WY) 2020 at this gage was >2 times higher than the overall average discharge from 1995-2021 and 33% higher in WY2021. While these rainfall and runoff patterns are high compared to the long-term average, recent studies suggest this may be a new normal as the frequency of high intensity rainfall events has increased since the early 2000s in the Ozarks.

2. **Physical water parameters (T, pH, SC, and DO) measured during sampling were generally lower and less variable at the lake sites compared to the stream sites.** Average DO for ranged from 6.6-9.4 mg/L stream sites and 6.8-7.6 mg/L for the lake sites. While the average DO readings were above the 6.0 mg/L limit for cold water fisheries, there were times in the summer and fall when DO was lower than 6.0 mg/L in the stream and lake. The

low variability at the lake sites is due to the relatively consistent inflow from Table Rock Dam that moderates these readings.

3. **Average concentrations of TP at three stream sites exceeded locally established eutrophic thresholds and two lake sites exceeded the TP criteria for Ozarks reservoirs**. Roark Creek, Lower Bull Creek, and Turkey Creek had average values greater than 0.075 mg/L, which is the eutrophic threshold established in the James River TMDL (MDNR, 2001). The James River is a major tributary of Table Rock Lake, and the watershed is located just west of the Lake Taneycomo-White River watershed over the divide. Average TP at these sites ranged from 0.08-0.16 mg/L. Turkey Creek has the highest average concentration (0.16 mg/L) and is also downstream of the Hollister wastewater treatment plant. Also, two of the three lake sites had average TP concentrations greater than the nutrient criteria screening value for Ozark Highland lakes. However, both sites are also downstream of the confluence with Turkey Creek.

4. **Sample sites within Lake Taneycomo all had average TN concentrations that exceeded the TN criteria for Ozarks reservoirs.** All three lake sites produced average TN concentrations greater than the nutrient criteria screening value for Ozark Highland lakes, which is 0.4 mg/L, and concentrations increased from upstream to downstream. Average TN at these sites ranged from 1.13-1.43 mg/L. Rainfall over the monitoring period was higher compared to the long-term average and may be partially responsible for higher TN values.

5. ***E. coli* results show that only one site, site 10 (Fall Creek), does not meet the state whole-body contact criteria, but higher levels of bacteria can be found in the urban areas of the watershed. These higher levels do not appear to extend into the lake.** Over the recreational season, only Site 10 exceeded the whole-body contact criteria with a geometric mean of 455 MPN/100 mL. The sites within the reservoir had much lower *E. coli* values compared to the tributary sites suggesting the lake dilutes the inputs from the tributaries.

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TABLES

Table 1. List of HUC12 watersheds within the Lake Taneycomo-White River Watershed with land use and sample site information.

HUC 12 #	HUC Name	Ad (km²)	% Urban	% Ag.	% Forest	% Other	Sample Site #	Type (S, L)
110100030104	Woods Fork	106.5	6.5	22.0	71.5	0.0	1	S
110100030105	Upper Bull Creek	146.6	3.5	24.5	71.8	0.2	2	S
110100030107	Middle Bull Creek	107.9	6.1	9.8	83.9	0.2	3	S
110100030106	Bear Creek	114.3	5.3	21.9	72.8	0.0	4	S
110100030108	Lower Bull Creek-Lake Taneycomo	46.9	16.7	12.0	69.0	2.3	5	S
110100030110	Silver Creek-Lake Taneycomo	46.2	16.2	13.8	60.2	9.8	6, 11	S, L
110100030109	Coon Creek-Lake Taneycomo	58.3	28.2	16.0	52.5	3.3	7, 12	S, L
110100030103	Roark Creek	98.1	19.8	9.7	70.2	0.3	8	S
110100030102	Turkey Creek	89.6	15.2	14.8	69.8	0.2	9	S
110100030101	Fall Creek-Lake Taneycomo	56.7	31.4	6.7	58.9	3.0	10, 13	S, L

HUC = Hydrological Unit Code
Ag = agriculture
S = stream site
L = lake site

Table 2. Mean annual discharge at Bull Creek and other nearby USGS gaging stations over the sampling period.

Site Name	USGS Gaging Station Number	Drainage Area (km²)	WY2020 Avg. Q (m³/s)	WY2021 Avg. Q (m³/s)	WY1995-2021 Avg. Q (m³/s)
Bull Creek near Walnut Shade	07053810	495	15.3	9.1	6.8

Table 3. Summary of physical water properties by site.

Site	Type (S, L)	n	Temp. (°C)			pH (std. units)			SC (µS/cm)			DO (mg/L)		
			Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	S	4	11.1	17.8	21.9	7.1	7.8	8.7	271	344	412	3.8	6.6	9.6
2	S	4	9.7	20.3	26.3	6.7	7.6	8.0	337	369	395	5.3	7.8	13.9
3	S	4	8.0	20.1	24.8	7.4	7.9	8.2	327	344	351	4.4	8.0	14.8
4	S	4	8.3	19.5	24.2	7.4	8.0	8.3	336	360	369	6.3	9.4	15.1
5	S	4	8.4	20.0	24.5	7.2	7.8	8.0	339	352	362	5.3	8.6	13.6
6	S	4	7.0	15.6	22.3	7.1	7.6	8.2	217	267	342	2.7	6.8	11.6
7	S	4	10.2	18.8	22.0	7.3	7.8	8.2	345	469	566	5.1	7.0	8.1
8	S	4	9.0	19.6	26.7	7.5	7.8	8.2	246	425	571	4.1	7.1	10.1
9	S	4	10.7	19.7	22.9	7.5	7.7	8.0	376	478	550	4.3	7.0	8.1
10	S	4	10.9	20.7	24.2	7.7	8.0	8.3	411	492	560	4.1	7.6	11.0
11	L	4	11.9	15.2	20.7	7.2	7.3	7.4	230	240	250	5.9	6.8	8.0
12	L	4	10.4	13.6	15.7	7.4	7.5	7.5	221	235	244	5.7	7.2	9.1
13	L	4	10.1	13.0	15.1	7.1	7.3	7.5	220	231	243	4.1	7.6	10.5

S = stream site
L = lake site
Temp. = temperature
SC = specific conductivity
DO = dissolved oxygen

Table 4. Summary of nutrients, chloride, TSS, and *E. coli* by site.

Site	Type (S, L)	n	TP (mg/L)			TN (mg/L)			Chloride (mg/L)			*E.coli* (MPN/100 mL)			TSS (mg/L)		
			Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	S	4	0.01	0.01	0.01	0.70	1.15	1.50	5.2	9.3	12.5	2.0	15.1	33.6	*0.25*	1.3	3.3
2	S	4	0.01	0.01	0.01	0.90	1.28	2.20	4.9	7.1	10.5	*0.5*	3.6	6.3	*0.25*	1.6	2.7
3	S	4	0.01	0.02	0.03	0.70	1.05	1.90	4.4	6.3	9.3	3.1	6.9	14.4	0.7	1.5	2.7
4	S	4	0.01	0.05	0.18	0.90	1.23	2.00	4.3	6.9	11.5	9.8	35.1	61	0.7	2.2	4.7
5	S	4	0.01	0.08	0.28	0.70	1.03	1.60	4.5	6.6	9.1	8.6	43.9	124	1.3	4.7	12.0
6	S	4	0.01	0.02	0.03	0.80	1.55	3.10	5.9	6.8	8.1	4.0	6.2	10.4	*0.25*	1.6	2.0
7	S	4	0.01	0.01	0.01	0.70	0.85	1.00	6.7	8.3	10.4	1.0	20.7	37	0.7	3.8	5.3
8	S	4	0.01	0.09	0.32	0.60	0.95	1.30	6.7	17.9	41.1	3.1	187.3	651	0.7	1.5	2.7
9	S	4	0.06	0.16	0.35	1.00	1.45	1.70	12.8	27.2	45.0	7.4	93.4	288	7.3	15.3	30.0
10	S	4	0.01	0.02	0.01	0.60	0.75	0.90	9.8	13.1	18.8	5.2	736.0	1,733	1.3	2.8	5.3
11	L	4	0.01	0.02	0.02	0.90	1.43	2.20	6.1	6.5	7.1	6.3	11.1	17.3	1.3	2.8	3.3
12	L	4	0.01	0.03	0.08	0.90	1.25	1.60	5.8	7.5	11.2	8.5	14.8	24.4	0.7	1.9	2.7
13	L	4	0.01	0.01	0.01	0.90	1.13	1.30	5.3	5.7	5.9	4.1	25.3	52.8	0.7	1.3	2.0

S = stream site
L = lake site
TP = total phosphorus
TN = total nitrogen
E. coli = Escherichia coli
TSS = total suspended solids
Italic = ½ detection limit

FIGURES

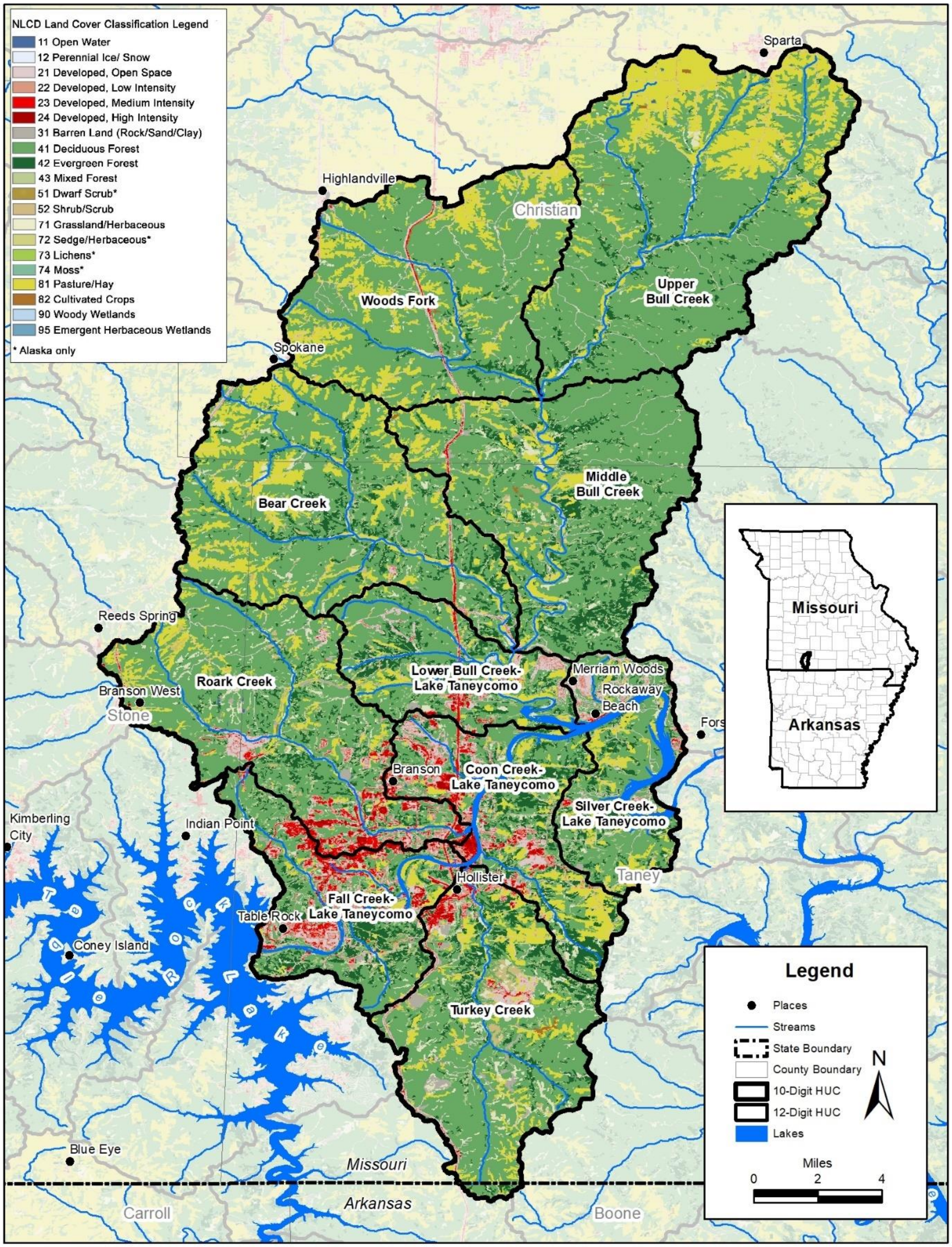

Figure 1. Lake Taneycomo-White River Land Use (NLCD 2016).

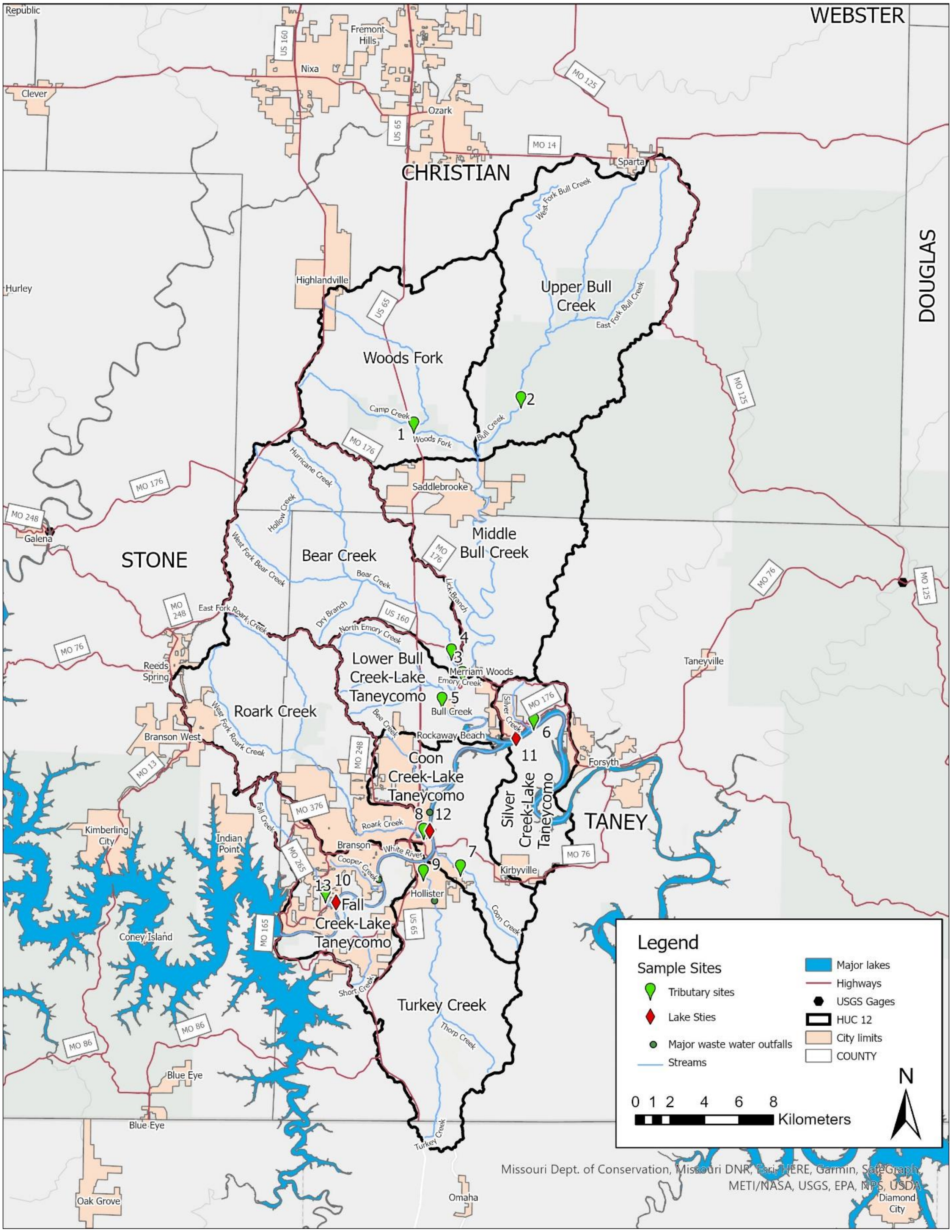

Figure 2. Lake Taneycomo-White River watershed sampling sites, wastewater outflows and USGS gages.

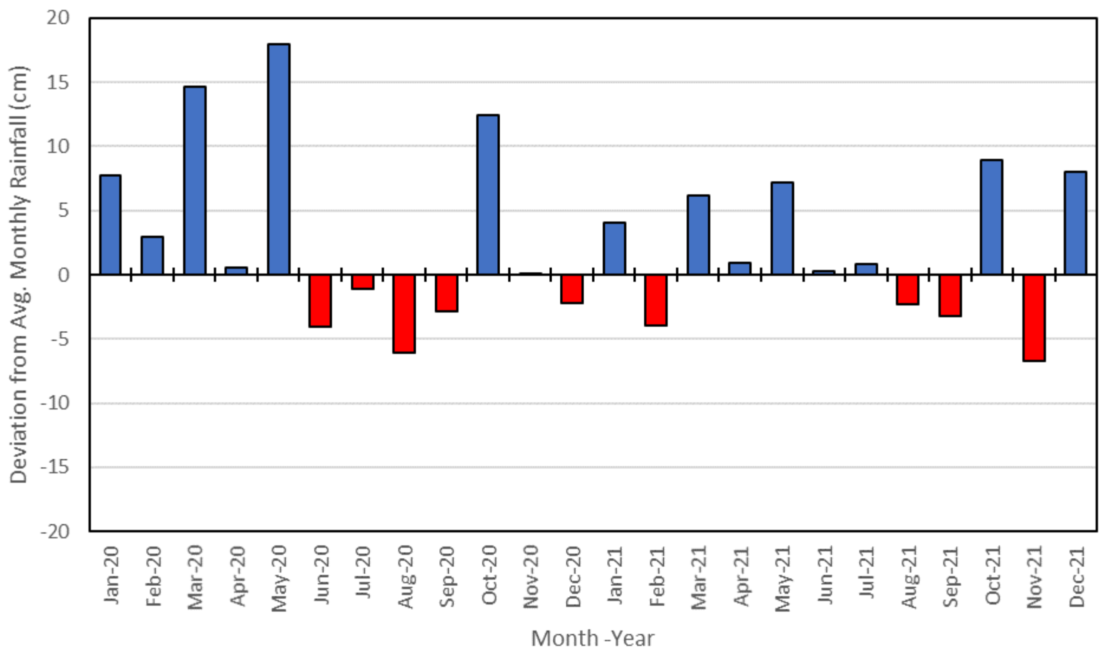

Figure 3. Departure from mean monthly rainfall (30-yrs) over the sampling period.

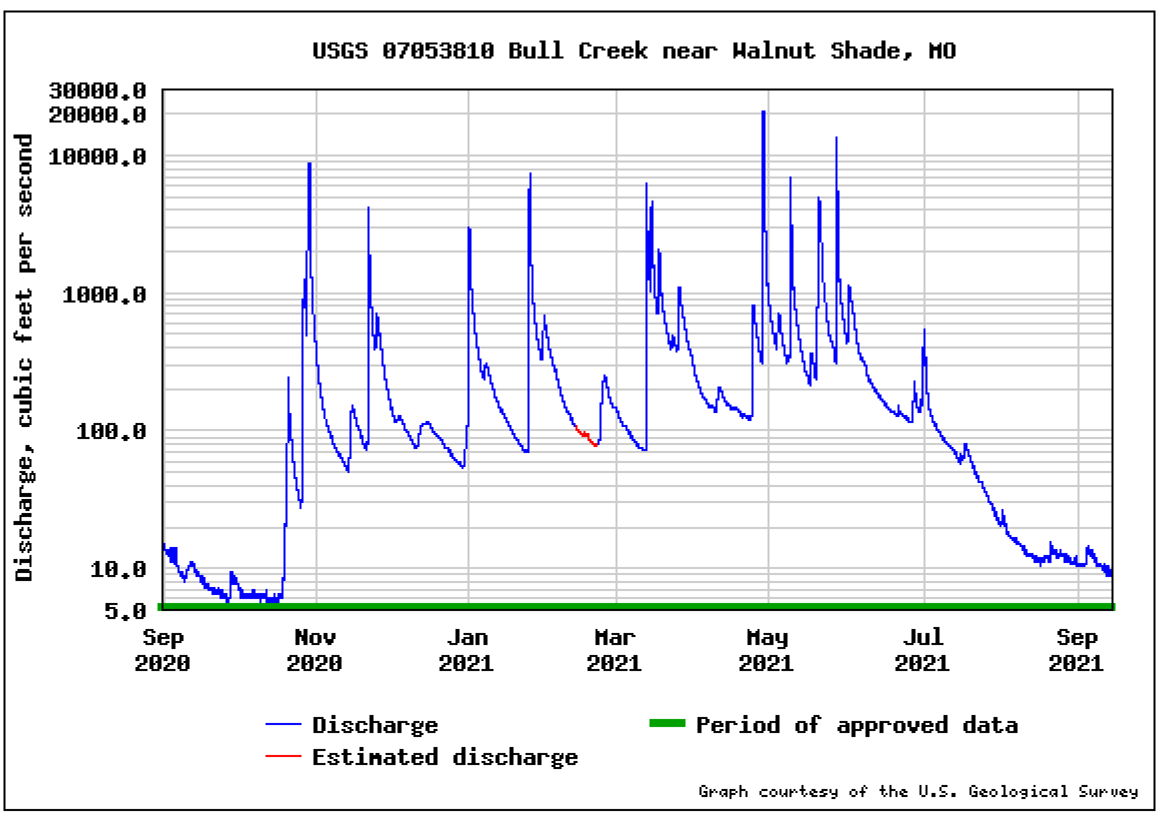

Figure 4 Instantaneous discharge from September 1, 2020 to September 30, 2021 from the USGS gaging stations used for this study. Sample site 5 was located near the Bull Creek gage.

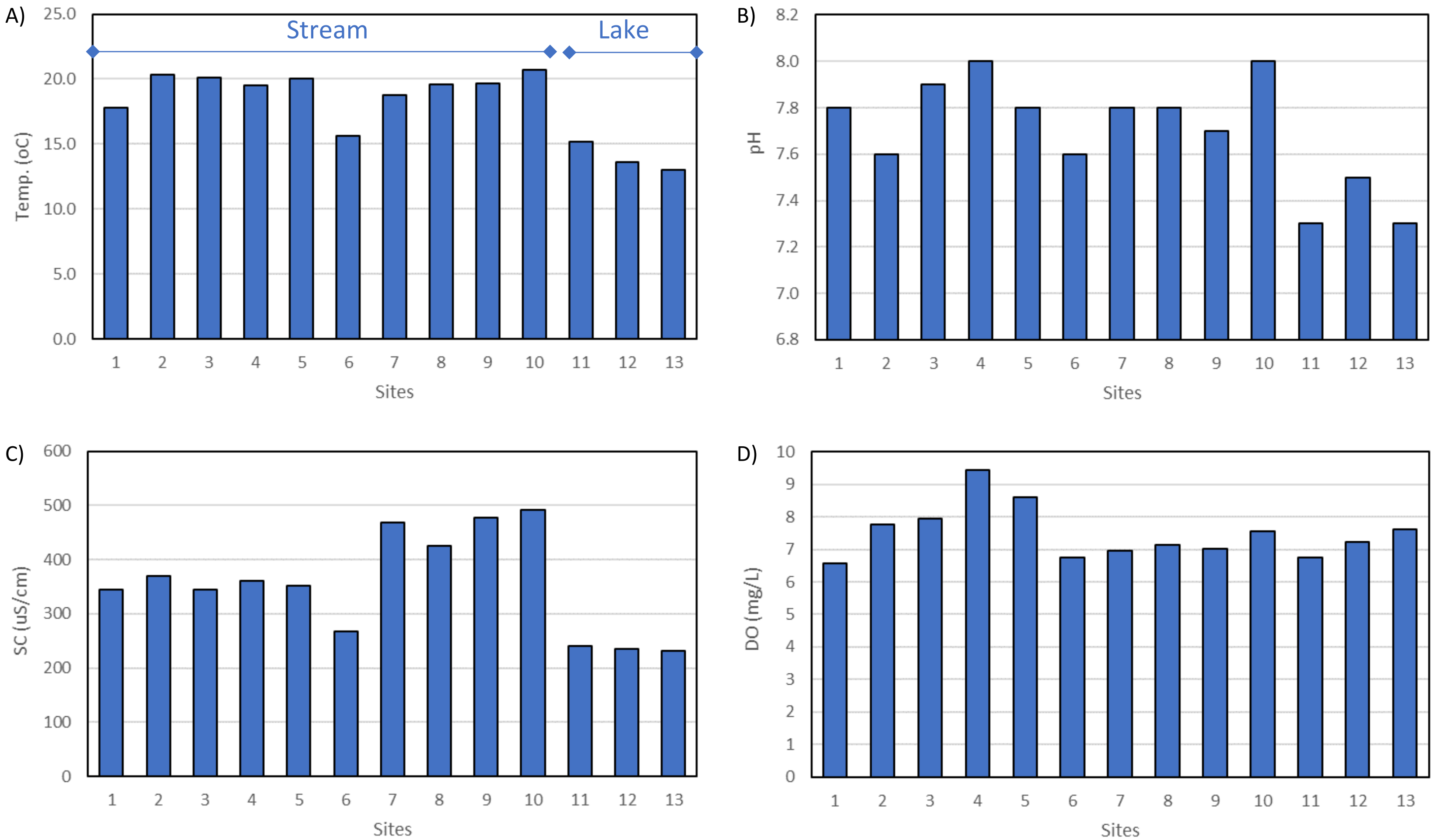

Figure 5. Average (n=4) A) temperature, B) pH, C) SC, and D) DO by site.

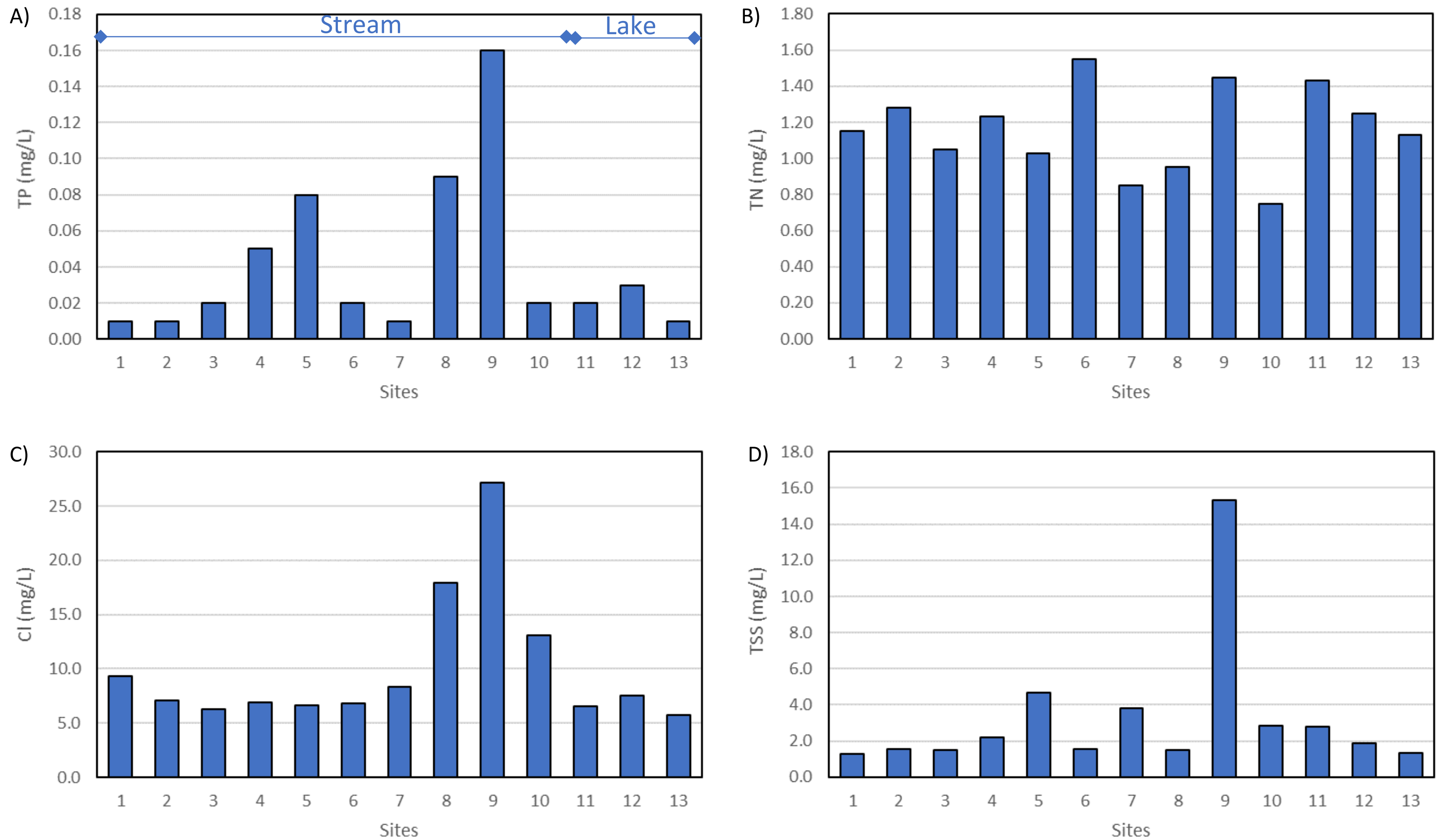

Figure 6. Average (n=4) A) TP, B) TN, C) chloride, and D) TSS by site.

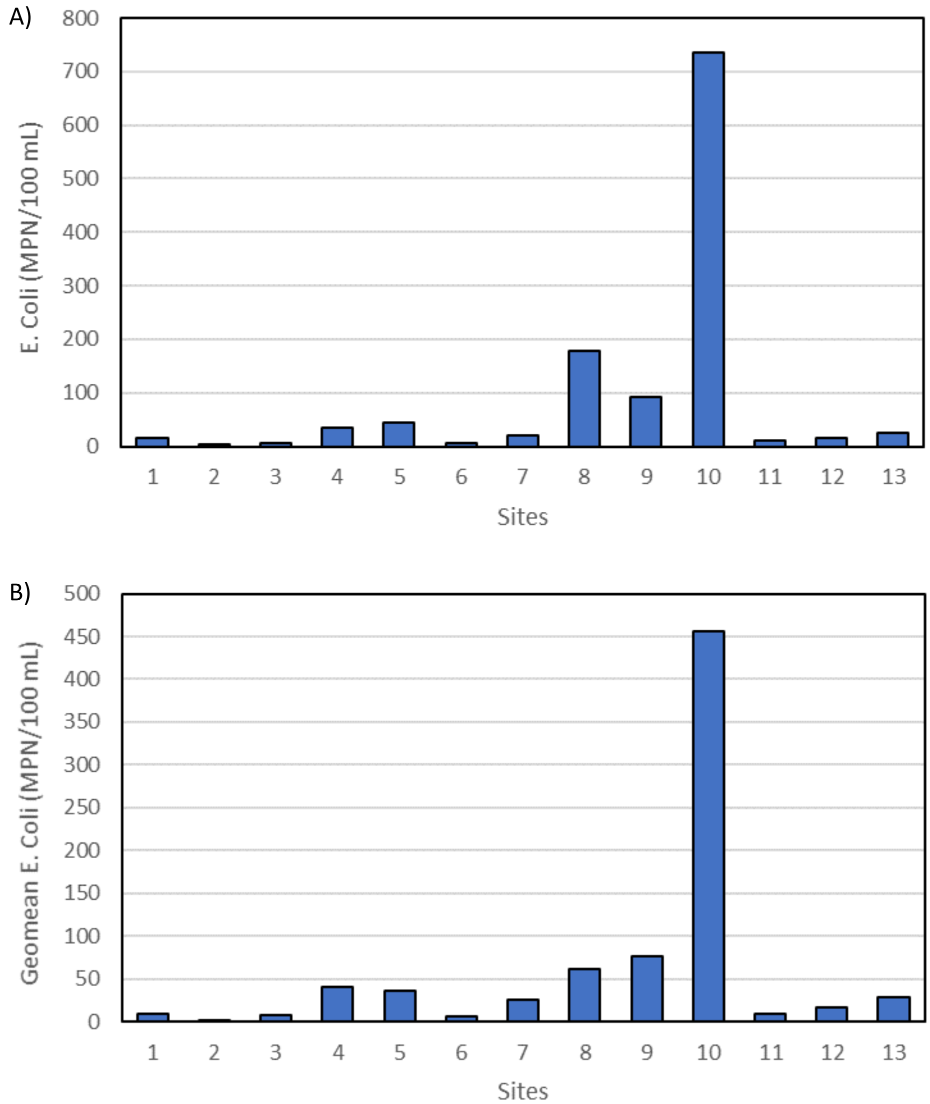

Figure 7. A) Average *E. coli* over the sampling period (n=4) and B) geometric mean of *E. coli* during the recreational season (n=3).

APPENDIX A - WATER QUALITY DATA BY SITE

Table 3. Total Phosphorus by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0
2	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	40
3	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.03	0.01	66.67
4	0.01	0.01	0.01	0.18	0.05	0.01	0.01	0.18	0.09	161.90
5	0.01	0.01	0.01	0.28	0.08	0.01	0.01	0.28	0.14	174.19
6	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.03	0.01	68.64
7	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	15.71
8	0.32	0.01	0.01	0.01	0.09	0.01	0.01	0.32	0.15	176.81
9	0.35	0.06	0.12	0.11	0.16	0.12	0.06	0.35	0.13	80.31
10	0.03	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	66.67
11	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.00	30.62
12	0.08	0.02	0.01	0.01	0.03	0.02	0.01	0.08	0.03	112.22
13	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	4.88
Overall Mean and Median					**0.04**	**0.01**				
Tributary (Sites 1 - 10) Mean and Median					**0.04**	**0.01**				
Reservoir (Sites 11-13) Mean and Median					**0.04**	**0.02**				

Table 4. Total Nitrogen (mg/L) by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	1.50	0.90	0.70	1.50	1.15	1.20	0.70	1.50	0.41	35.85
2	0.90	0.90	1.10	2.20	1.28	1.00	0.90	2.20	0.62	48.93
3	0.90	0.70	0.70	1.90	1.05	0.80	0.70	1.90	0.57	54.71
4	1.10	0.90	0.90	2.00	1.23	1.00	0.90	2.00	0.53	42.87
5	1.00	0.80	0.70	1.60	1.03	0.90	0.70	1.60	0.40	39.33
6	1.30	0.80	1.00	3.10	1.55	1.15	0.80	3.10	1.05	67.97
7	1.00	0.70	0.70	1.00	0.85	0.85	0.70	1.00	0.17	20.38
8	1.20	0.60	0.70	1.30	0.95	0.95	0.60	1.30	0.35	36.97
9	1.70	1.00	1.60	1.50	1.45	1.55	1.00	1.70	0.31	21.44
10	0.80	0.60	0.70	0.90	0.75	0.75	0.60	0.90	0.13	17.21
11	1.50	0.90	1.10	2.20	1.43	1.30	0.90	2.20	0.57	40.26
12	1.60	0.90	1.00	1.50	1.25	1.25	0.90	1.60	0.35	28.10
13	1.30	0.90	1.00	1.30	1.13	1.15	0.90	1.30	0.21	18.32
Overall Mean and Median					**1.16**	**1.00**				
Tributary (Sites 1 - 10) Mean and Median					**1.13**	**0.98**				
Reservoir (Sites 11-13) Mean and Median					**1.27**	**1.25**				

Table 5. ***E. coli*** **(MPN/100mL) by Site**

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	33.60	12.40	12.40	2.00	15.10	12.40	2.00	33.60	13.27	87.89
2	0.00	6.30	6.20	2.00	3.63	4.10	0.00	6.30	3.14	86.60
3	14.40	3.10	4.00	6.00	6.88	5.00	3.10	14.40	5.16	75.07
4	48.10	9.80	61.00	21.60	35.13	34.85	9.80	61.00	23.54	67.01
5	12.00	8.60	31.00	124.00	43.90	21.50	8.60	124.00	54.30	123.69
6	4.10	6.30	10.40	4.00	6.20	5.20	4.00	10.40	2.99	48.30
7	15.60	1.00	37.00	29.00	20.65	22.30	1.00	37.00	15.80	76.50
8	90.90	3.10	4.00	651.00	187.25	47.45	3.10	651.00	311.90	166.57
9	35.00	7.40	43.20	288.00	93.40	39.10	7.40	288.00	130.63	139.87
10	1732.90	5.20	47.00	1158.80	735.98	602.90	5.20	1732.90	852.71	115.86
11	6.30	17.30	10.40	10.40	11.10	10.40	6.30	17.30	4.56	41.11
12	15.80	8.50	10.40	24.40	14.78	13.10	8.50	24.40	7.12	48.21
13	52.80	4.10	14.80	29.60	25.33	22.20	4.10	52.80	21.09	83.28
Overall Mean and Median					**92.25**	**21.50**				
Tributary (Sites 1 - 10) Mean and Median					**114.81**	**21.90**				
Reservoir (Sites 11-13) Mean and Median					**17.07**	**13.10**				

Table 6. Monthly Total Suspended Solids by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	3.30	*0.25*	1.33	*0.25*	1.16	0.67	0.00	3.30	1.56	134.76
2	1.30	2.70	2.00	*0.25*	1.50	1.65	0.00	2.70	1.15	76.79
3	0.70	2.00	2.67	0.67	1.51	1.35	0.67	2.67	0.99	65.64
4	2.70	0.70	0.67	4.67	2.19	1.70	0.67	4.67	1.91	87.40
5	1.30	2.70	2.67	12.00	4.67	2.69	1.30	12.00	4.93	105.66
6	2.00	*0.25*	2.00	2.00	1.50	2.00	0.00	2.00	1.00	66.67
7	5.30	0.70	5.33	4.00	3.83	4.65	0.70	5.33	2.18	56.84
8	2.70	0.70	1.33	1.33	1.52	1.33	0.70	2.70	0.84	55.71
9	7.30	16.70	30.00	7.33	15.33	12.02	7.30	30.00	10.73	70.00
10	5.30	1.30	2.00	2.67	2.82	2.34	1.30	5.30	1.75	62.00
11	3.30	1.30	3.30	3.33	2.81	3.30	1.30	3.33	1.01	35.80
12	2.70	2.70	1.33	0.67	1.85	2.02	0.67	2.70	1.02	55.02
13	1.30	1.30	2.00	0.67	1.32	1.30	0.67	2.00	0.54	41.24
Overall Mean and Median					**3.23**	**2.00**				
Tributary (Sites 1 - 10) Mean and Median					**3.60**	**1.85**				
Reservoir (Sites 11-13) Mean and Median					**1.99**	**2.02**				

Table 7. Monthly Specific Conductivity (mS/cm) by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	376.90	316.50	271.20	412.40	344.25	346.70	271.20	412.40	62.76	18.23
2	394.80	337.10	358.40	385.20	368.88	371.80	337.10	394.80	26.19	7.10
3	350.40	327.30	348.80	351.20	344.43	349.60	327.30	351.20	11.46	3.33
4	368.80	336.10	364.30	369.20	359.60	366.55	336.10	369.20	15.82	4.40
5	339.30	344.60	362.20	360.00	351.53	352.30	339.30	362.20	11.30	3.22
6	266.70	342.00	240.80	216.60	266.53	253.75	216.60	342.00	54.32	20.38
7	523.40	442.20	345.10	566.00	469.18	482.80	345.10	566.00	97.36	20.75
8	246.10	417.00	467.40	571.00	425.38	442.20	246.10	571.00	135.62	31.88
9	550.00	486.20	376.40	499.10	477.93	492.65	376.40	550.00	73.07	15.29
10	560.00	472.00	525.00	411.40	492.10	498.50	411.40	560.00	64.83	13.17
11	241.80	240.20	249.50	230.40	240.48	241.00	230.40	249.50	7.85	3.26
12	231.60	244.10	243.90	220.60	235.05	237.75	220.60	244.10	11.27	4.79
13	228.00	242.90	235.20	219.50	231.40	231.60	219.50	242.90	10.00	4.32
Overall Mean and Median					**354.36**	**352.30**				
Tributary (Sites 1 - 10) Mean and Median					**389.98**	**369.18**				
Reservoir (Sites 11-13) Mean and Median					**235.64**	**237.75**				

Table 8. Temperature (C) by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	21.90	11.10	18.10	19.90	17.75	19.00	11.10	21.90	4.70	26.46
2	23.20	9.70	26.30	22.00	20.30	22.60	9.70	26.30	7.30	35.94
3	24.80	8.00	23.40	24.30	20.13	23.85	8.00	24.80	8.10	40.27
4	24.20	8.30	22.00	23.40	19.48	22.70	8.30	24.20	7.51	38.54
5	24.50	8.40	22.60	24.30	19.95	23.45	8.40	24.50	7.75	38.83
6	22.30	7.00	16.10	17.00	15.60	16.55	7.00	22.30	6.35	40.72
7	21.50	10.20	22.00	21.30	18.75	21.40	10.20	22.00	5.71	30.44
8	16.90	9.00	26.70	25.80	19.60	21.35	9.00	26.70	8.34	42.53
9	22.80	10.70	22.40	22.90	19.70	22.60	10.70	22.90	6.00	30.48
10	24.20	10.90	24.20	23.30	20.65	23.75	10.90	24.20	6.51	31.54
11	20.70	12.10	11.90	16.10	15.20	14.10	11.90	20.70	4.15	27.27
12	15.60	12.50	10.40	15.70	13.55	14.05	10.40	15.70	2.57	18.98
13	15.10	12.80	10.10	13.90	12.98	13.35	10.10	15.10	2.13	16.45
Overall Mean and Median					**17.97**	**21.40**				
Tributary (Sites 1 - 10) Mean and Median					**19.19**	**22.60**				
Reservoir (Sites 11-13) Mean and Median					**13.91**	**14.05**				

Table 9. pH by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	7.72	7.74	8.73	7.11	7.83	7.73	7.11	8.73	0.67	8.57
2	7.65	7.98	7.94	6.74	7.58	7.80	6.74	7.98	0.58	7.62
3	8.06	8.19	8.06	7.40	7.93	8.06	7.40	8.19	0.36	4.50
4	8.21	8.28	8.06	7.40	7.99	8.14	7.40	8.28	0.40	5.04
5	7.86	7.96	7.99	7.19	7.75	7.91	7.19	7.99	0.38	4.87
6	7.44	7.60	8.16	7.09	7.57	7.52	7.09	8.16	0.45	5.89
7	7.73	8.18	7.77	7.30	7.75	7.75	7.30	8.18	0.36	4.64
8	7.47	8.20	7.84	7.75	7.82	7.80	7.47	8.20	0.30	3.85
9	7.87	7.55	8.03	7.47	7.73	7.71	7.47	8.03	0.26	3.42
10	7.70	8.31	8.07	7.99	8.02	8.03	7.70	8.31	0.25	3.14
11	7.44	7.39	7.18	7.35	7.34	7.37	7.18	7.44	0.11	1.54
12	7.45	7.54	7.47	7.44	7.48	7.46	7.44	7.54	0.05	0.60
13	7.23	7.40	7.46	7.06	7.29	7.32	7.06	7.46	0.18	2.47
Overall Mean and Median					**7.70**	**7.75**				
Tributary (Sites 1 - 10) Mean and Median					**7.79**	**7.80**				
Reservoir (Sites 11-13) Mean and Median					**7.37**	**7.37**				

Table 10. Dissolved Oxygen (mg/L) by Site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	4.61	9.55	8.33	3.84	6.58	6.47	3.84	9.55	2.79	42.31
2	6.38	13.92	5.42	5.33	7.76	5.90	5.33	13.92	4.13	53.24
3	7.59	14.75	4.37	5.07	7.95	6.33	4.37	14.75	4.74	59.69
4	8.70	15.08	7.66	6.26	9.43	8.18	6.26	15.08	3.90	41.38
5	7.13	13.62	8.32	5.33	8.60	7.73	5.33	13.62	3.57	41.46
6	3.02	9.70	11.62	2.70	6.76	6.36	2.70	11.62	4.57	67.65
7	6.23	8.40	8.06	5.11	6.95	7.15	5.11	8.06	1.55	22.35
8	4.05	10.12	7.76	6.58	7.13	7.17	4.05	10.12	2.52	35.43
9	4.32	8.13	7.85	7.80	7.03	7.83	4.32	8.13	1.81	25.75
10	4.05	10.99	9.21	5.93	7.55	7.57	4.05	10.99	3.13	41.54
11	6.42	7.99	6.79	5.85	6.76	6.61	5.85	7.99	0.91	13.38
12	5.71	6.36	9.13	7.77	7.24	7.07	5.71	9.13	1.52	21.04
13	5.55	10.24	10.51	4.14	7.61	7.90	4.14	10.51	3.25	42.66
Overall Mean and Median					**7.49**	**7.15**				
Tributary (Sites 1 - 10) Mean and Median					**7.57**	**7.16**				
Reservoir (Sites 11-13) Mean and Median					**7.21**	**7.07**				

Table 11. Chloride by site

Site Number	Fall	Winter	Spring	Summer	Mean	Median	Min	Max	Standard Dev.	CV%
1	12.49	7.15	5.23	12.25	9.28	9.70	5.23	12.49	3.65	39.37
2	7.86	4.97	4.85	10.54	7.05	6.41	4.85	10.54	2.71	38.38
3	6.27	5.09	4.42	9.30	6.27	5.68	4.42	9.30	2.16	34.43
4	6.74	5.04	4.29	11.54	6.90	5.89	4.29	11.54	3.25	47.17
5	7.29	5.49	4.45	9.14	6.59	6.39	4.45	9.14	2.07	31.35
6	6.91	5.91	6.36	8.10	6.82	6.64	5.91	8.10	0.94	13.85
7	10.40	6.73	7.43	9.77	8.58	8.60	6.73	10.40	1.78	20.70
8	16.19	6.68	7.48	41.14	17.87	11.83	6.68	41.14	16.10	90.09
9	45.00	12.82	15.36	35.60	27.19	25.48	12.82	45.00	15.65	57.55
10	13.94	9.75	10.01	18.79	13.12	11.97	9.75	18.79	4.24	32.28
11	6.10	6.16	6.72	7.08	6.52	6.44	6.10	7.08	0.47	7.17
12	11.19	6.69	5.82	6.42	7.53	6.55	5.82	11.19	2.47	32.75
13	5.25	5.60	5.85	5.91	5.65	5.72	5.25	5.91	0.30	5.30
Overall Mean and Median					**9.95**	**6.55**				
Tributary (Sites 1 - 10) Mean and Median					**10.97**	**7.62**				
Reservoir (Sites 11-13) Mean and Median					**6.57**	**6.44**				