**West Boggs Lake Watershed Diagnostic Study**

Prepared by

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**List of Acronyms**

| | |
|---|---|
| BMP | Best Management Practices |
| CFO | Confined Feeding Operation |
| CFS | Cubic Feet Per Second |
| DNR | Indiana Department of Natural Resources |
| ECI | Ecosystems Connections Institute |
| HUC | Hydrologic Unit Code |
| HRT | Hydraulic Residency Time |
| IBI | Index of Biotic Integrity |
| IDEM | Indiana Department of Environmental Management |
| INCLP | Indiana Clean Lake Program |
| ISDA | Indiana Department of Agriculture |
| LUST | Leaking Underground Storage Tank |
| MPN | Most Probable Number |
| NPDES | National Pollution Discharge Elimination System |
| NPS | Nonpoint Source |
| TKN | Total Kjeldahl Nitrogen |
| TSI | Carlson Trophic State Index |
| TSS | Total Suspended Solids |
| QAPP | Quality Assurance Project Plan |
| QHEI | Qualitative Habitat Evaluation Index |

**Executive Summary**

West Boggs Lake is a 622-Acre reservoir located in Southwestern Indiana and just north of the Town of Loogootee. The lake has year-round and summertime residents, as well as West Boggs Park on the eastern shore that includes a campground and boat launch accessible via a fee. The lake is popular location for boating, fishing, and swimming. In fact, West Boggs Lake has gained a reputation as being an excellent lake for sport fishing. Like many lakes and impounded waters across Indiana, West Boggs Lake has and continues to experience the acute and chronic ecological effects of a too many nutrients (most notably Phosphorus) and sediment entering the lake.

As Europeans colonized what is now Indiana, vast landscape-level ecological changes occurred with clearing of forests and draining wetlands in response to a rapidly changing cultural shift as agriculture and urban areas became the predominant land use. As cities and towns were charted and farms expanded there was little to no thought about the negative externalities of indiscriminate water pollution associated with this changing landscape. While there have been significant advances to address point source pollutants from urban areas with wastewater treatment plants, nutrients and sediment from nonpoint sources continue to be a significant challenge for the ecological integrity of lakes and streams. The amount of nutrients and sediment being delivered to lakes and streams far exceed the ability of these aquatic ecosystems to assimilate them. There is much work to do. Simply put, elevated levels of nutrients and sediment is the single greatest threat to the health of lakes and streams. Regardless of the source of nutrients and sediment, there is a predictable cascade of ecological responses in lakes that includes excessive aquatic plants, algal blooms, hypoxia[1], and reduced water clarity. These ecological responses also include an increased probability of unpredictable toxic Cyanobacteria (blue green algae) that limit recreational opportunities, cause illness in humans and pets, and negatively affect property values. Excess quantities of nutrients and sediment can elevate any lake to eutrophic or hypereutrophic status with "pea soup" colored water as an acute response or through a slow, chronic accumulation of nutrients and sediment.

[1] Hypoxia is dissolved oxygen in a lake below a concentration, 2 mg/L, that will support fish and other important organisms.

Every lake or Reservoir has the capacity to reach an "ecological tipping point" that will compromise water quality from excessive nutrients and sediment. Perhaps one of best examples is the western basin of Lake Erie where toxic algal blooms occur on an annual basis and water quality is significantly compromised. It is important to understand this same ecological response can occur and is far too common in Indiana glacial lakes and impoundments like West Boggs Lake. Ecological response of a lake to nutrient and sediment pollution is measured as trophic status. Very clean lakes are considered Oligotrophic (low nutrients and sediment) and waterbodies with high amounts of nutrients and sediment are considered eutrophic or hypereutrophic. Unfortunately, West Boggs Lake is a prime example of the effects of unmitigated chronic nutrient pollution causing the lake to become hypereutrophic with "pea soup" colored water in the summer months that compromises use of the lake for recreation. West Boggs Lake has been considered one of the best fishing lakes in Southern Indiana, but over time there have had to be multiple fisheries renovations along with regular occurrence of summer-time blue green algal blooms which negatively affect the use of the lake. Harmful Algal Blooms (HAB) have become a regular occurrence and the lake must periodically be closed in the summer months. Multiple projects have been completed to assess the quality of West Boggs Lake including the creation of sediment basins at inlet streams and bank erosion mitigation. These projects may have resulted in a temporary improvement in water quality, but the lake has remained hypereutrophic, and conditions have worsened and is focus of this study.

To better understand lake and watershed conditions and dynamics, Ecosystems Connections Institute, LLC (ECI) was contracted to complete a IDNR Lake and River Enhancement Watershed Diagnostic Study. The study summarized previous work completed on West Boggs Lake and its watershed. Data on the watershed was collected using publicly available sources and analyzed using computer-based mapping software. Water quality data was collected by conducting two rounds of water sampling, one in 2021 and one in 2022, at 14 tributary sites and 3 lake sites (Figure 1). Water samples were analyzed for Nitrogen, Phosphorus, and Total Suspended Solids (Sediment). Water samples from tributary sites was also evaluated for *Escherichia coli* (*E. coli*), and stream habitat and fish community structure and function. Sample concentrations were compared to water quality target values for the region (Table 1). In short West Boggs Lake has an extraordinary nutrient loading challenge and is in the most severe trophic state of hyper eutrophication.

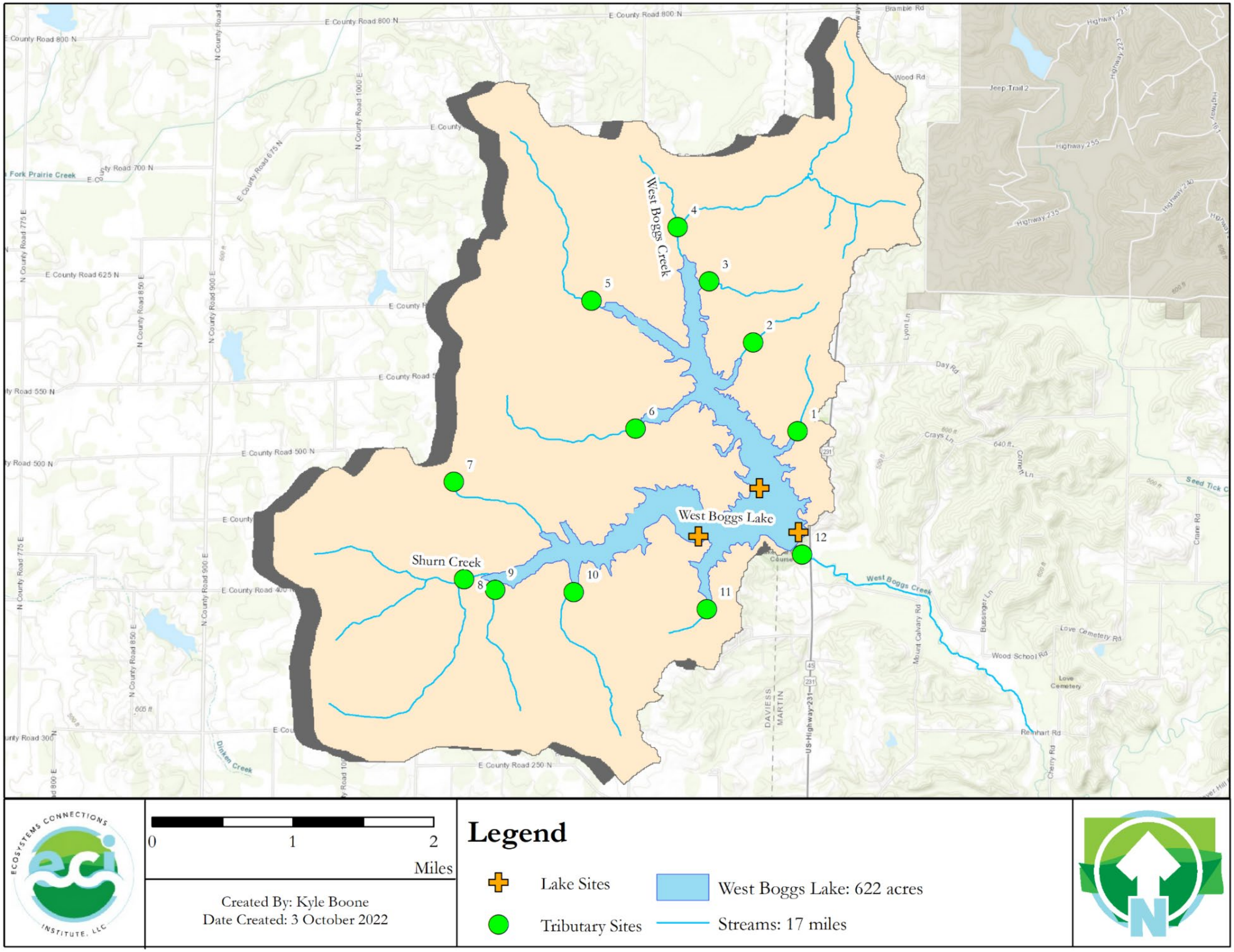


Figure 1. The fourteen tributary and three lake sample sites at West Boggs Lake 2021-2022. Watershed area is 8,439-Acres.

Table 1. Water quality target values for Nitrogen, Phosphorus, and Total Suspended Solids for the Interior River Valleys and Hills Ecoregion.

| Parameter | Description | Water Quality Standard for Interior River Valleys and Hills |
|---|---|---|
| Nitrate+Nitrite-Nitrogen ($NO_3^-$) | Nitrate-N (mg/L) | 0.2 mg/L |
| Total Kjeldahl Nitrogen | sum of organic nitrogen and ammonia (mg/L) | 0.54 mg/L |
| Total Nitrogen | sum of all forms of nitrogen-inorganic (nitrite, nitrate and ammonia) and organic nitrogen (mg/L) | 1.7 mg/L |
| Soluble Reactive Phosphorus | Inorganic form of phosphorus | 0.005 mg/L or 5 µg/L[2] |
| Total Phosphorus | All forms of phosphorus, soluble reactive or non-reactive (mg/L or µg/L) | 0.031 mg/L or 31 µg/L[2] |
| Total Suspended Sediment | Dry weight of filtered solids gravimetrically (mg/L) | 25 mg/L |

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[2] The soluble reactive phosphorus and Total Phosphorus target values for this study are derived from the more conservative values of the Southern Michigan, Northern Indiana Till Plains target values.

Data from the water quality assessment suggests water quality across all tributaries and the lake itself is severely degraded with high concentrations of Phosphorus and Nitrogen that exceeded target values at all sites on two sampling dates (2021-2022). Site 7 had the highest nutrient concentrations and *E. coli* concentrations and exceeded the targets in 80% of samples. Biological and habitat data indicated that tributaries are also biologically degraded. The fish community at eight of nine sites were ranked as "Poor" with stream habitat more variable, ranking from "Very Poor" to "Good."

The Hydraulic Residency Time for West Boggs was 0.62-years (time it takes to replace all water in the lake) and had a Flushing Rate was 1.61 times (water volume replaced each year). Phosphorus and Nitrogen exceeded target values at all three lake sample sites and depths during two sample dates in 2021 and 2022 and data suggests Phosphorus is the most important water quality parameter and responsible for the excessive plant and algal growth. Nitrogen to Phosphorus ratio (N:P) was calculated as 11:1 and verified Phosphorus as the limiting nutrient in West Boggs Lake. This N:P ratio is also relatively low. This low ratio is known to favor Harmful Algal Blooms (HAB) or toxic blue green algae during summer months. Toxins from these HAB make the lake unsafe for recreational use and can have a severe effect on dogs.

The target or desired Phosphorus load in the lake was calculated as 2,655 pounds. The actual Phosphorus load was calculated as 24,322 pounds or a 160% difference. Phosphorus loading needs to be reduced by 21,668 pounds per year to bring West Boggs Lake into ecological compliance.

These calculations are based on only two samples and should be viewed as provisional. There is a critical need to begin a more robust scientific study of each tributary and the lake itself with more samples. This type of study will identify and quantify more accurately the tributary or tributaries that contribute the most nutrients and sediment to the lake. This data is fundamental to communicate with stakeholders across the basin and lead to a reduction in nutrient loadings through a holistic watershed restoration design. Restoration must include a cooperative strategy with all stakeholders along with an aggressive Phosphorus sequestration project. The Phosphorus sequestration in the lake in concert with conservation strategies to reduce loadings will improve water quality in the lake over an approximate 5-year period. Water quality assessment should continue consistently across this time to document changes in nutrient and sediment loadings and subsequent lake improvement. West Boggs Lake is a tremendous resource for Indiana and for the local economy. It should never have to be closed because of Harmful Algal Blooms.

## Introduction and Project Purpose

West Boggs Lake was created in 1971 when the United States Department of Agriculture, Soil Conservation Service built a dam for the purpose of flood control and sediment retention under Public Law 566. The primary purpose of the lake was to serve as a large sediment trap. The resulting waterbody is a dimictic ("turns over" once in the fall and spring) reservoir in Southwestern Indiana with a surface area of 622-Acres and a watershed of 8,439-Acres in Daviees and Martin Counties, resulting in a watershed to lake ratio of 13.6:1(Figure 2). The lake and watershed are within the Interior River Valleys and Hills ecoregion. This ecoregion is defined by wide, flat bottomed, terraced valleys, forested valley slopes, and dissected glacial-till plains. Less land is dedicated to cultivated crop agriculture in this ecoregion when compared to adjacent regions. Approximately half of the land area is dedicated to cultivated crops, 30 percent to pasture, and remaining land is forested. In pre-development conditions, deciduous forest and forested swamps were common on lowlands with mixed oak and oak-hickory forests on uplands.

After its creation in 1971, West Boggs Lake gained a reputation for providing excellent recreational opportunities. However, water quality in the reservoir quickly degraded due to cultural eutrophication caused by human induced water pollution that causes a lake to age more rapidly (become more eutrophic) by exceeding the lakes capacity to assimilate nutrients and sediment. Sources of pollution can vary but, in many instances, the main culprit is nonpoint source (NPS) pollution. While NPS pollution is diffuse and occurs on a large spatial scale, the cumulative effects to receiving waterbodies can be severe. West Boggs Lake is a textbook example of cultural eutrophication driven by NPS pollution causing an acute response in water quality. In its current state, West Boggs Lake experiences regular summertime Harmful Algal Blooms (HAB) that hinder the use of the lake. Additionally, the fishery of the lake has gone through two total renovations due to Gizzard Shad (*Dorosoma cepedianum*) becoming overly abundant in the lake. Predatory fish favor Gizzard Shad to small Bluegills causing an overabundance of small Bluegills. Both the HAB and state of the fishery suggest that West Boggs Lake has become degraded overtime.

It is known that chronic, unmitigated NPS pollution from the watershed is the main cause of water quality degradation in West Boggs Lake. However, the watershed and tributaries of West Boggs Lake have never been fully studied. This Watershed Diagnostic Study was conducted to better understand West Boggs Lake and its watershed by utilizing previous studies, publicly available data sources, and collected water quality data. Water samples were collected from each of 14 tributaries of West Boggs Lake to measure their individual contribution and estimate cumulative load of pollutants coming into West Boggs Lake. This information was used to identify sources of pollution in the watershed and prioritize watershed improvement projects albeit with an extremely low sample size. Having strong, science-based information on the quality of West Boggs Lake and its watershed will help guide future work and provide background data to compare progress of restoration projects against.

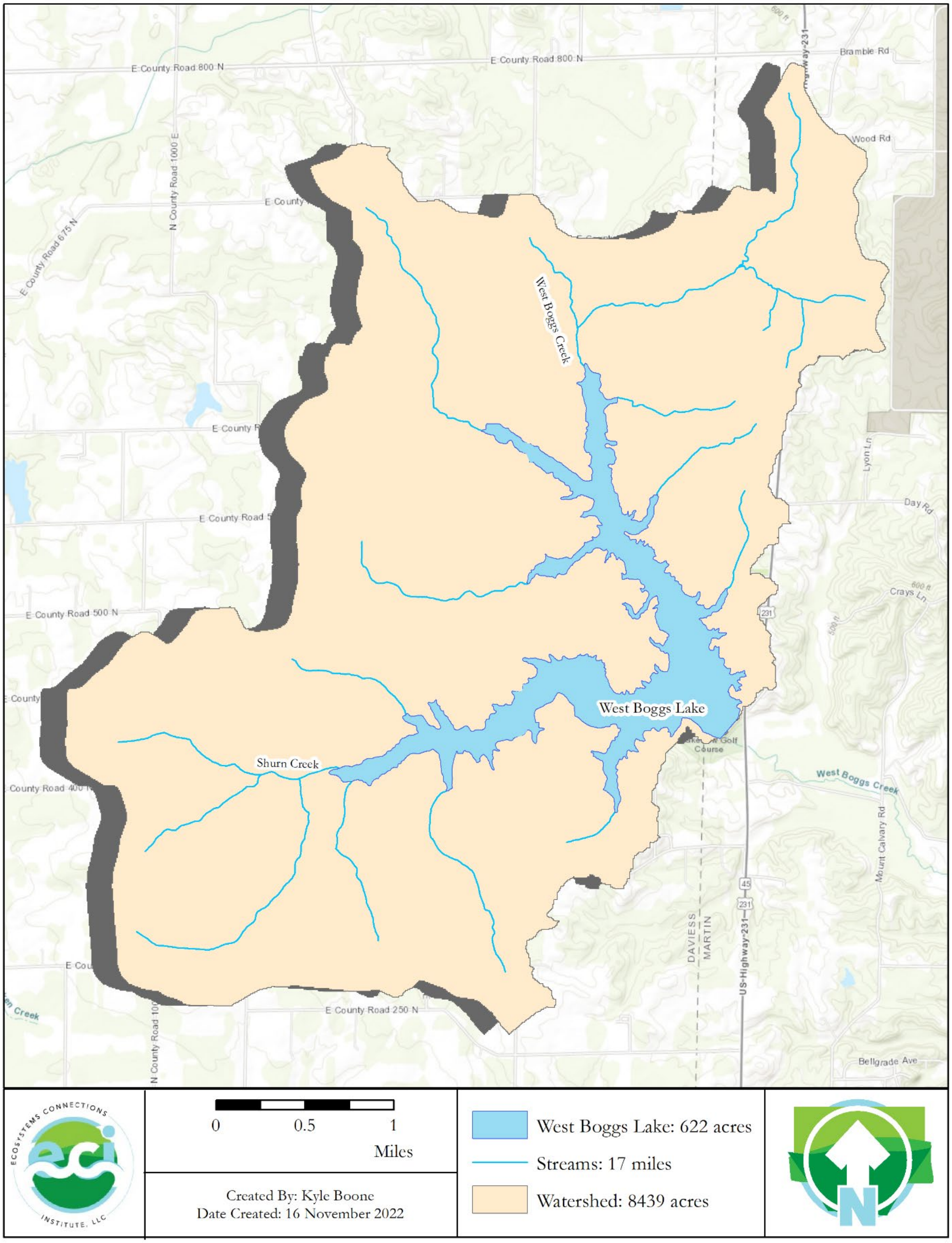



Figure 2. Overview of West Boggs Lake watershed, a subwatershed of HUC 12: 051202081102. The watershed contains 17 miles of streams which drain 8,439 acres.

**Task 1: Summarize historical information on trends in land use and water quality**

Water Quality

Historic water quality data is relatively scarce for West Boggs Lake and its watershed. Donan Engineering (1991) reported that Indian Department of Environmental Management (IDEM) collected water quality data in 1976, 1978, and 1989 to calculate a eutrophication index. These studies found that West Boggs Lake was a "Class Two" lake meaning the lake is between oligotrophic and eutrophic. The next water quality sampling was done by Indiana Clean Lake Program (INCLP) in 1989, 1996, and 2009. Results from all sampling years are similar, showing that West Boggs Lake was eutrophic with the algal community being dominated by blue green algae. More in-depth analysis of the West Boggs Lake and its watershed were done by Donan Engineering (1991) and Donan Engineering (2002). In the earlier study, Donan Engineering found that West Boggs Lake was a "Class Two" lake that was experiencing bank erosion. For the first time, Donan Engineering (1991) also collected water quality data in the tributary streams of West Boggs Lake. This study collected water samples from seven inlet streams during a storm event. Findings from this sampling effort show elevated phosphorus and sediment concentrations at all seven tributaries. Findings from Donan Engineering (1991) led to the construction of wetlands at two inlet streams to capture sediment and nutrients. Post construction monitoring show that the creation of the wetlands did not improve the trophic state of West Boggs Lake (Donan Engineering 2002). In fact, trophic state metrics indicated conditions had worsened in the decade between the two studies.

Fisheries

West Boggs Lake was a popular destination for fishing and recreation but over time water quality and fisheries degraded that affected use of the lake and park attendance. Quickly after its creation in 1971, West Boggs Lake gained a reputation providing excellent fishing opportunities (Kittaka 2010). Changes to the fishery started to occur in the late 1970's when Gizzard Shad (*Dorosoma cepedianum*) were introduced to the lake. By the 1980's, Gizzard Shad became well established and were negatively impacting the sport fishery (Kittaka 2010). The reduction in the sport fishery and abundance of Gizzard Shad led DNR to conduct a total fisheries renovation of the lake and its watershed in 1994. This renovation was successful in reestablishing the sport fishery and increasing fishing effort from anglers. However, Gizzard Shad became reestablished in the lake by the early 2000's (King 2011).

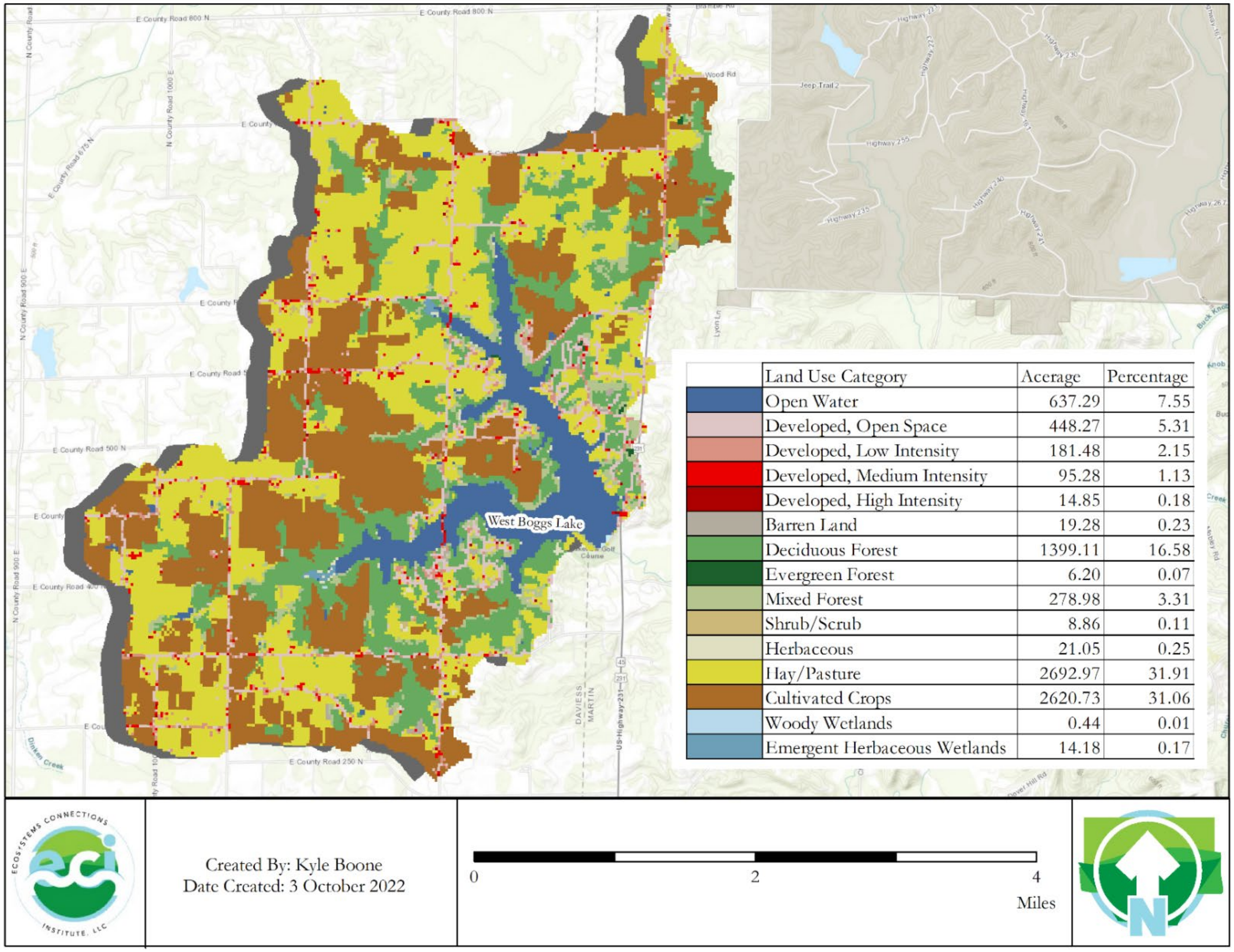
Again, the sport fishery and subsequently angler effort declined (Kittaka 2011, Kittaka 2014). DNR tried several methods to reduce Gizzard Shad abundance but ultimately another watershed and lake renovation was conducted in 2014 (Kittaka 2014). This renovation successfully reestablished Bluegills, Largemouth Bass, and Crappie populations (King 2016). Local reports indicate that fish capture rates are meeting angler's expectations and fish size are desirable (Johnson 2020).

**Task 2: Map and describe current watershed condition**

*Land Use*

Land in the watershed is used primarily for agricultural purposes such as pasture and cultivated crops (Figure 3). There are swaths of forested land near West Boggs Lake and along Shurn Creek. Development is concentrated around the lakeshore. Other development related to farms, businesses, and homes is interspersed throughout the watershed. There is one permitted confined feeding operation (CFO) in the watershed as of 2 April 2020 (Figure 4). There were no documented occurrences of leaking underground storage tanks (LUST), Brownfields, Superfund sites, National Pollution Discharge Elimination Systems (NPDES) point sources, or large septic fields were found for the West Boggs Lake watershed.

Tillage transects show that Daviess and Martin Counties (the counties that are within the West Boggs Lake Watershed) have 19% and 25% of cultivated crop acreage in fall and winter cover crop. Data on no-till practices show that 61% and 96% of corn acreage was not tilled after the 2021 harvest in Daviess and Martin Counties. For soybeans acreage, 95% and 100% of acreage was not tilled after the 2021 harvest. Cover crops and no-till are known to reduce nonpoint source (NPS) pollution in watersheds where land use is predominately agricultural.




| | Land Use Category | Acerage | Percentage |
|---|---|---|---|
| | Open Water | 637.29 | 7.55 |
| | Developed, Open Space | 448.27 | 5.31 |
| | Developed, Low Intensity | 181.48 | 2.15 |
| | Developed, Medium Intensity | 95.28 | 1.13 |
| | Developed, High Intensity | 14.85 | 0.18 |
| | Barren Land | 19.28 | 0.23 |
| | Deciduous Forest | 1399.11 | 16.58 |
| | Evergreen Forest | 6.20 | 0.07 |
| | Mixed Forest | 278.98 | 3.31 |
| | Shrub/Scrub | 8.86 | 0.11 |
| | Herbaceous | 21.05 | 0.25 |
| | Hay/Pasture | 2692.97 | 31.91 |
| | Cultivated Crops | 2620.73 | 31.06 |
| | Woody Wetlands | 0.44 | 0.01 |
| | Emergent Herbaceous Wetlands | 14.18 | 0.17 |

Figure 3. Land use by Acres and Percentage in West Boggs Lake Watershed. Cultivated agriculture represents 31% of land use and Hay/Pasture represents 32% of land use.

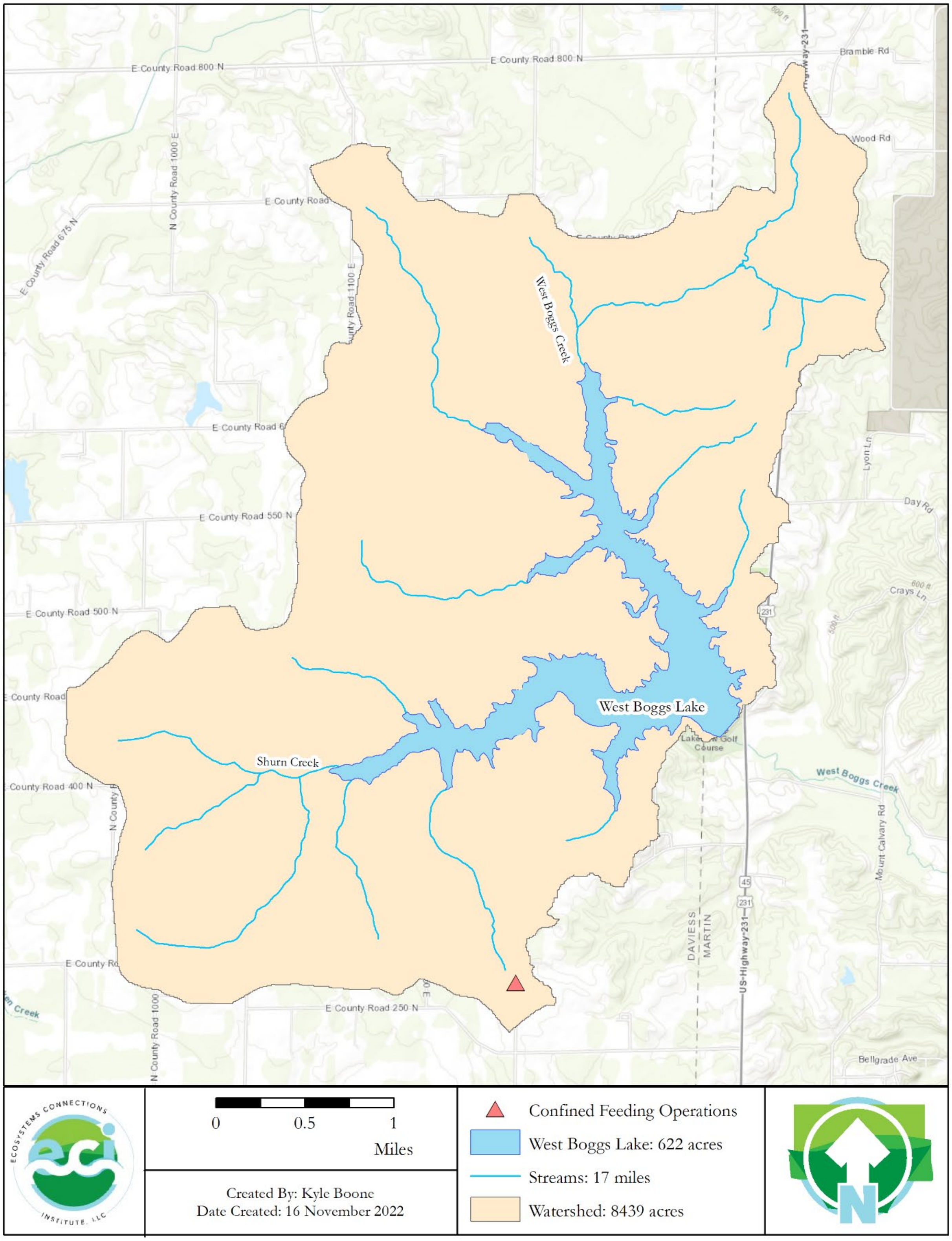



Figure 4. Location of one Confined Feeding Operation (CFO) in West Boggs Lake Watershed.

*Wetlands, Floodplains, and Soils*

Historically, the West Boggs Lake watershed had few wetlands. In total, wetlands only covered 14.33 acres (0.17%) (Figure 5). Current wetlands cover 816.46-Acres (Figure 6). The increase in wetlands is largely attributed to the creation of West Boggs Lake. Floodplains are limited to areas immediately adjacent to and including West Boggs Lake (Figure 7). Hydric soils are more prevalent in the watershed and cover 1,794-Acres in the watershed (Figure 8). Hydric soils are mostly adjacent to streams, but isolated pockets of hydric soils do exist.

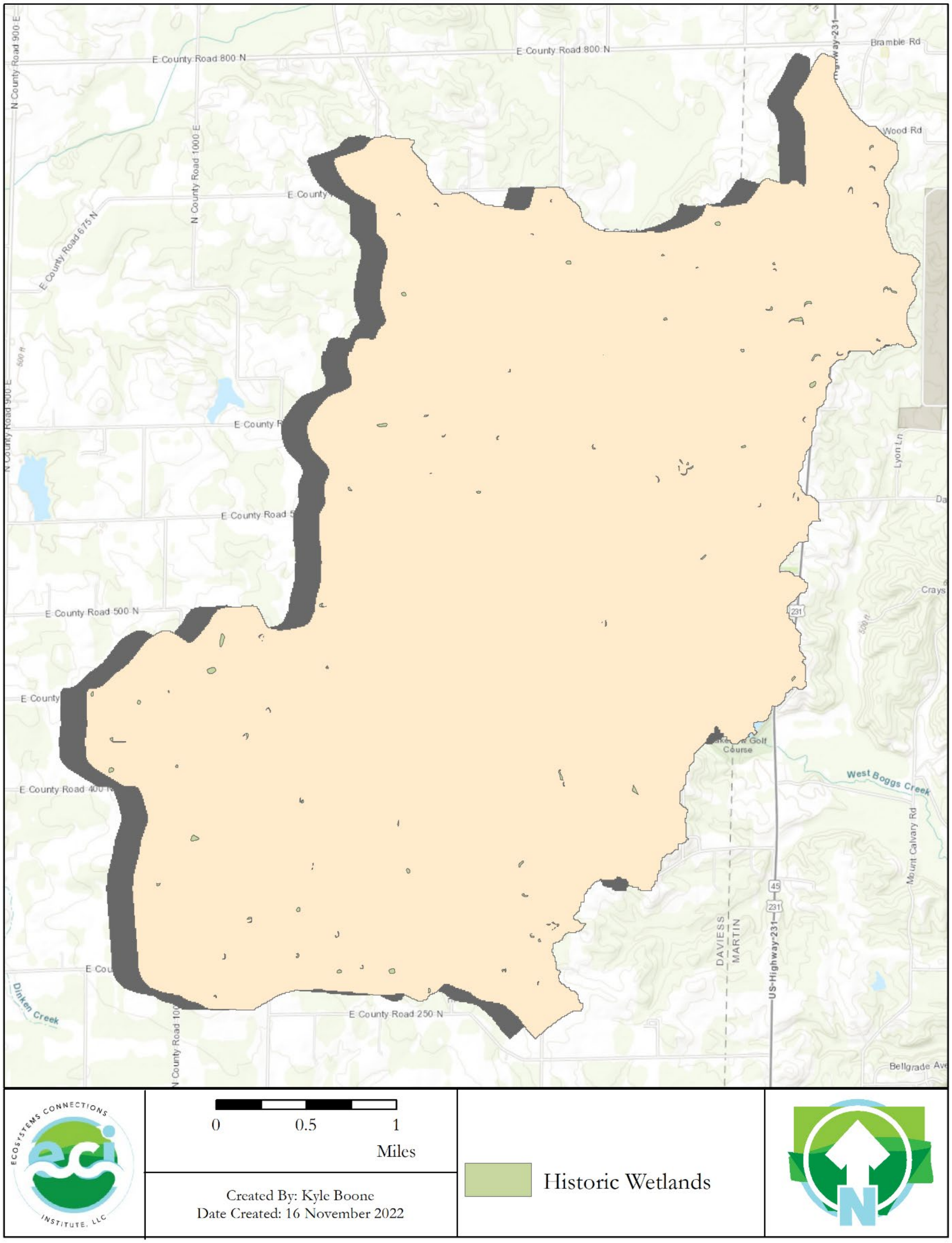



Figure 5. Historic wetlands in West Boggs Lake Watersheds.

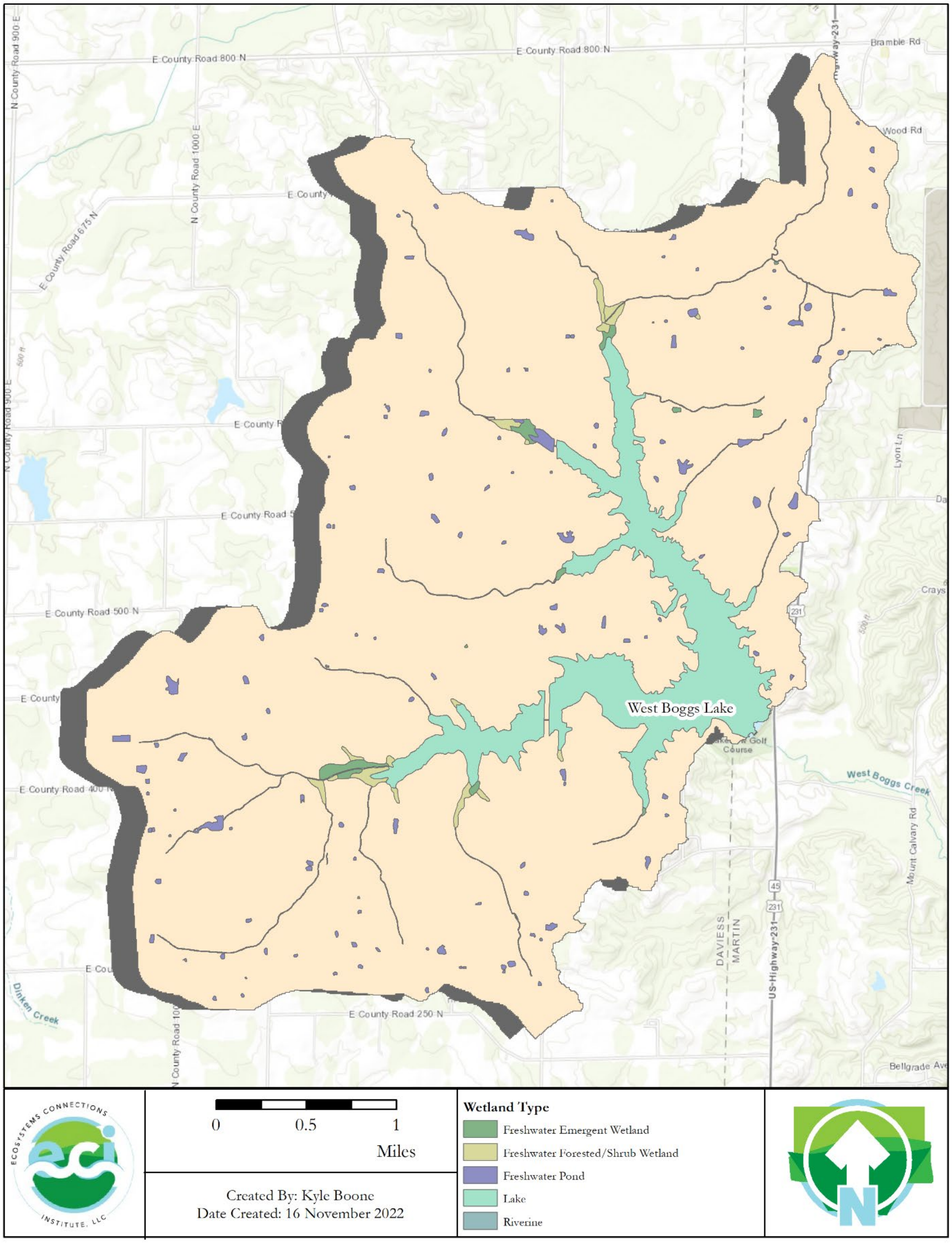



Figure 6. Location of current wetlands in West Boggs Lake Watershed.

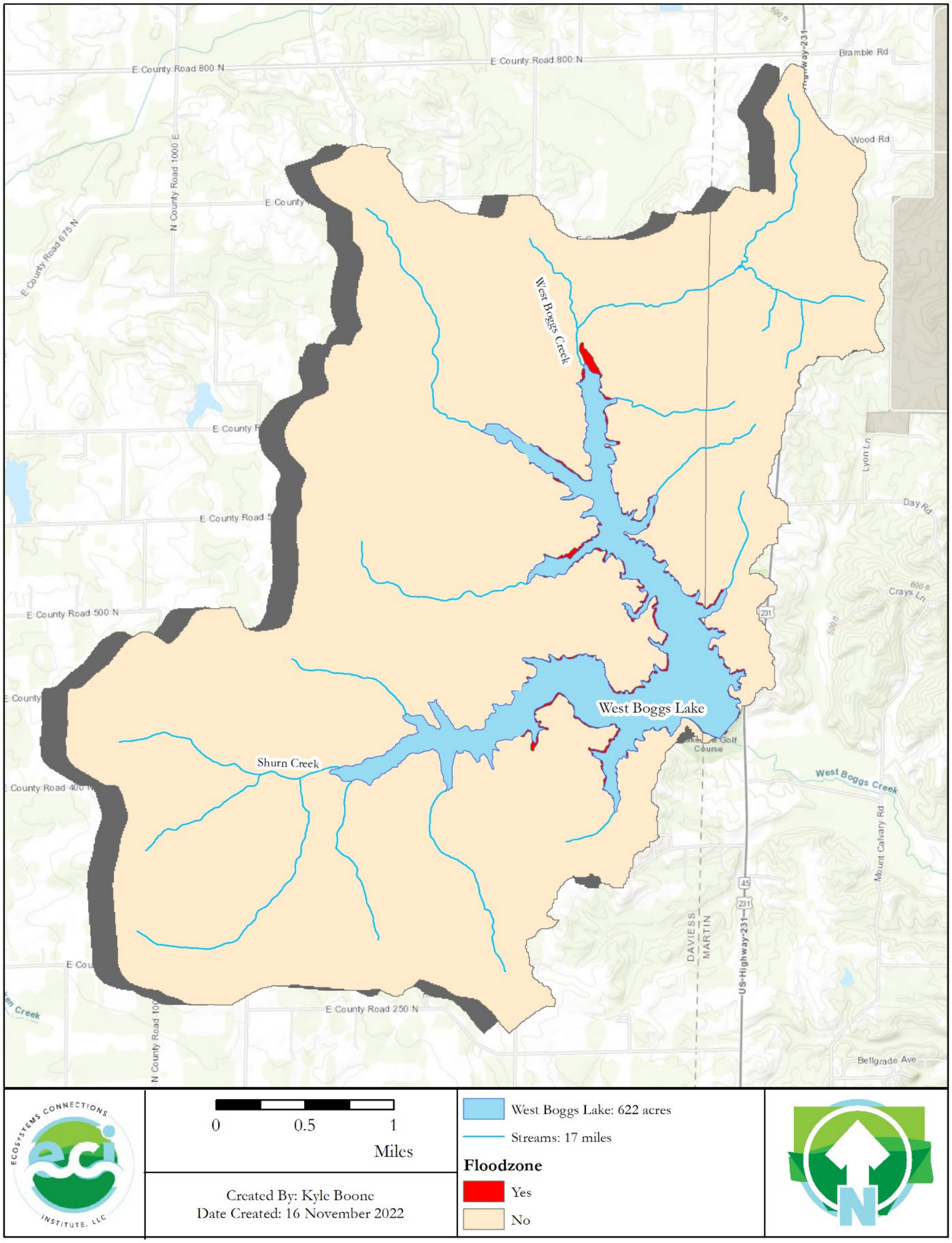



Figure 7. Flood zones in West Boggs Lake Watershed.

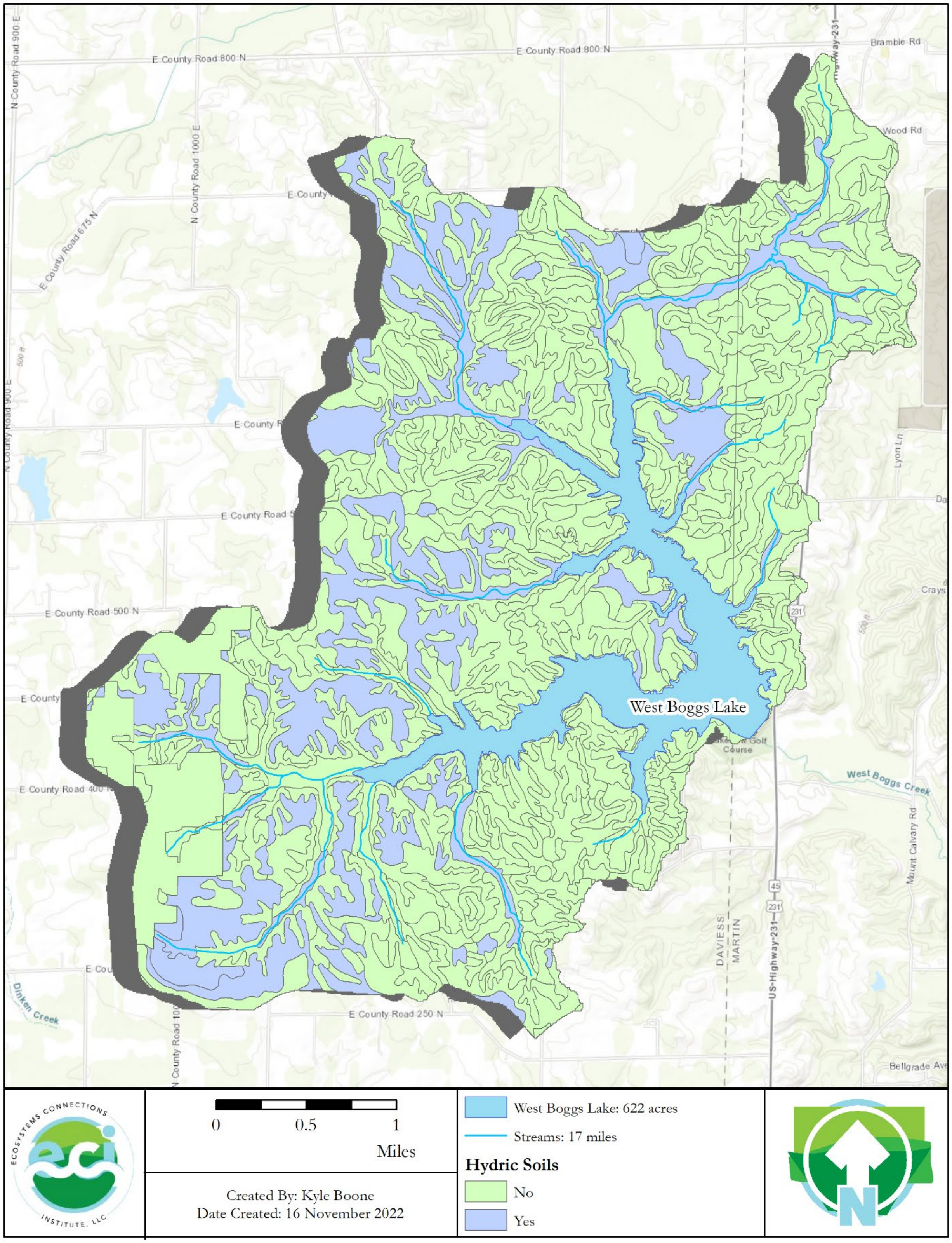



Figure 8. Hydric soils in West Boggs Lake Watershed.

*Conservation Areas*

The primary conservation area in the West Boggs Lake Watershed is West Boggs Park (Park) (Figure 9). The Park includes much of the shoreline of West Boggs Lake, the Washington Boat Club, and Lakeview Golf Course. There is publicly accessible boat ramp at the park that allows for access of West Boggs Lake. The Park is managed by Daviess-Martin Joint County Parks and Recreation Department.

There were no identified locations of state and federally listed animal or plant species.

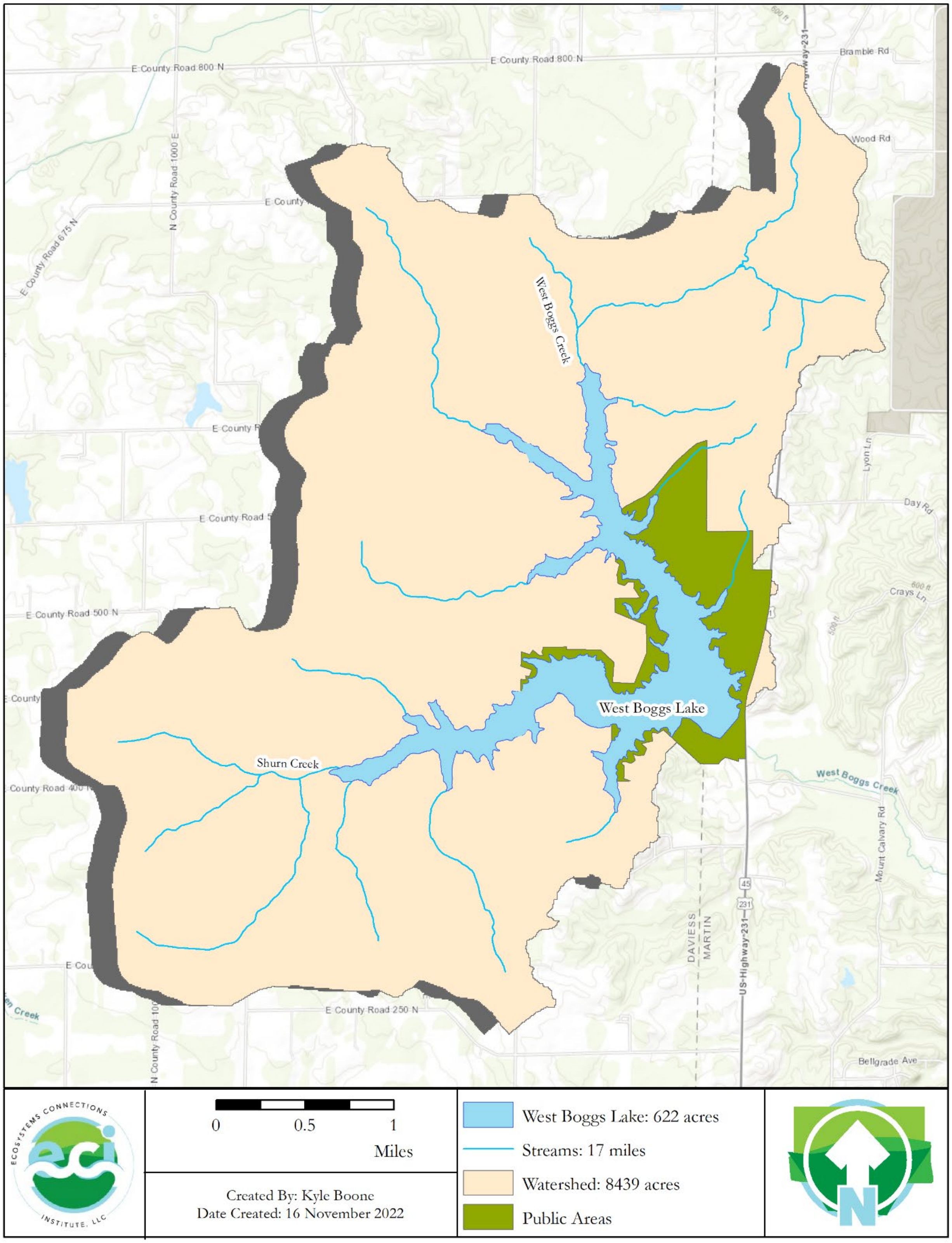



Figure 9. Public lands in West Boggs Lake Watershed includes approximately 1,600-Acres including the 622-Acre Boggs Reservoir.

**Task 3: Collect and analyze information on water quality, biology, and habitat**

*Materials and Methods*

Limnologist with Ecosystems Connections Institute (ECI) conducted two (N=2) water quality sampling events at 14 tributary sites (Figure 10). One grab sample and stream discharge (Q) was taken at each tributary site (Figure 11). Lake sampling occurred twice (N=2) at three sites in the lake. At each site, a lake profile was created by taking Secchi depth, light and dissolved oxygen profile at the surface and once meter to the bottom of the lake. Water samples were collected at the surface, middle, and bottom of the water column (Figure 12, Figure 13, Table 2). All water samples were analyzed at the ECI laboratory using a Seal Analytic AQ 400 autoanalyzer following EPA Standard Methods and an approved quality assurance project plan (QAPP). Parameters measured from each water sample are shown in Table 3. Resulting concentrations were compared to regional water quality target values (Table 4). Sampling dates were 15 June 2021 and again on 20 July 2022.

Fish and stream habitat were assessed at nine (N=9) tributary sites on 20 July 2022. There were three sites that were inaccessible at the time of sampling. Fish were sampled at these sites to complete an Index of Biotic Integrity (IBI) to measure ecological quality. Fish were sampled using a Smith-Root LR-20B backpack electrofisher. Habitat at tributary sites was measured using the Qualitative Habitat Evaluation Index (QHEI).

Table 2. Depths where water samples were collected at the three sampling sites on West Boggs Lake.

| Depth | West | North | South |
|---|---|---|---|
| Surface | 0 meters | 0 meters | 0 meters |
| Middle | 3 meters | 3 meters | 4 meters |
| Bottom | 5 meters | 5 meters | 8 meters |

Table 3. Parameters recorded for either stream inflow water analysis or lake sampling.

| Parameter | Unit | Sample sites |
|---|---|---|
| Water Temperature | °C | Lake and Stream |
| Dissolved Oxygen | mg/L | Lake and Stream |
| Nitrate-N ($NO_3^-$) | mg/L | Lake and Stream |
| Total Nitrogen | mg/L | Lake and Stream |
| Total Kjeldahl Nitrogen (TKN) | mg/L | Lake and Stream |
| Soluble Reactive Phosphorus | mg/L | Lake and Stream |
| Total Phosphorus | mg/L | Lake and Stream |
| Total Suspended Solids | mg/L and NTU | Lake and Stream |
| E. coli (*Escherichia coli*) | CFU | Streams |
| Stream Discharge | Cubic Feet/Second (CFS) | Streams |
| Secchi | Feet and Meters | Lake |
| Light | micromole/$m^2$ | Lake |
| Conductivity | µS/cm | Lake and Stream |
| Chlorophyll-a | mg/L | Lake |

Table 4. Water quality target values for nitrogen and phosphorus, as well as Total Suspended Solids for the Interior River Valleys and Hills Ecoregion.

| Parameter | Description | Water Quality Standard for Interior River Valleys and Hills |
|---|---|---|
| Nitrate+Nitrite-Nitrogen ($NO_3^-$) | Nitrate-N (mg/L) | 0.2 mg/L |
| Total Kjeldahl Nitrogen | sum of organic nitrogen and ammonia (mg/L) | 0.54 mg/L |
| Total Nitrogen | sum of all forms of nitrogen-inorganic (nitrite, nitrate and ammonia) and organic nitrogen (mg/L) | 1.7 mg/L |
| Soluble Reactive Phosphorus | Inorganic form of phosphorus | 0.005 mg/L or 5 µg/L[3] |
| Total Phosphorus | All forms of phosphorus, soluble reactive or non-reactive (mg/L or µg/L) | 0.031 mg/L or 31 µg/L[3] |
| Total Suspended Sediment | Dry weight of filtered solids gravimetrically (mg/L) | 25 mg/L |

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[3] The soluble reactive phosphorus and Total Phosphorus target values for this study are derived from the more conservative values of the Southern Michigan, Northern Indiana Till Plains target values.

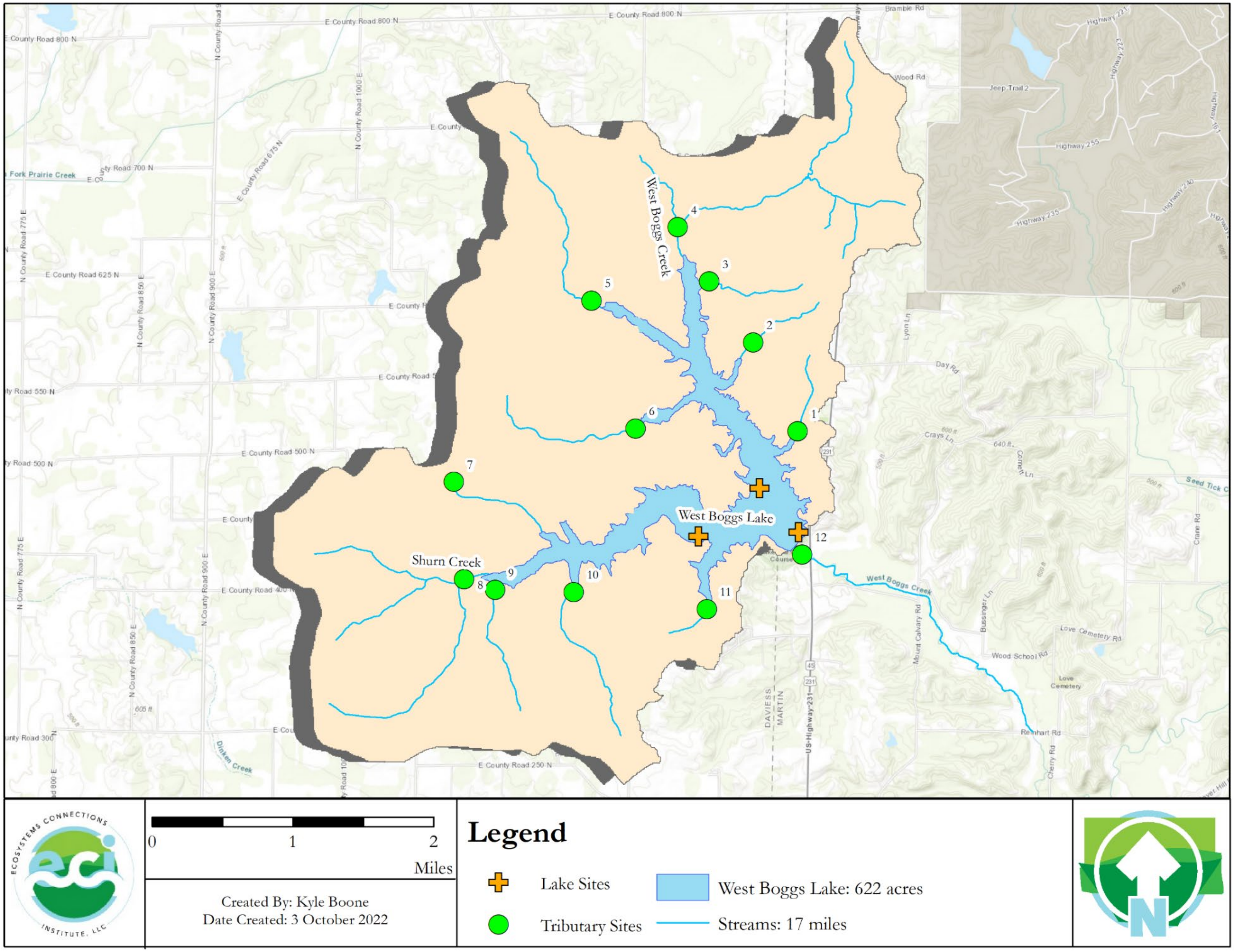



Figure 10. The fourteen tributary and three lake sampling sites at West Boggs Lake.


Figure 11. An Ecosystems Connections Institute intern taking a stream discharge measurement at a tributary of West Boggs Lake on 14 June 2021.

Figure 12. An Ecosystems Connections Institute employee and intern preparing a sonde to utilize for the creation of lake profiles 14 July 2022.


Figure 13. Water sample collection from West Boggs Lake using a Kemmerer bottle on 14 July 2021.

*Results*

Water Quality Assessment

Physical parameters collected at tributary sites and the lake outflow included conductivity, stream discharge, water temperature, dissolved oxygen, and percent saturation of dissolved oxygen. Average conductivity across all sites was 507.42 µs/L. Maximum conductivity of 1,418.9 µs/L was recorded on 14 June 2021 at Site 3 (Figure 14). Average discharge across all sites was 1.70 cubic feet per second (cfs). Maximum discharge of 34.08 cfs was recorded on 20 July 2022 at Site 12 (West Boggs Lake Outlet) (Figure 15). Average water temperature across all sites was 24.46 °C. Maximum temperature of 28.1 °C was recorded on 20 July 2022 at Site 12 (Figure 16). Average dissolved oxygen across all sites was 5.82 mg/L. Maximum dissolved oxygen of 7.71 mg/L was recorded on 14 June 2021 at Site 12 (Figure 17). Minimum dissolved oxygen of 2.75 mg/L was recorded on 14 June 2021 at Site 8. Average percent saturation of dissolved oxygen across all sites was 68.91%. Maximum percent saturation of 101.8% was recorded on 14 June 2021 at Site 11 (Figure 18). Minimum percent saturation of 29.5% was recorded on 14 June 2021 at Site 8.

Water quality parameters collected at tributary sites and the lake outflow included Total Phosphorus, Soluble Phosphorus, Total Nitrogen, Nitrate-N, and Total Kjeldahl Nitrogen (TKN). Additionally, *Escherichia coli* (*E. coli*), Total Suspended Solids (TSS), and Turbidity were also measured at all sites. Total Phosphorus, Soluble Phosphorus, Total Nitrogen, and TKN concentrations exceeded target values at all sites on both sampling dates (Figure 19 – Figure 22). Site 7 routinely had the highest nutrient concentrations. Sample concentrations exceeded the Nitrate-N threshold value of 0.2 mg/L in 80% of samples (Figure 23). *E. coli* concentrations exceeded the target threshold of 235 most probable number (mpn)/100mL in 80% of samples (Figure 24). The TSS target threshold was never exceeded by sample concentrations (Figure 25). Turbidity was also measured but there is not a target value for Turbidity (Figure 26). Average Turbidity across all sites was 11.61 NTU. Maximum Turbidity of 80.9 NTU was recorded on 14 June 2021 at Site 8.

Sample concentration was related to stream discharge at the time the sample was taken to calculate loading in pounds per day. Load was calculated for Total Phosphorus, Soluble Phosphorus, Total Nitrogen, Nitrate-N, and TKN. Site 12 (West Boggs Lake Outlet) on 20 July 2022 routinely had the highest loading of all parameters except Nitrate-N (Figure 27 - Figure 32). The high loading rate was a result of the elevated discharge measured at Site 12 on 20 July 2022. For example, the measured discharge on 20 July 2022 was 34.08 cfs. This is 483% higher than the next highest discharge. Tributary sites had relatively low loading rate when compared to the Site 12.

Physical parameters collected on West Boggs Lake at three sampling sites included Secchi depth as well as water temperature and light at every meter depth. Together these parameters create a lake profile. Average Secchi depth across all three sampling sites was 8.2 feet on 15 June 2021 and was 1.1 feet on 20 July 2022. It should be noted that there was a major blue green algal bloom on West Boggs Lake during the 2022 sampling date and the lake was closed to recreational use. Lake profiles on 15 June 2021 showed the thermocline (the depth at which water temperature decreases 1°C in 1 meter of depth) varied from 6.5 to 9.8 feet deep. Dissolved oxygen and light followed a similar pattern as water temperature with a sharp decline is both parameters between 6.5 and 9.8 feet deep. Lake profiles completed on 20 July 2022 showed more variable thermocline depths from 3.3 to 9.8 feet deep. Dissolved oxygen and light measurements varied at depth likely due to a rain event recently occurring. The photic zone depth (depth at which photosynthesis can occur) was between 0 feet and 3.3 feet at all three sampling sites (Lake Profiles are in Appendix 1).

Nutrient parameters collected on West Boggs Lake included Total Phosphorus, Soluble Phosphorus, Total Nitrogen, Nitrate-N, and Total Kjeldahl Nitrogen (TKN). All parameters, except Nitrate-N, exceeded target values at all sites and depths on both sampling dates (Figure 33 – Figure 36). The target threshold of 0.2 mg/L of Nitrate-N was never exceeded by sample concentrations (Figure 37). The calculated Total Nitrogen to Total Phosphorus ratio (N:P) was 11:1, meaning phosphorus is the limiting nutrient in West Boggs Lake.

Physical and nutrient parameters were used to calculate the Trophic Status of West Boggs Lake. The Trophic Status is an important indicator of the health of a lake. For example, lakes with a low Trophic Status (oligotrophic) are clear with low algal abundance while lakes with a high Trophic Status (hypereutrophic) are turbid with high algal abundance and the algal community being dominated by blue green algae. West Boggs Lake ranked as hypereutrophic in every parameter used to measured Trophic State (Figure 38). Possibly the most telling measurement of the Trophic Status of West Boggs Lake is the Carlson's Trophic State Indicator (TSI). The TSI uses the average Total Phosphorus concentration of a lake to create a score that is then qualitatively ranked on a scale of oligotrophic to hypereutrophic. The TSI score of West Boggs Lake is 85.6. A score this high firmly ranks West Boggs Lake as hypereutrophic and nearly off the charts.

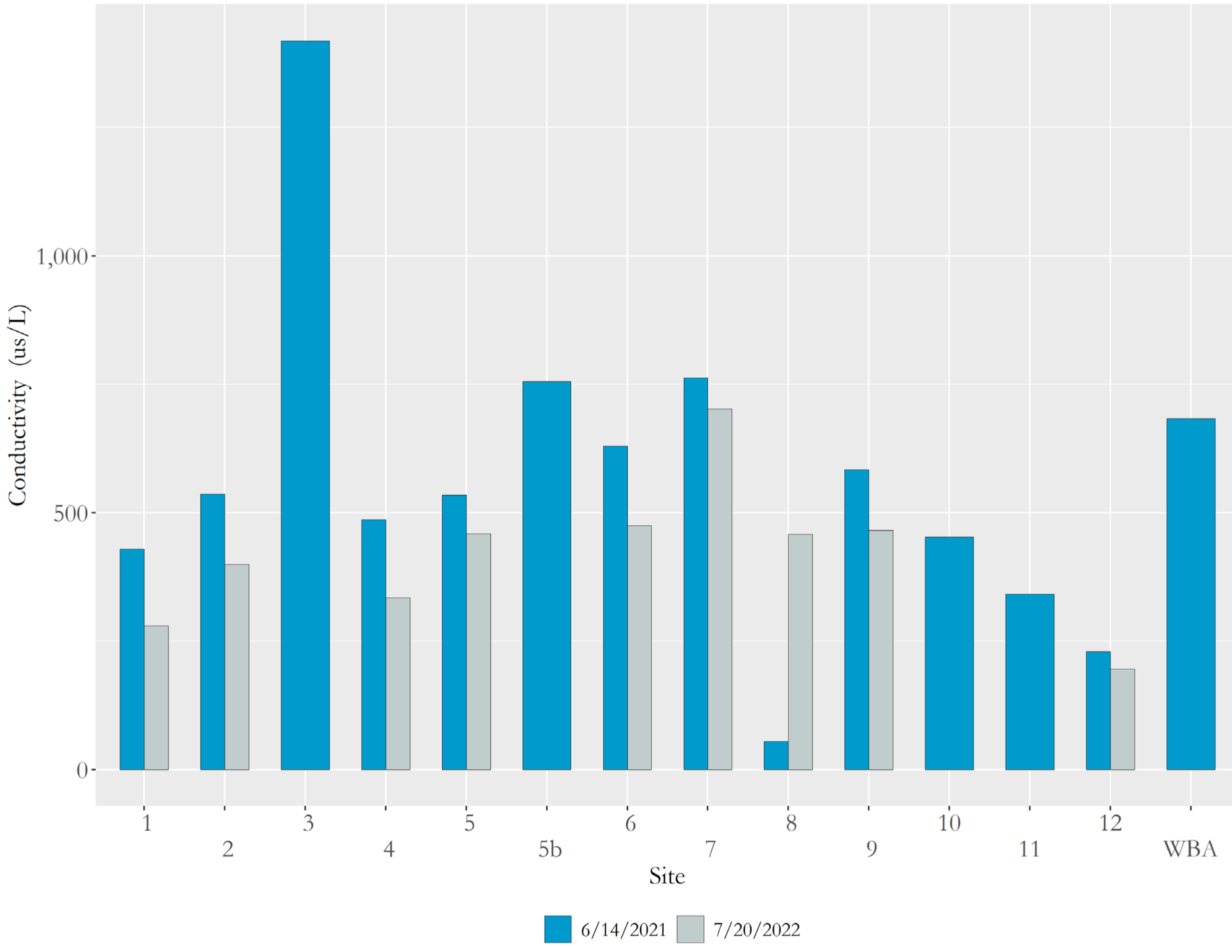



Figure 14. Conductivity at 14 tributary sites on 14 June 2021 and 20 July 2022. Site 3 represents an exceptionally high value.

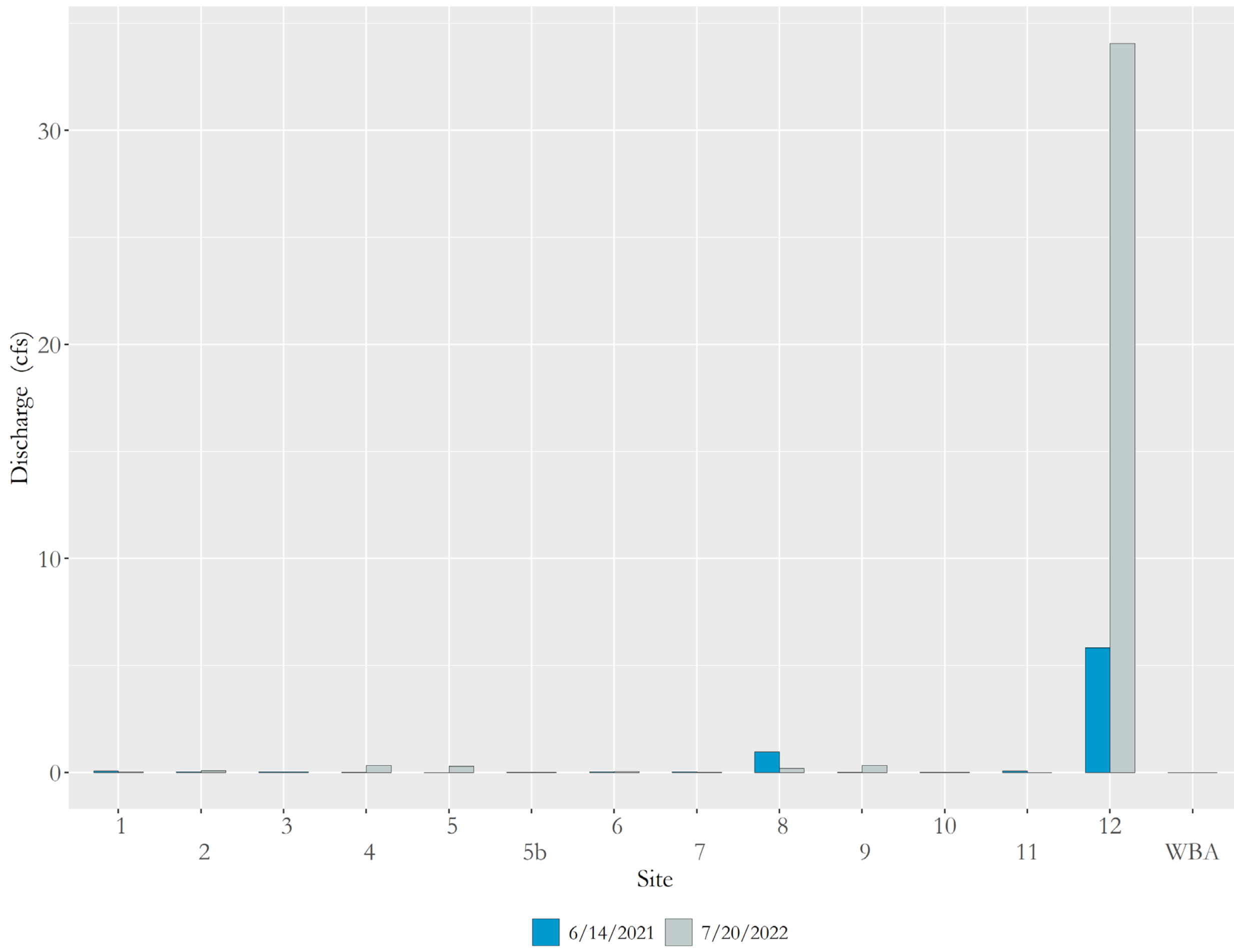



Figure 15. Discharge (flow) at 14 tributary sites on 14 June 2021 and 20 July 2022.

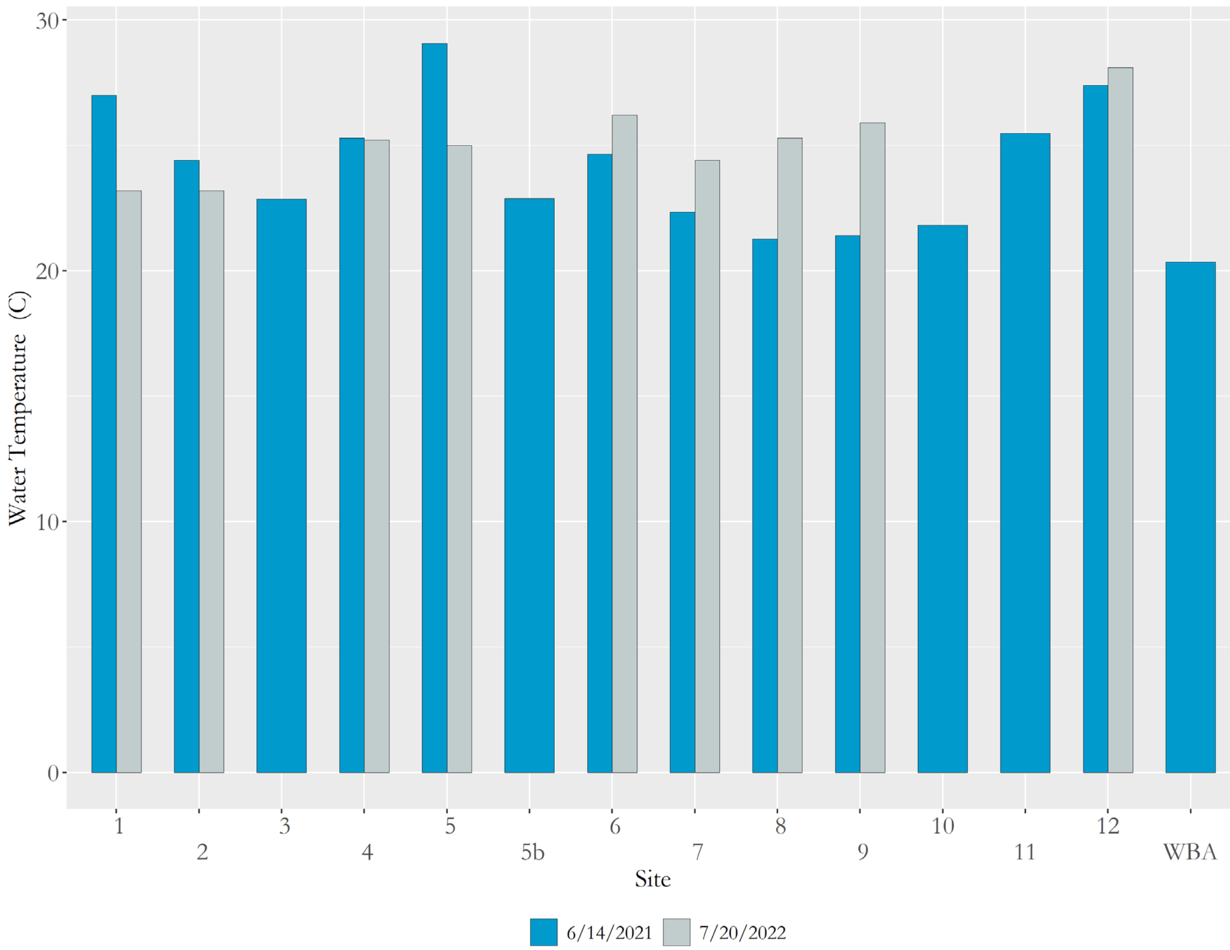



Figure 16. Water temperature at 14 tributary sites on 14 June 2021 and 20 July 2022.

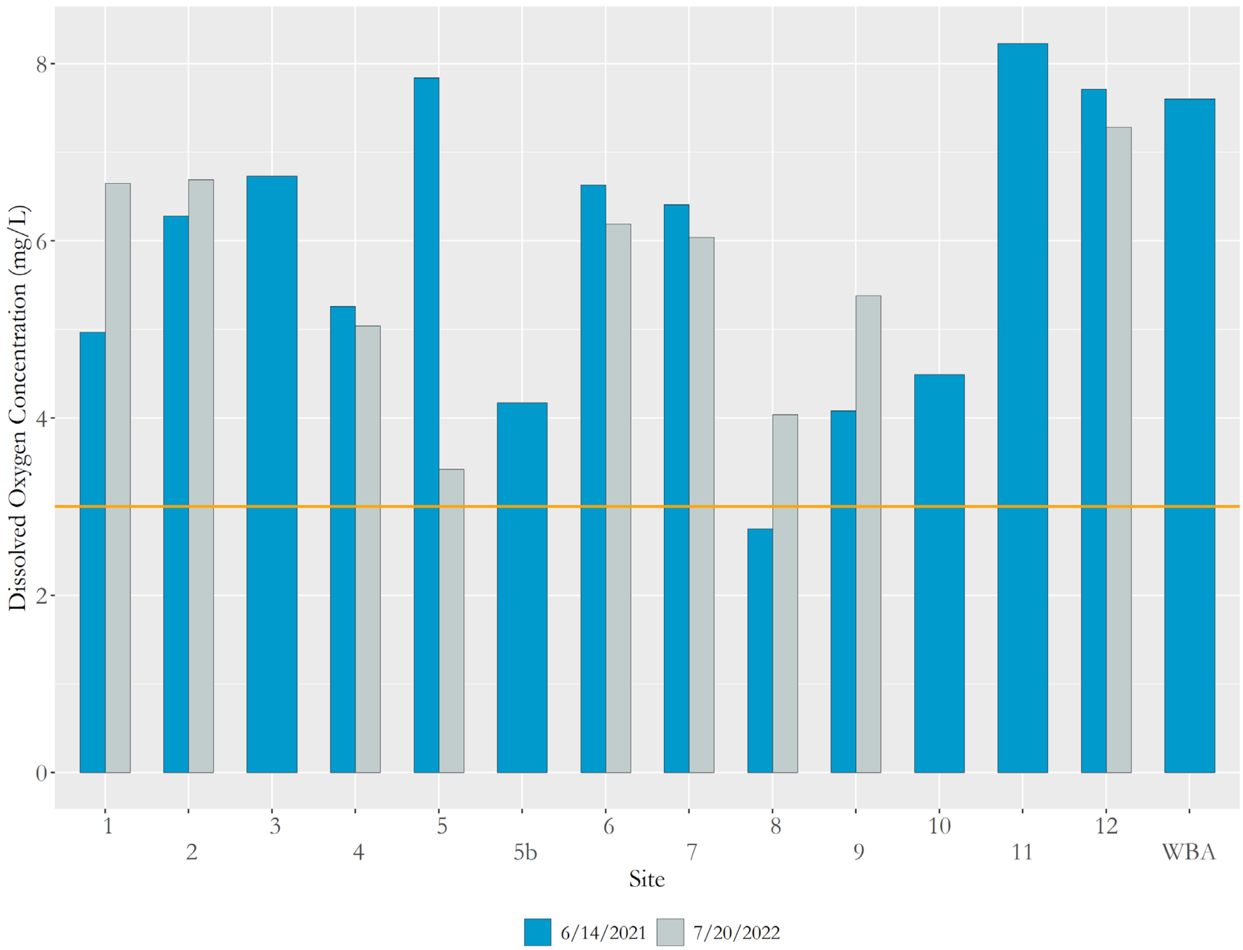



Figure 17. Dissolved oxygen at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents a low dissolved oxygen value of 3 mg/L. Many fish species would struggle to survive at dissolved oxygen concentrations below 3 mg/L.

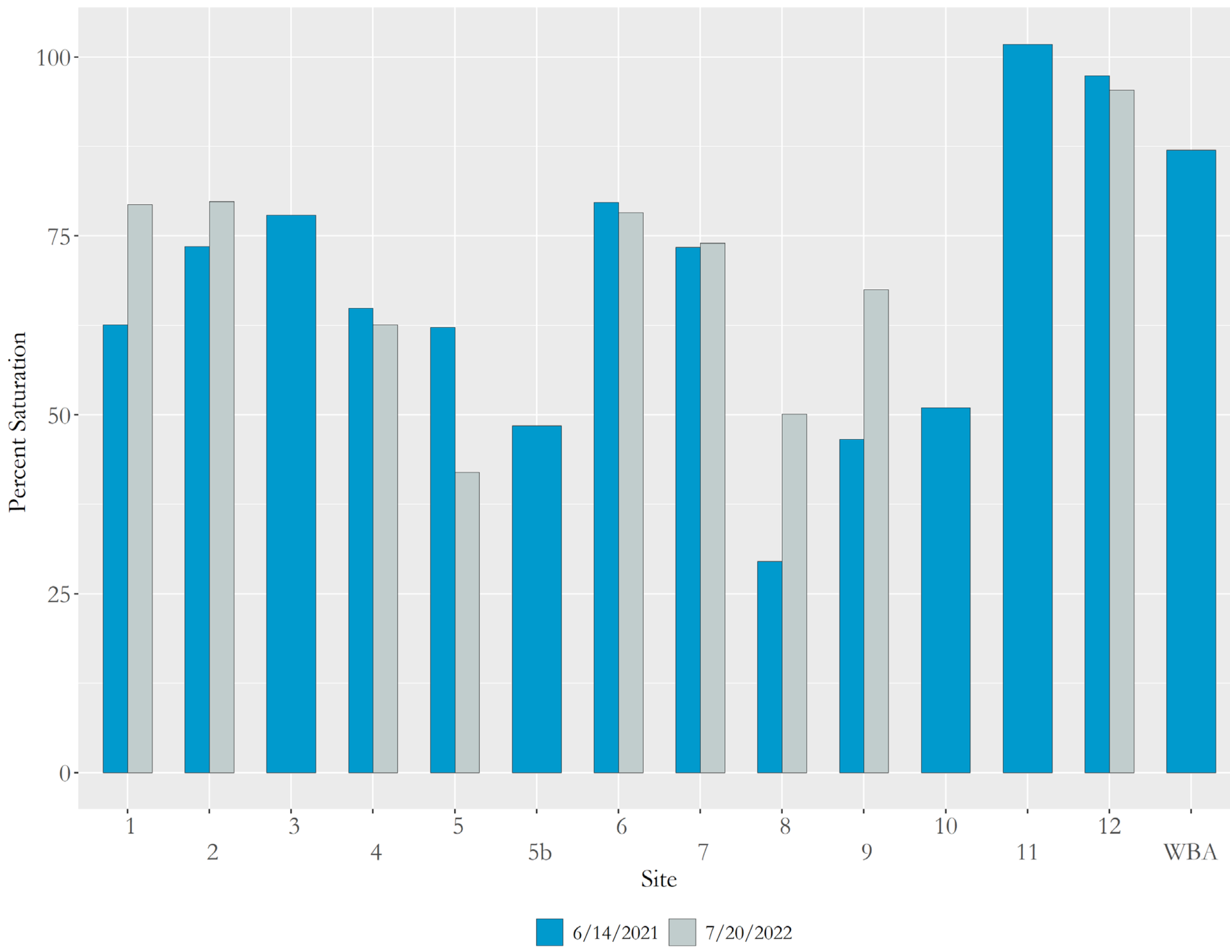



Figure 18. Percent saturation of dissolved oxygen at 14 tributary sites on 14 June 2021 and 20 July 2022.

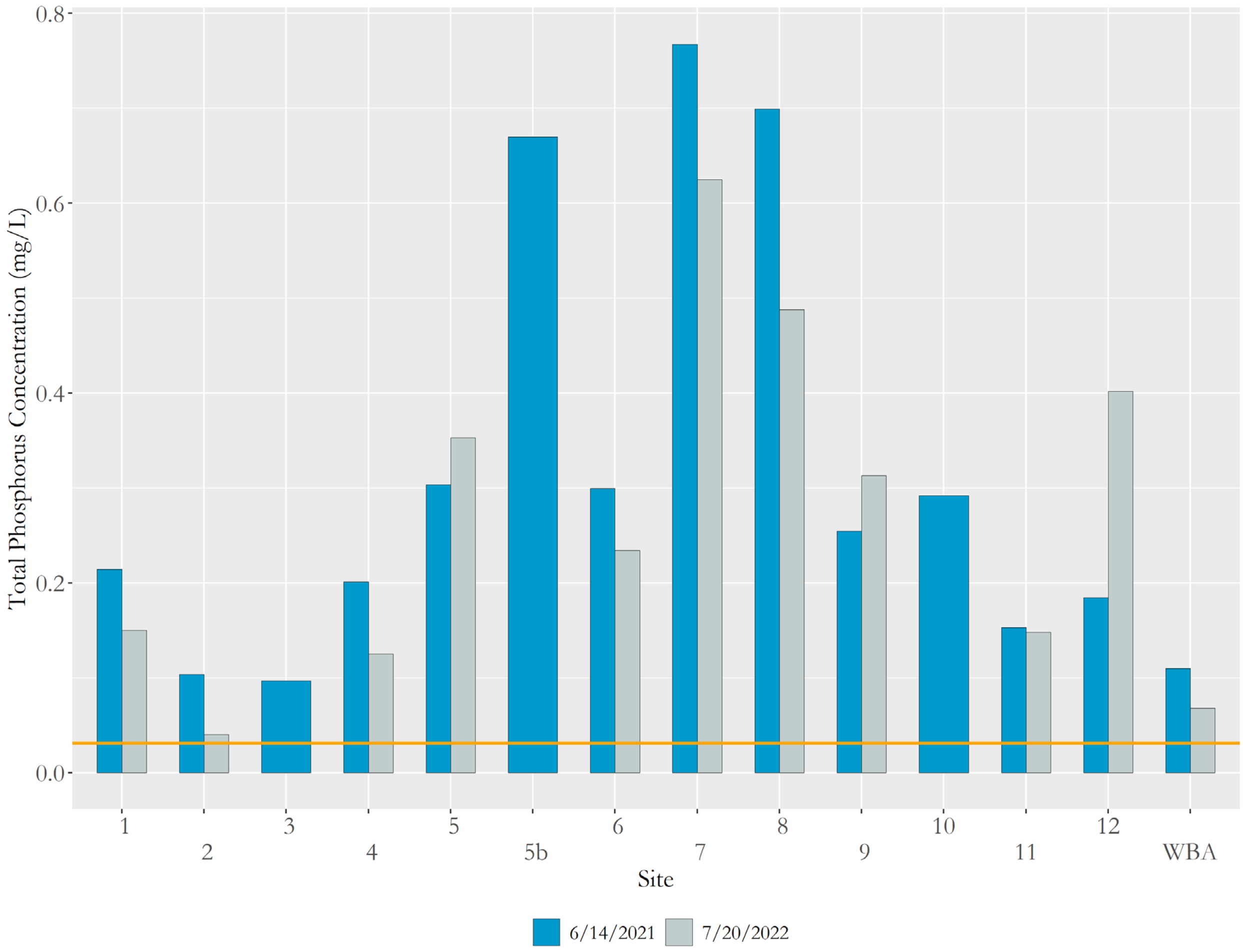



Figure 19. Total Phosphorus concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for Total Phosphorus of 0.031 mg/L.

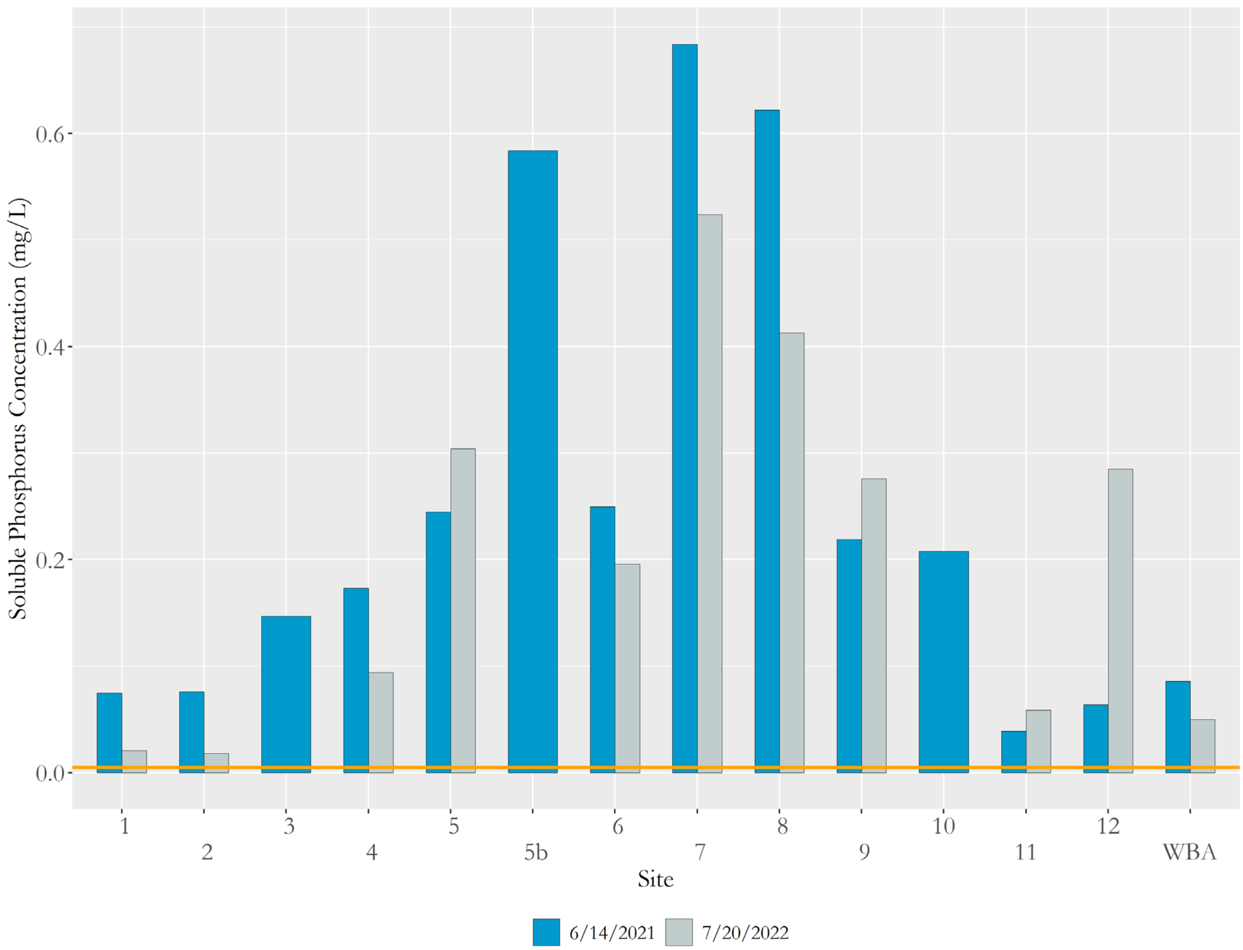



Figure 20. Soluble Phosphorus concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for Soluble Phosphorus of 0.005 mg/L.

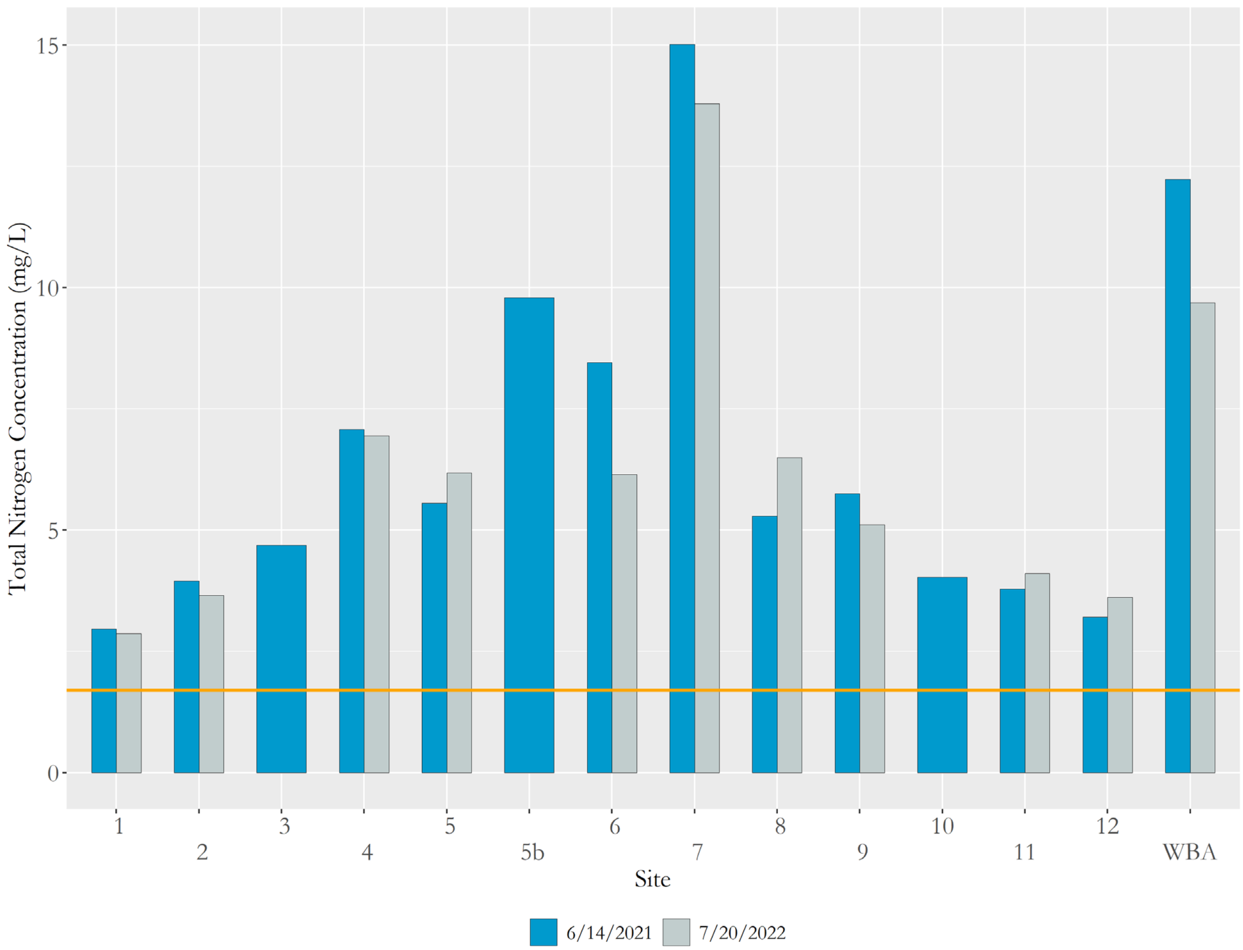



Figure 21. Total Nitrogen concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for Total Nitrogen of 1.7 mg/L.

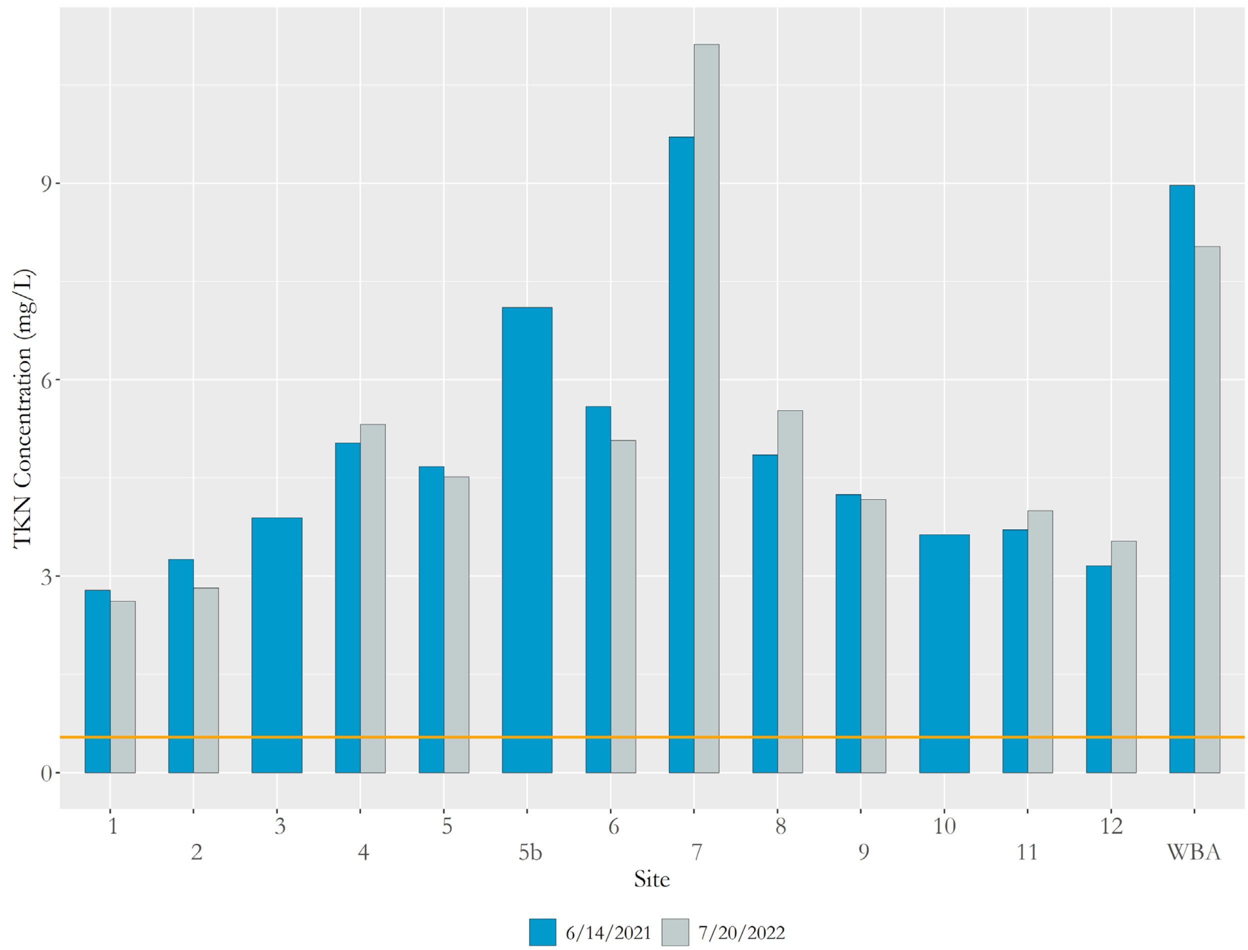



Figure 22. Total Kjeldahl Nitrogen concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for Total Kjeldahl Nitrogen of 0.54 mg/L.

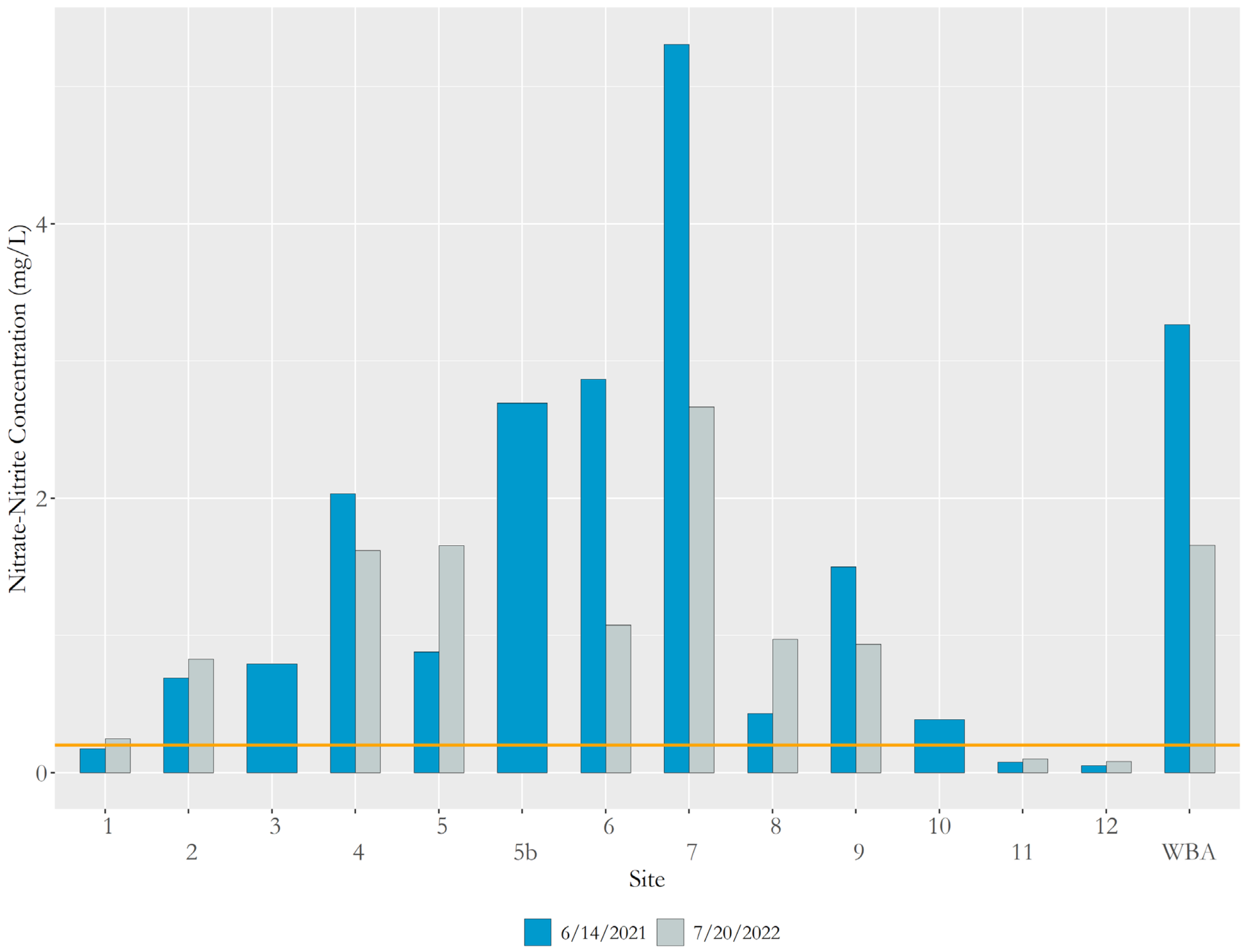



Figure 23. Nitrate-Nitrite concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for Nitrate-Nitrite of 0.2 mg/L.

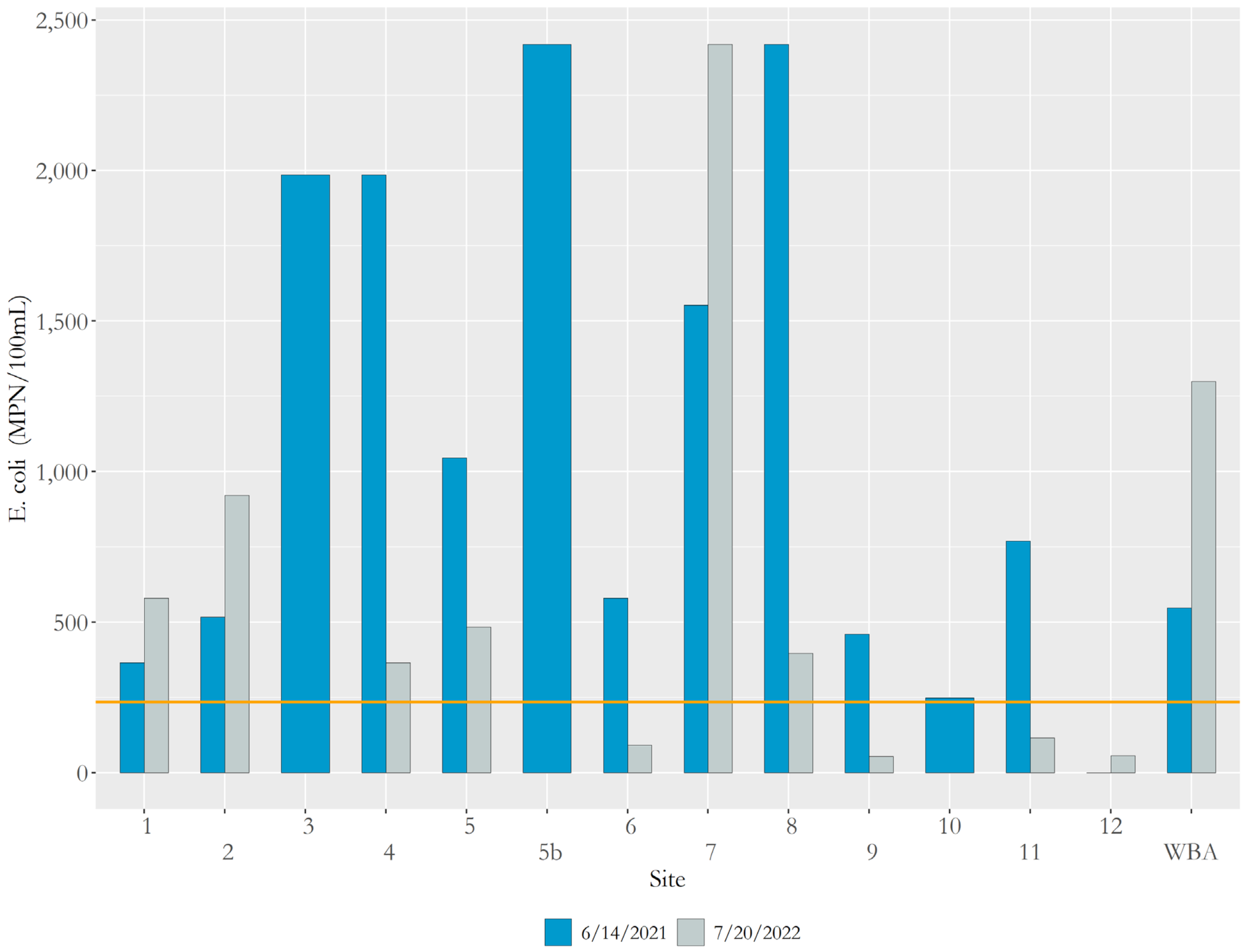



Figure 24. *Escherichia coli* (*E. coli*) abundance at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for *E. coli* of 235 mpn/100mL.

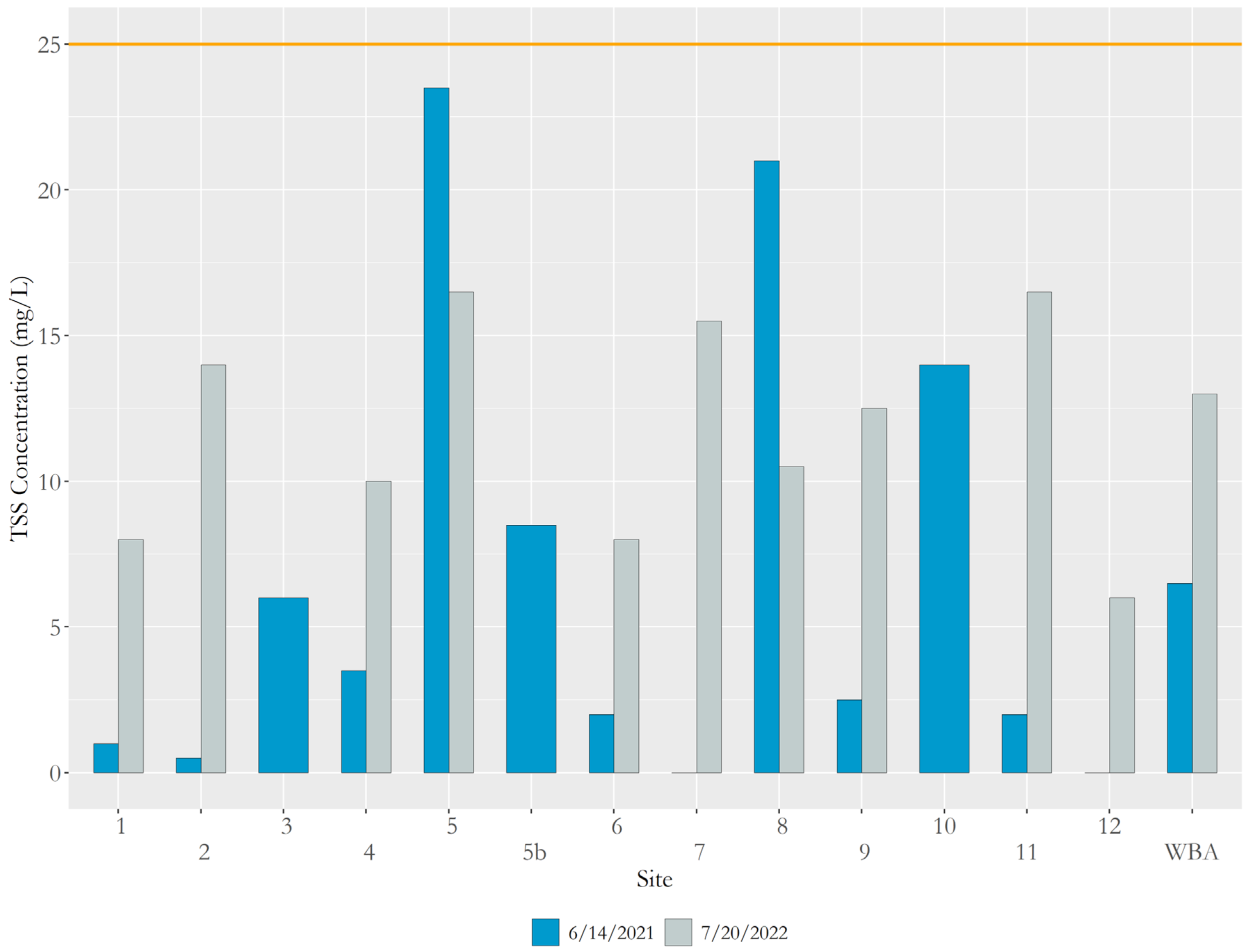



Figure 25. Total suspended solid (TSS) concentration at 14 tributary sites on 14 June 2021 and 20 July 2022. The horizontal orange line represents the water quality target value for TSS of 25 mg/L.

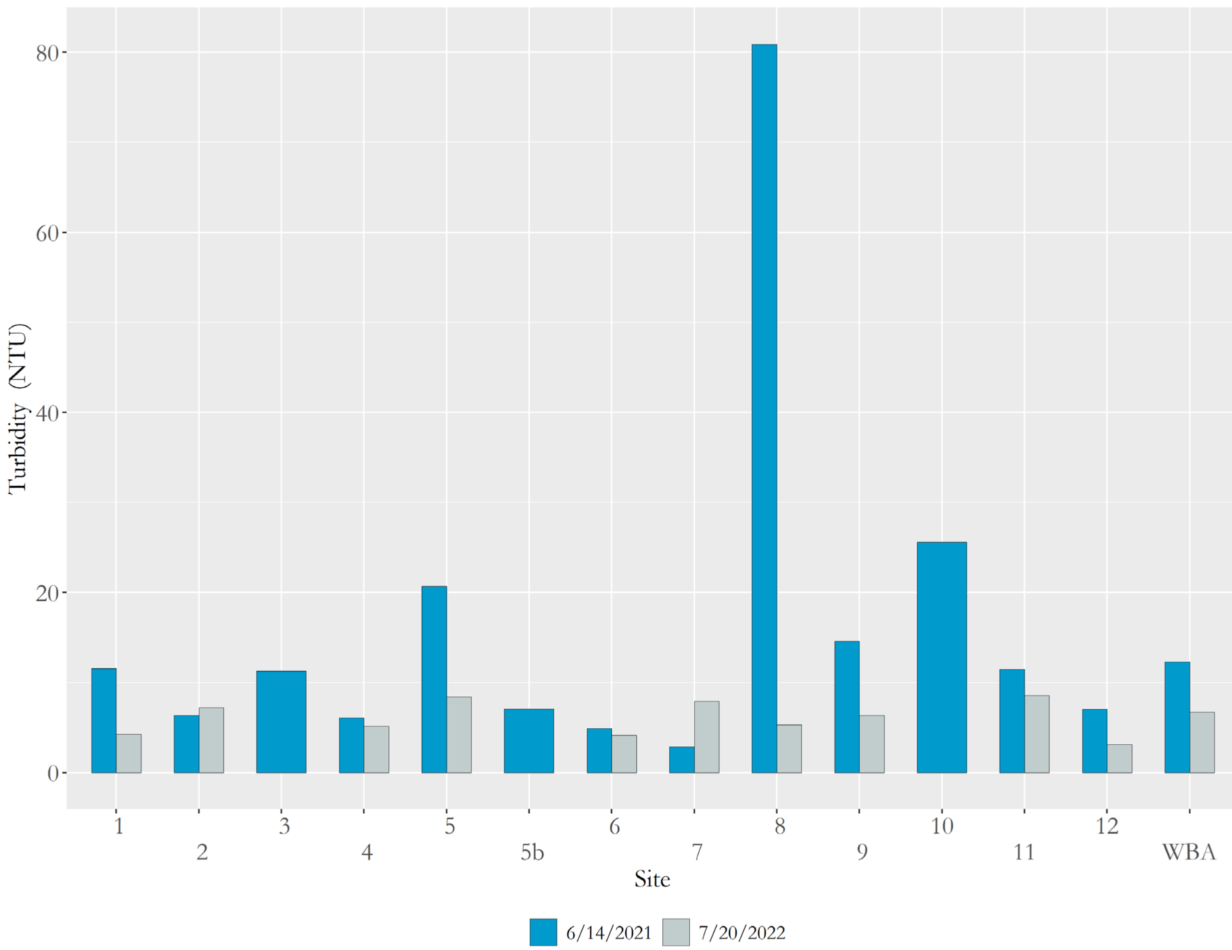



Figure 26. Turbidity in NTUs at 14 tributary sites on 14 June 2021 and 20 July 2022.

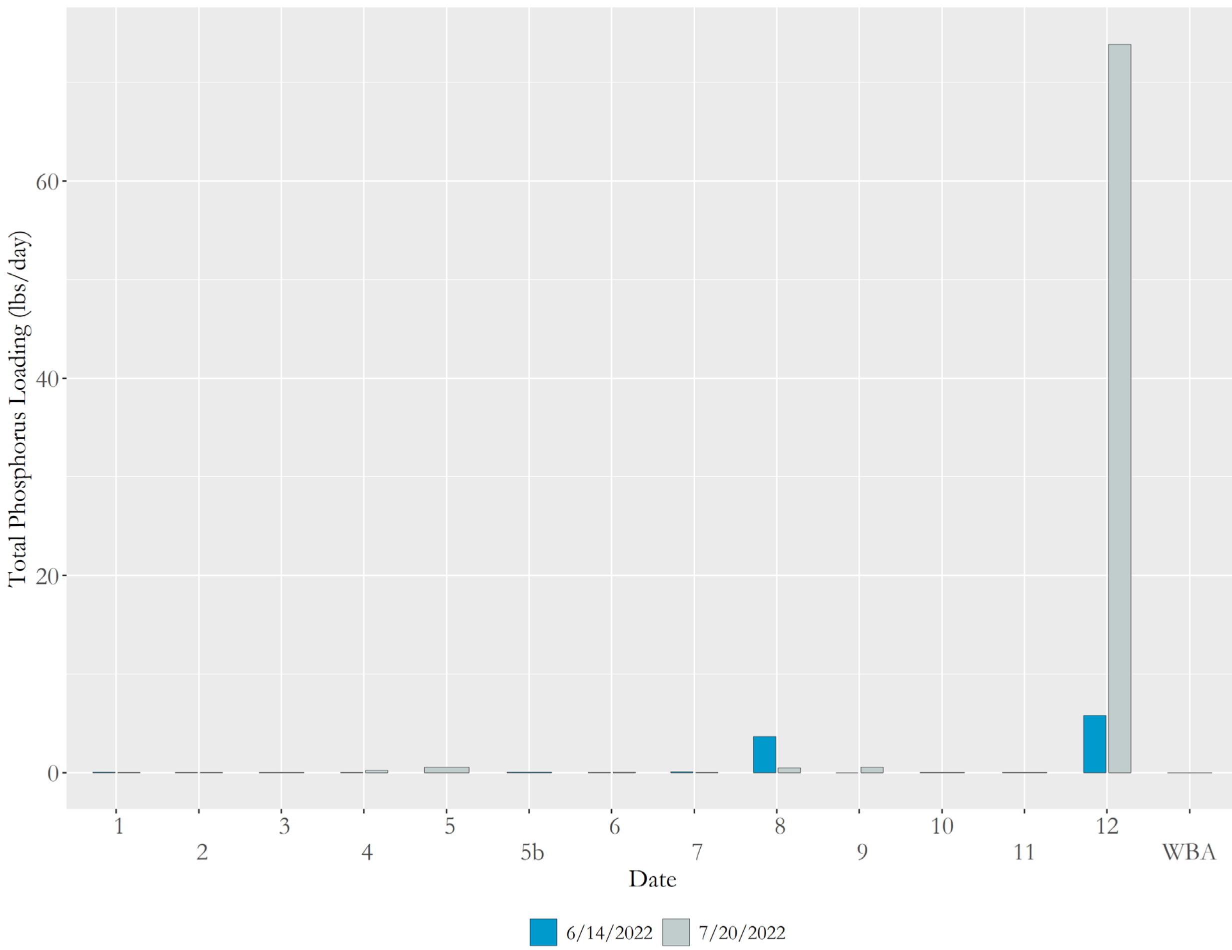



Figure 27. Total Phosphorus loading in pounds per day at 14 tributary sites on 14 June 2021 and 20 July 2022.

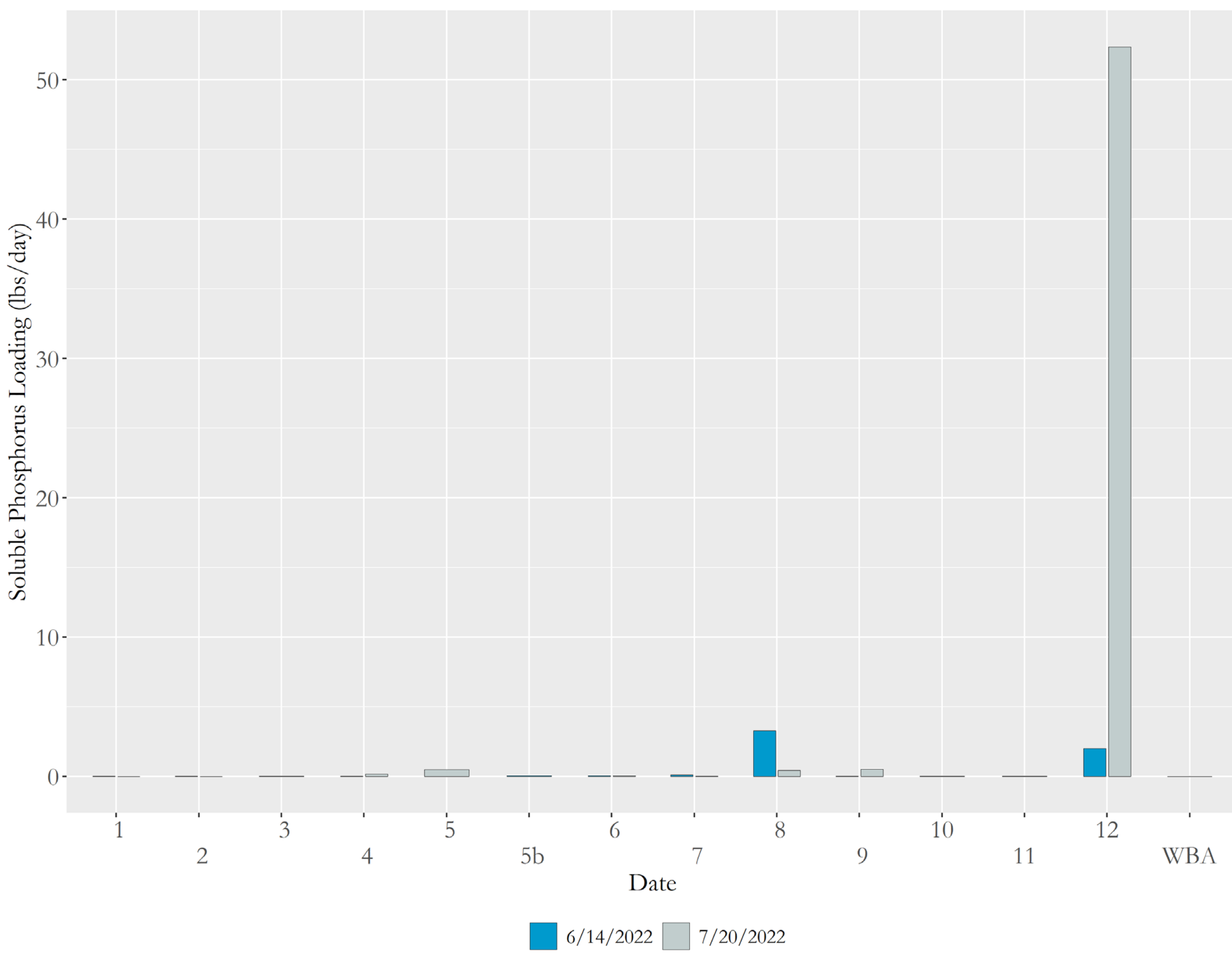



Figure 28. Soluble Phosphorus loading in pounds per day at 14 tributary sites on 14 June 2021 and 20 July 2022.

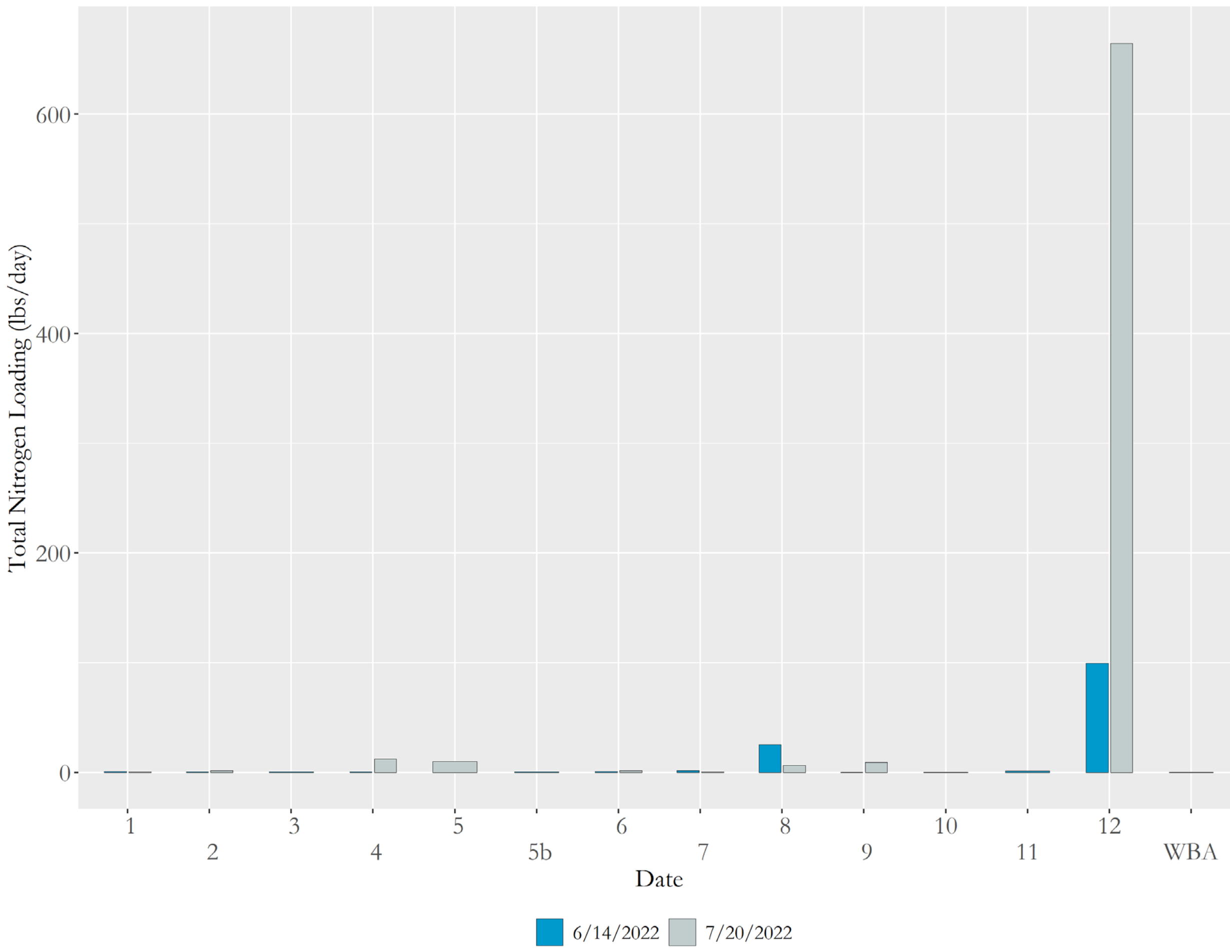



Figure 29. Total Nitrogen loading as pounds per day at 14 tributary sites on 14 June 2021 and 20 July 2022.

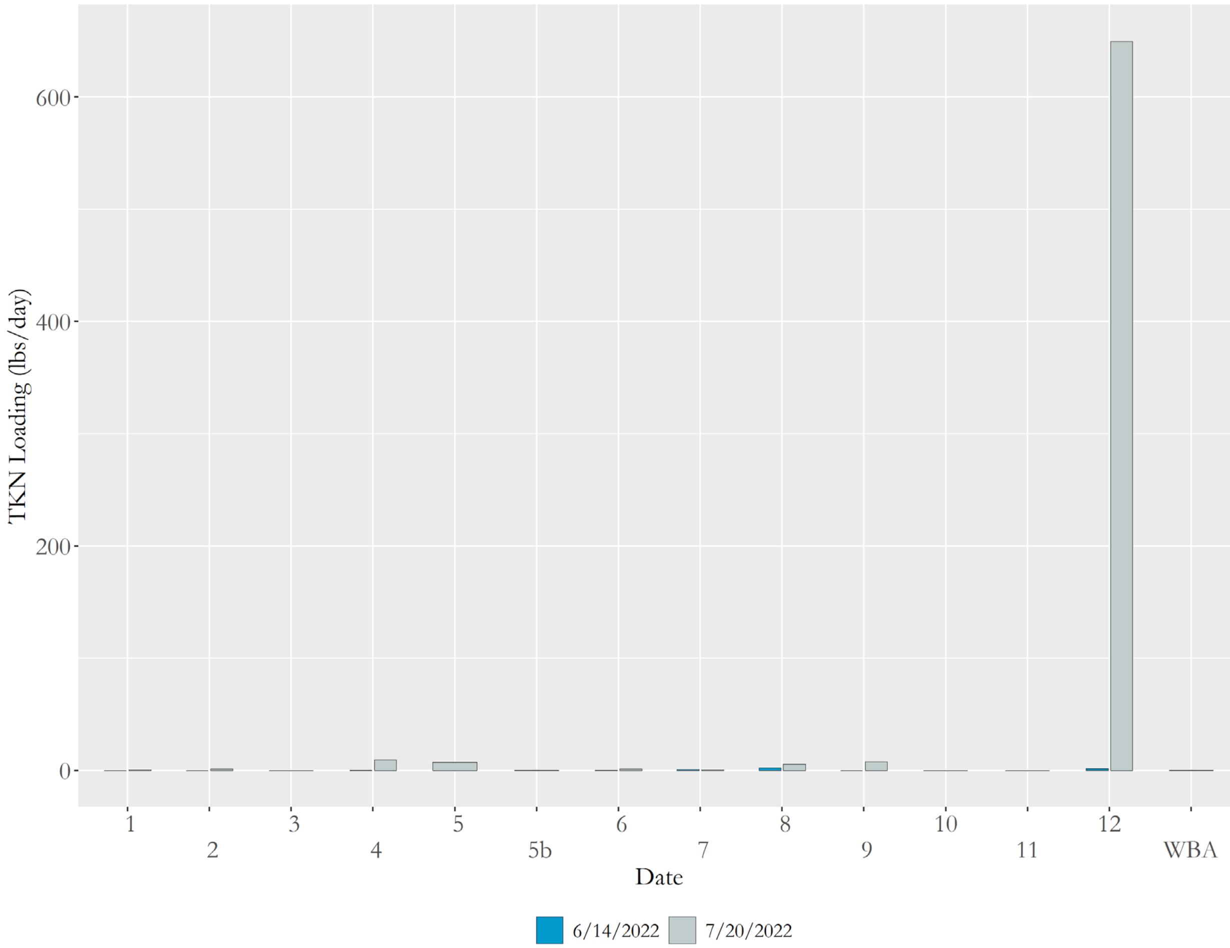



Figure 30. Total Kjeldahl Nitrogen (TKN) loading as pounds per day at 14 tributary sites on 14 June 2021 and 20 July 2022.

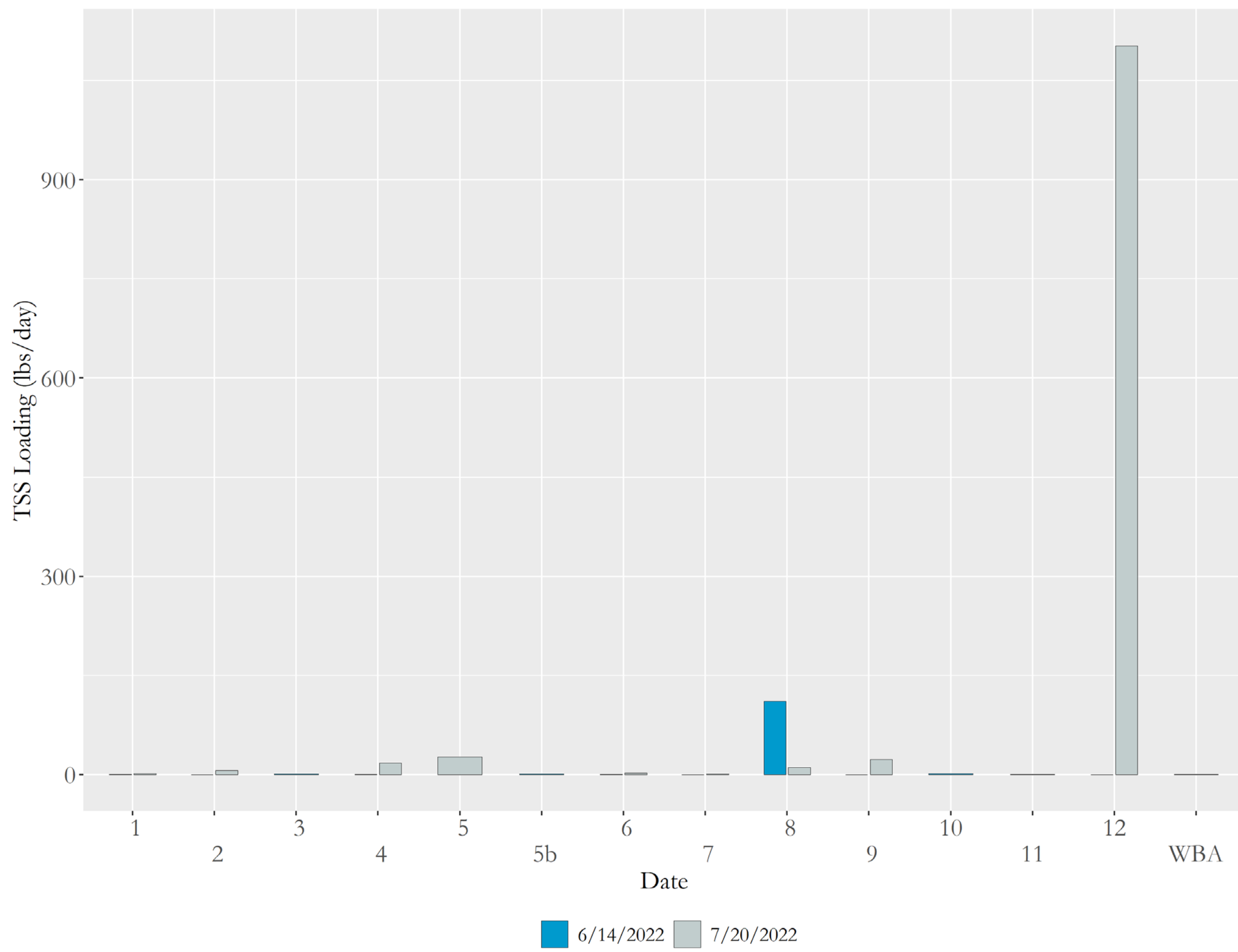



Figure 31. Total Suspended Solids (TSS) loading as pounds per day at 14 tributary sites on 14 June 2021 and 20 July 2022.

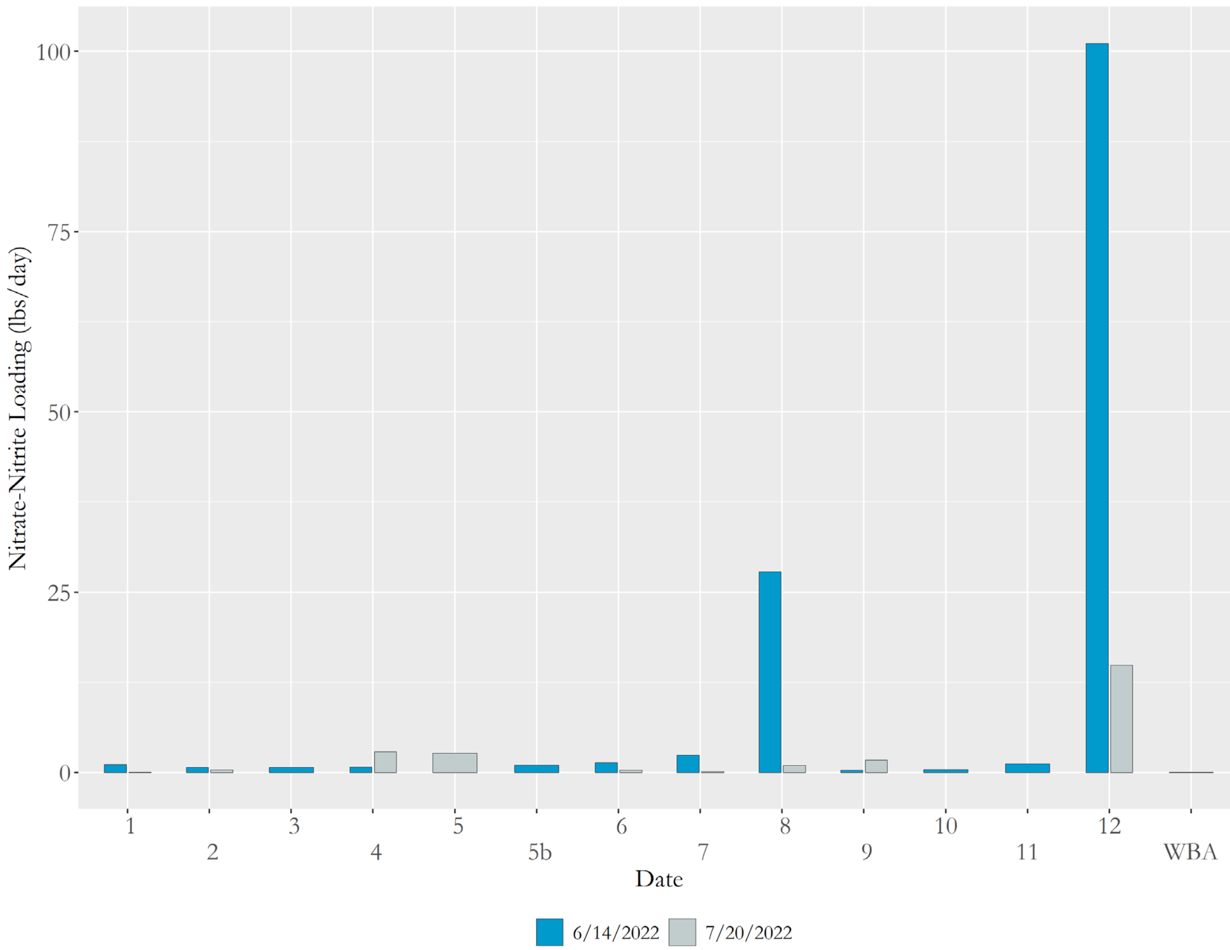



Figure 32. Nitrate-Nitrite loading at 14 tributary sites on 14 June 2021 and 20 July 2022.

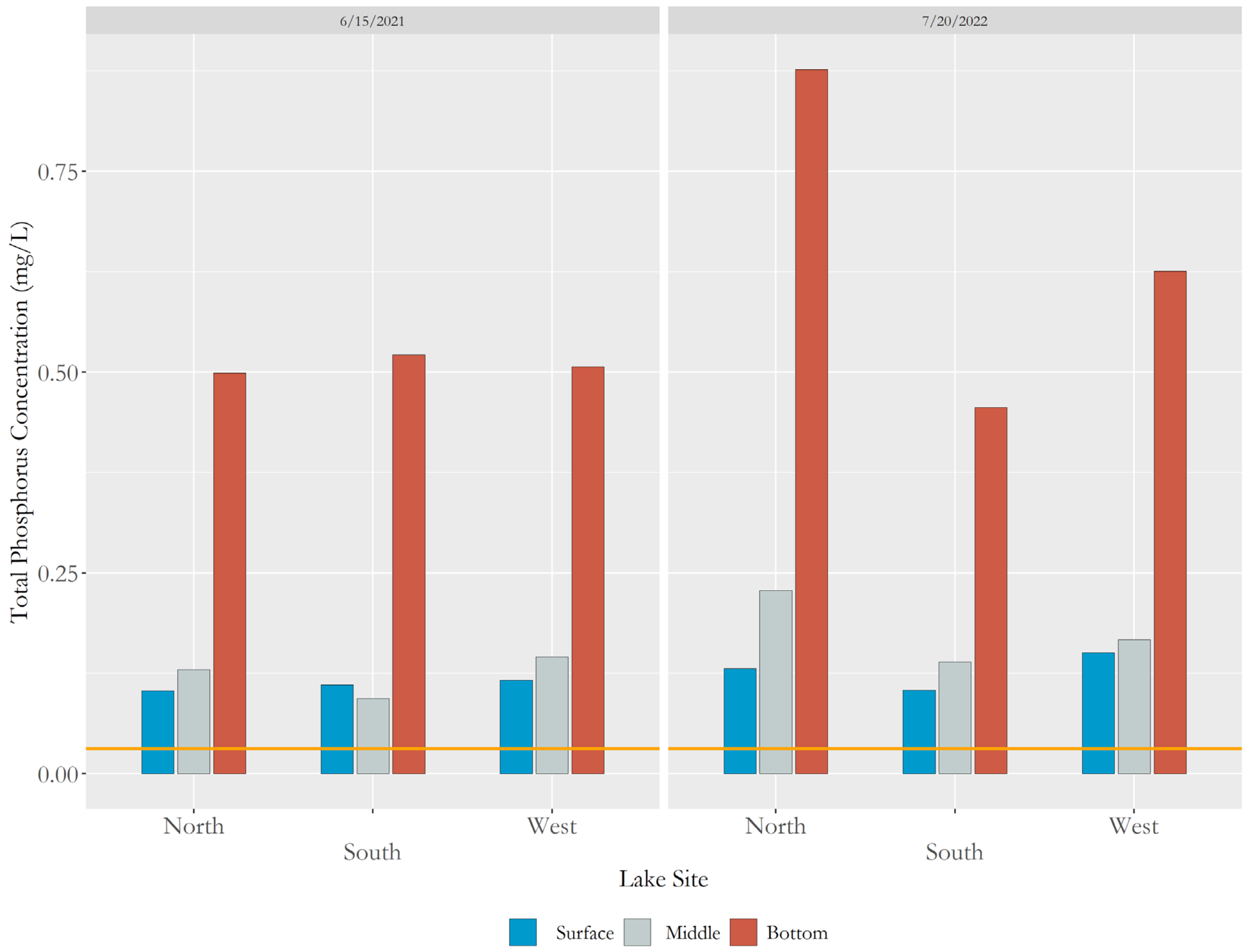



Figure 33. Total Phosphorus concentration in West Boggs Lake at the surface, middle, and bottom of the water column at the North, South, and West sampling sites on 15 June 2021 and 20 July 2022. The horizontal orange bar represents the target value for Total Phosphorus of 0.031 mg/L.

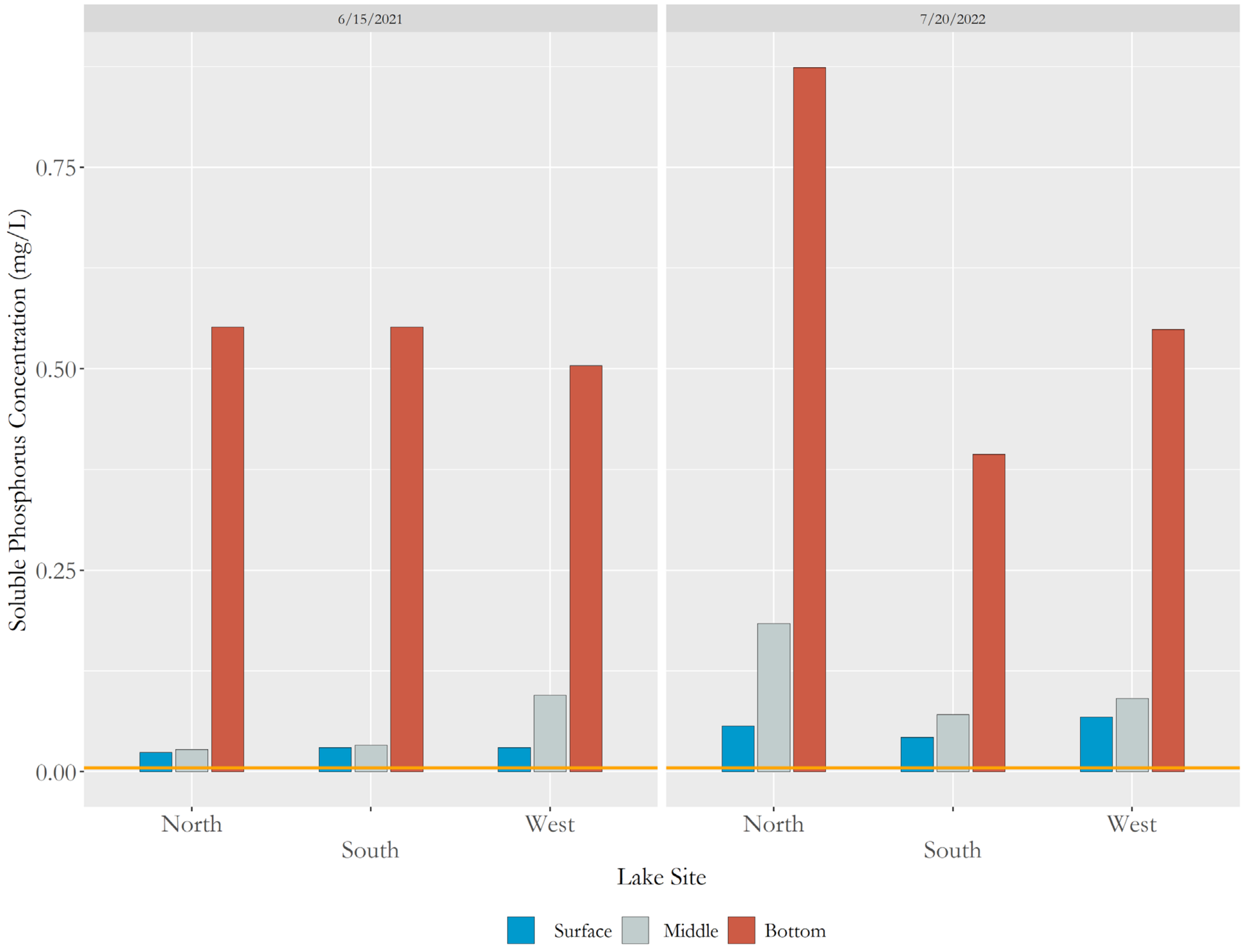



Figure 34. Soluble Phosphorus concentration in West Boggs Lake at the surface, middle, and bottom of the water column at the North, South, and West sampling sites on 15 June 2021 and 20 July 2022. The horizontal orange bar represents the target value for Soluble Phosphorus of 0.005 mg/L.

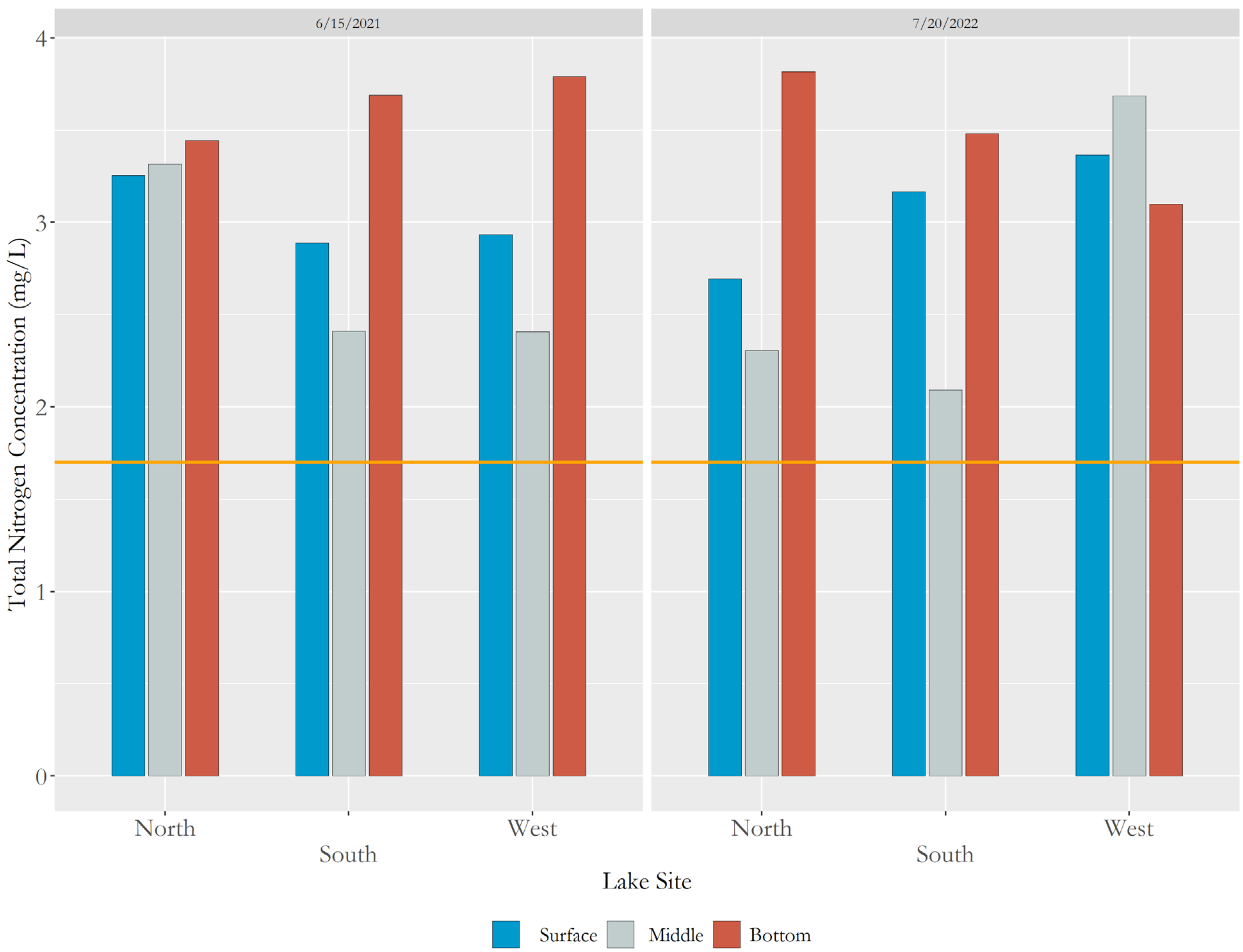



Figure 35. Total Nitrogen concentration in West Boggs Lake at the surface, middle, and bottom of the water column at the North, South, and West sampling sites on 15 June 2021 and 20 July 2022. The horizontal orange bar represents the target value for Total Nitrogen of 1.7 mg/L.

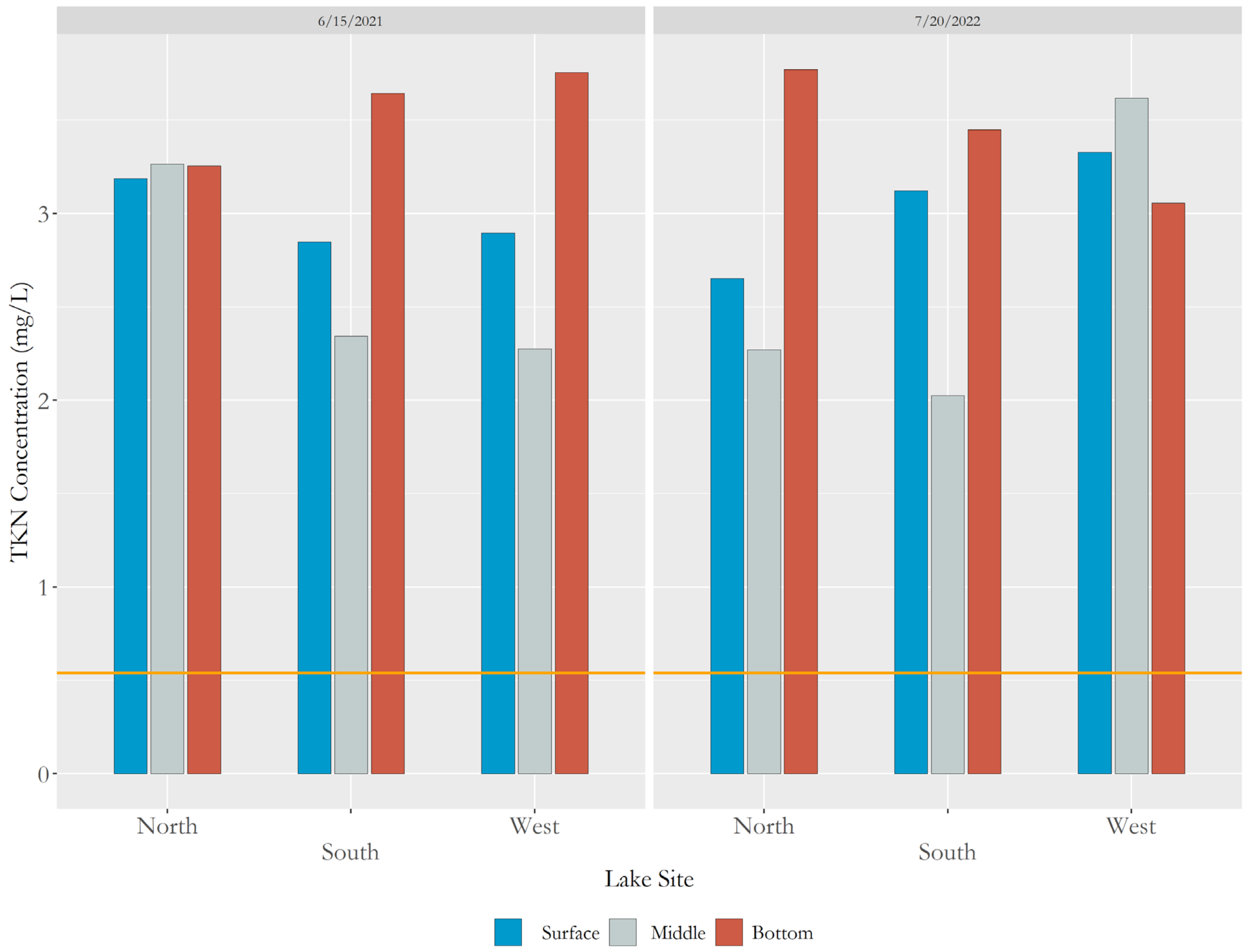



Figure 36. Total Kjeldahl Nitrogen concentration in West Boggs Lake at the surface, middle, and bottom of the water column at the North, South, and West sampling sites on 15 June 2021 and 20 July 2022. The horizontal orange bar represents the target value for Total Kjeldahl Nitrogen of 0.54 mg/L.

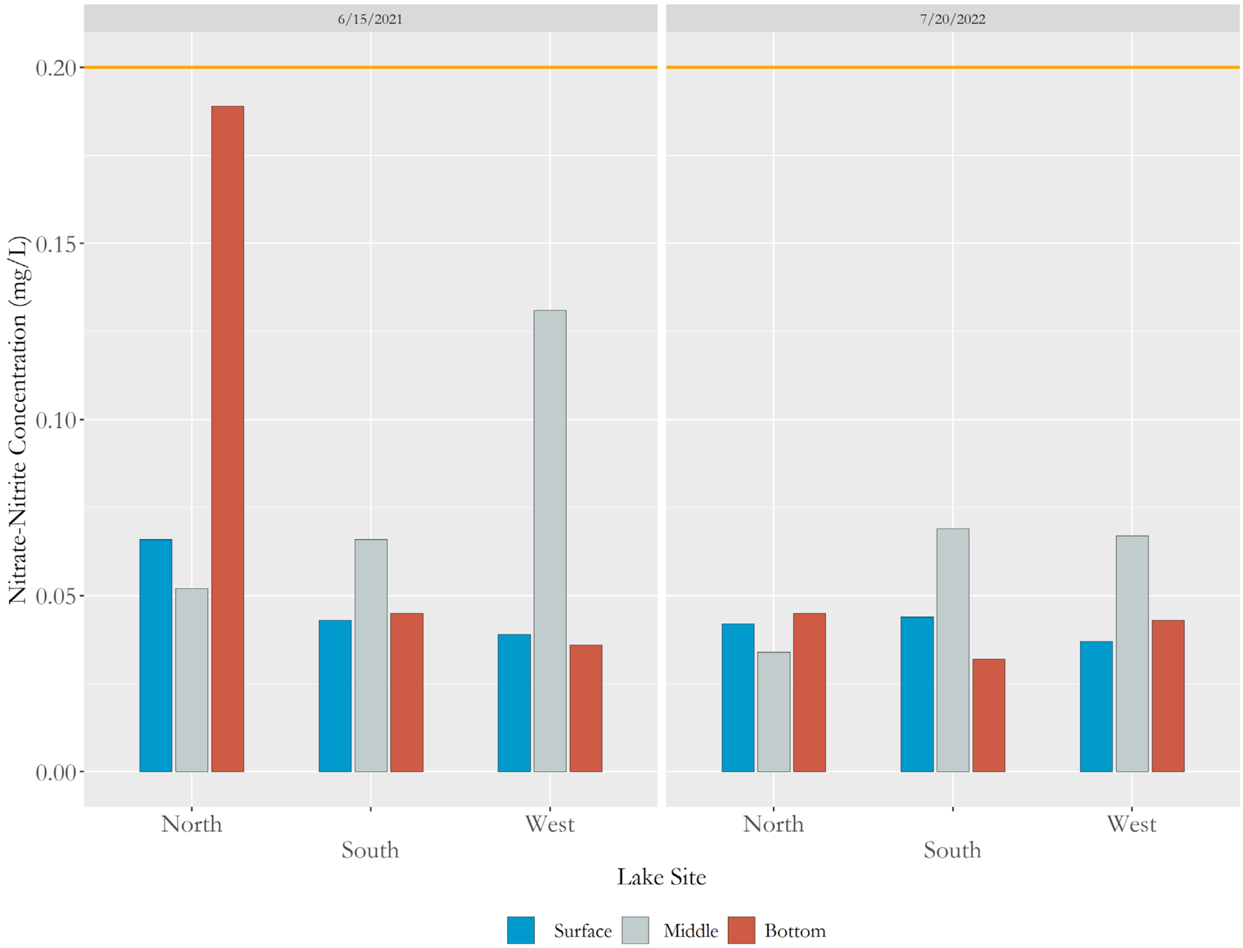



Figure 37. Nitrate-Nitrite concentration in West Boggs Lake at the surface, middle, and bottom of the water column at the North, South, and West sampling sites on 15 June 2021 and 20 July 2022. The horizontal orange bar represents the target value for Nitrate-Nitrite of 0.2 mg/L.

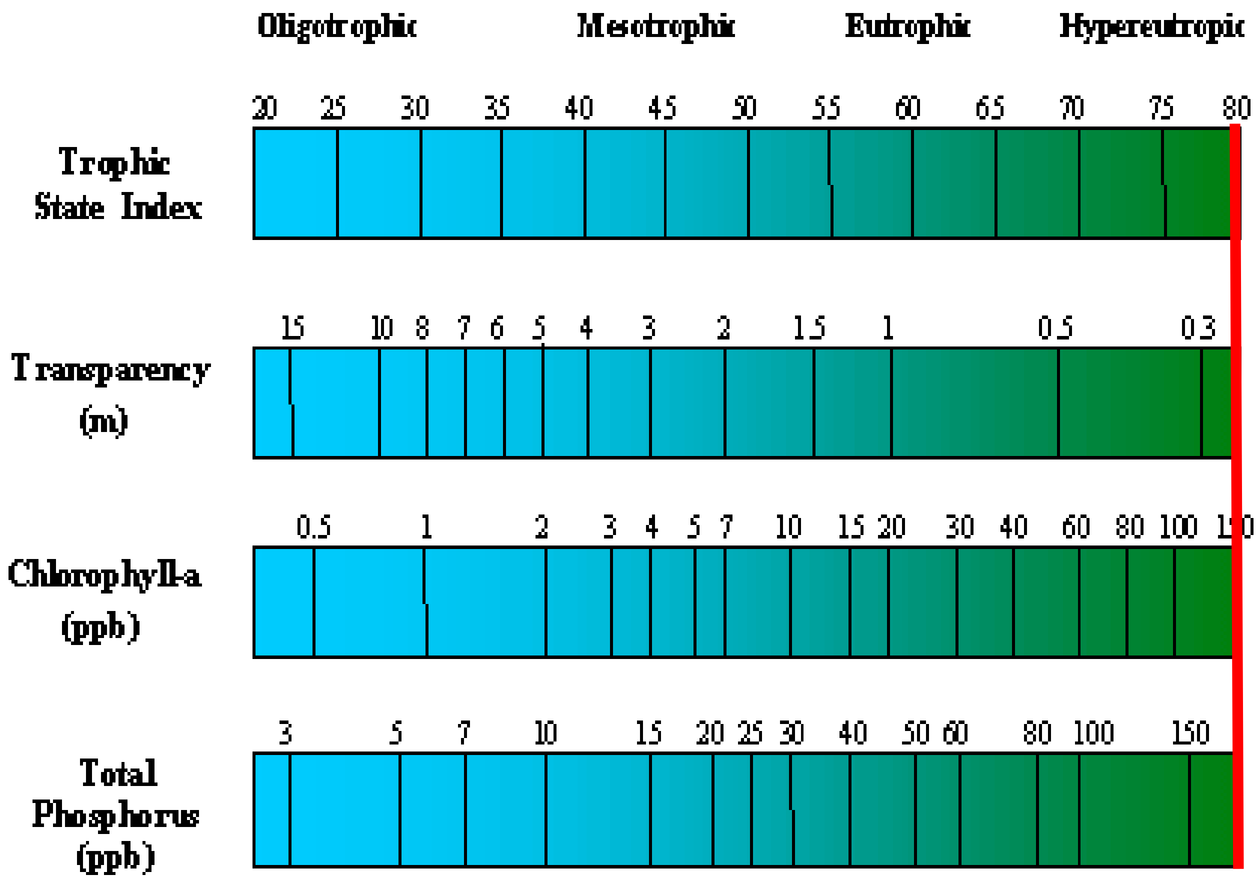



Figure 38. The Carlson Trophic State Index (TSI) score for West Boggs Lake and accompanying parameters used to rank Carlson TSI. The TSI score for West Boggs Lake is 85.6, or off this chart.

Biological and Habitat Sampling

A total of nine sites were evaluated for fish community assessment and stream habitat. Three sites (Site 3, Site 10, Site 11) were not able to be accessed due to low water conditions and logistical restraints. Resulting IBI scores from fish sampling at eight evaluated sites ranked as "Poor". No fish were found at Site 7, therefore an IBI score could not be calculated. Scores ranged from a low of 26 and a high of 30 (Figure 39). Habitat scores were more variable than IBI scores. QHEI scores ranked from "Very Poor" to "Good." Scores ranged from a low of 18 to a high of 59 (Figure 39).

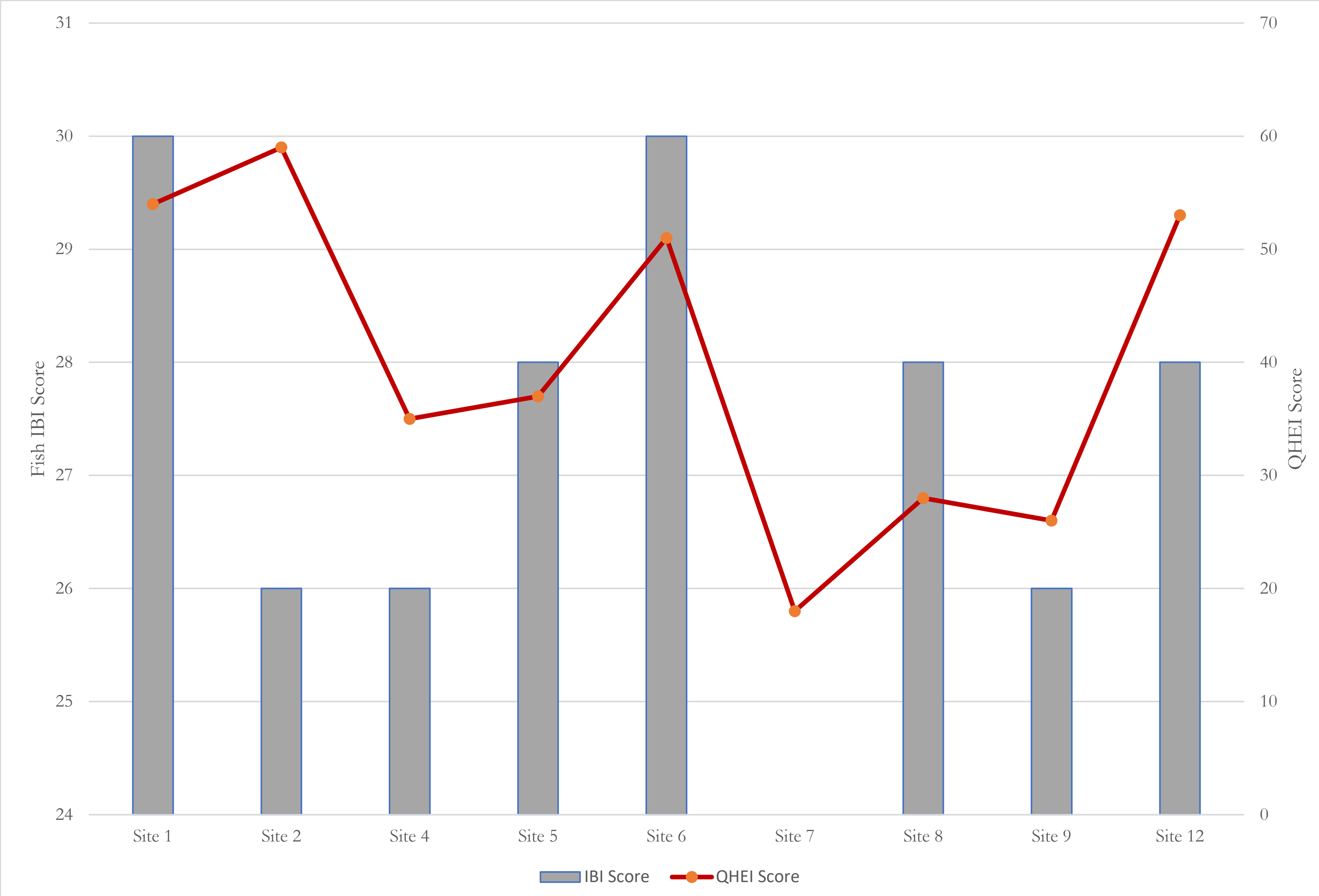



Figure 39. Index of biotic integrity (IBI) and Qualitative Habitat Evaluation Index (QHEI) scores at nine evaluated sites on West Boggs Lake tributaries. No fish were sampled at Site 7

| QHEI Rating | Score |
|---|---|
| Fully supporting | >64 |
| Partially supporting | 51-56 |
| Non-supporting | <51 |

| IBI Rating | Score |
|---|---|
| Exceptional | 50-60 |
| Very good | 42-49 |
| Good | 34-41 |
| Fair | 27-33 |
| Poor | 17-29 |
| Very poor | <17 |

*Discussion of Results*

Water quality sampling at tributary sites show elevated phosphorus and nitrogen concentrations across all sites. Concentration of all parameters, except Nitrate-N, exceeded target values on both sampling dates. Loading values at tributary sites were relatively low. However, to calculate loading discharge needs to be related to sample concentration. Discharge was very low or nonexistent during both sampling dates. The low discharge drove loading to be low even through sample concentration was high. Given the elevated nutrient concentrations at sites, it is expected that loading would increase rapidly once discharge increases after a rain event.

Water quality sampling at West Boggs Lake also show elevated phosphorus and nitrogen concentrations, evidence of a severely degraded lake. All parameters, except Nitrate-N, exceeded target values at all sites and depths. The N:P ratio is an important factor that determines the algal community of a lake. Low N:P ratios can lead blue green algae (Harmful Algal Bloom) to become the dominant algae. The conditions for blue green algae to become dominant certainly exist in West Boggs Lake since the N:P is 11:1. For reference, a N:P ratio of 25-28:1 is required to limit blue green algal growth. Reports on West Boggs Lake, including this one, have documented blue green algal blooms consistently occurring at the lake. In fact, the lake was closed in July 2022 because of a major Harmful Algal Bloom. Water quality data collected for this study suggest that Harmful Algal Blooms (HAB) will continue to occur until nutrient loadings can be reduced. The severity of the HAB will be dependent on climatic conditions experienced across all seasons and current external Phosphorus loads entering the lake.

Biological and habitat sampling at tributary sites show that sites are degraded. The fish community, assessed using IBI scores, ranked as "Poor" at eight of the nine sites. Habitat scores were also consistently low, but some sites did rank as "Good". Site degradation, including embedded substrate and severe bank erosion, was observed at every site. These observations suggest that water storage capacity in the watershed is limited, and water from precipitation is entering streams uninhibited. This causes discharge to peak and drop rapidly which degrades stream habitat, making it difficult for more sensitive species to inhabit the system. The rapid peak and drop dynamic of streams in the watershed also negatively impact water quality.

**Task 4: Hydrology and Lake Habitat Quality**

*Water Budget*

Although a lake appears to be "standing still", water is on the move albeit slowly. The rate of water movement through a lake is highly variable and depends on many complex physical interactions. But water will always flow downhill. A water budget for a lake helps to explain the source of water entering and leaving the lake, and this data is critical to understanding the Trophic State and overall lake health. Water enters a lake from precipitation across the basin and ground water. Water leaves the lake via the lake outflow, evaporation, and directly into groundwater. For this analysis water leaving the lake was measured at West Boggs Lake Outflow (Figure 40). This data was used to measure Lake Flushing Rate and Hydraulic Residency Time (HRT). Additionally, physical features of the lake, such as bathymetry and average depth, can be important in determining these values (Figure 41). This information is required to create a phosphorus and nitrogen budget for a lake.

The Flushing Rate represents the percent of water replaced in the lake each year and the HRT is the number of years it takes to replace the total volume of the lake. For example, the Hydraulic Residency Time for Lake Superior is 200-Years with a Flushing Rate of 0.5% and for Lake Erie the Hydraulic Residency Time is only 2-Years with a Flushing Rate of 50%. The Flushing Rate for West Boggs Lake was 1.61 or 161% of the lake was replaced from April 2021-March 2022 (excluding evapotranspiration and evaporation). The Hydraulic Residency Time for West Boggs Lake was 0.62 years over the study period. The entire lake volume is replaced approximately every 7.5 months. These values can change over time depending on climatic conditions and land use changes in the watershed, but these data suggest water is being replaced in Boggs Lake at a rapid rate.

Figure 40. The pressure transducer at West Boggs Lake Outflow. The pressure transducer was used to measured discharge or the amount of water leaving the lake. Once discharge is measured a water budget for a lake can be created.

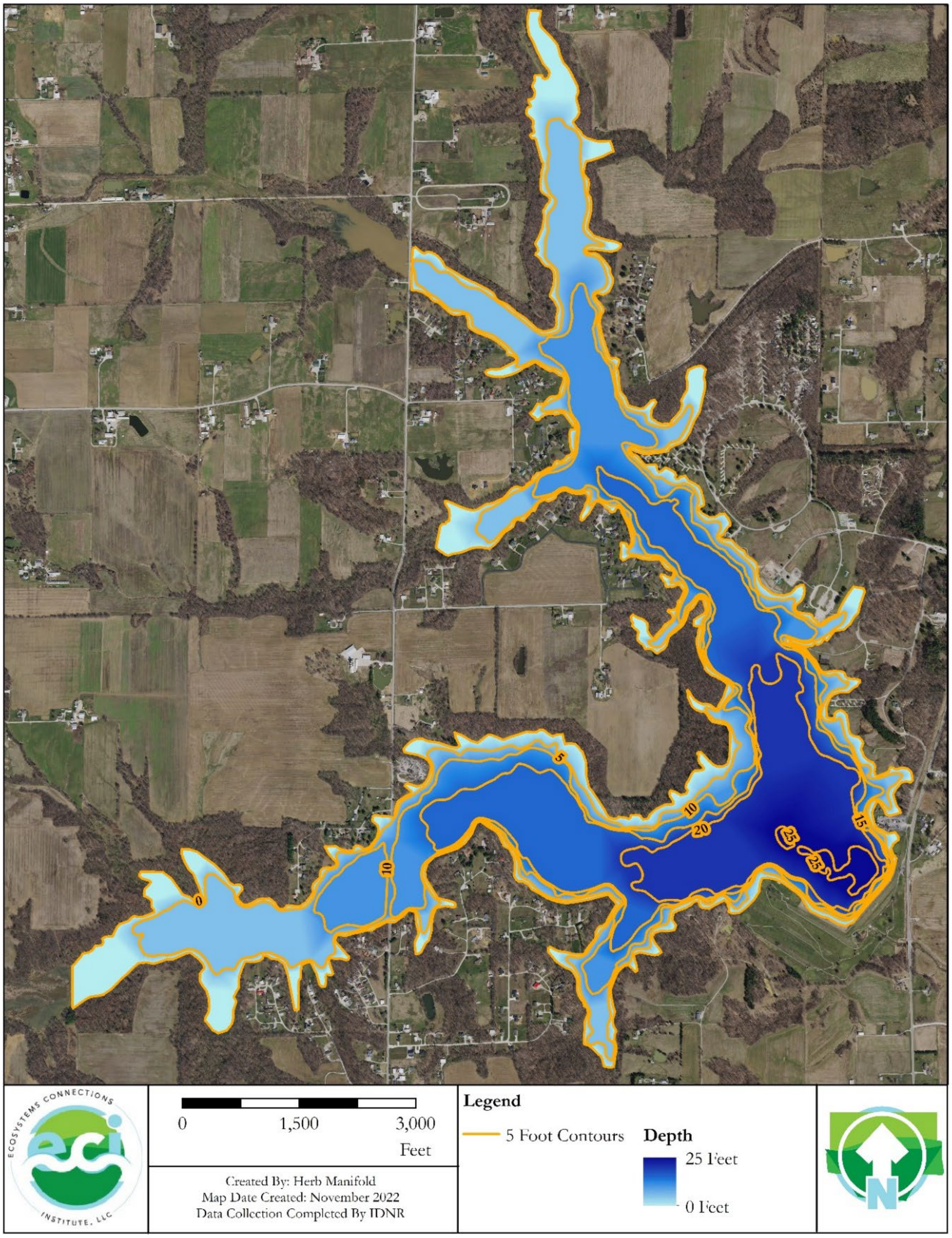



Figure 41. Bathymetry of West Boggs Lake. The dark blue shaded areas represent the deeper portions of the lake, and the light blue represents shallower portions of the lake. Contour lines are at 5-foot increments. The area of Best Boggs Lake is 622-Acres and has a watershed to lake ratio of 13.6:1 or there are 13.6-Acres of watershed for each Acre of the lake.

*Nutrient Budget*

Water quality data has shown that phosphorus and nitrogen are essential nutrients that dictate the health of West Boggs Lake. Since these nutrients are consequential, it is important to understand how phosphorus and nitrogen are brought into, processed, and exit the lake. This is done by creating a phosphorus and nitrogen budget. Budgets for both nutrients were created using the Vollenweider (1975) model. This model uses the nutrient concentration in the lake, mean depth, and flushing rate to estimate load. The estimated load from the model does not differentiate between external (from the watershed) and internal (from the lake) loading.

Vollenweider Model Equation:

$$L = [P] * (10 + \bar{z}p)$$

Where:

$L$ = Areal Load Rate, g/m$^2$/year

$[P]$ = Average nutrient concentration in the lake, mg/L

$\bar{z}$ = Average depth of the lake, m

$p$ = flushing rate as % water replacement/year

Water samples from the surface, middle, and bottom of the water column from three sampling sites during two sampling events were used to calculate the average Total Phosphorus and Total Nitrogen concentration in West Boggs Lake. The measured average Total Phosphorus concentration was 0.284 mg/L and the average Total Nitrogen concentration was 3.254 mg/L. The flushing rate was 1.61. The average depth of the lake is 3.11 meters.

Results from the Vollenweider model estimate a Total Phosphorus loading rate of 4.262 g/m$^2$/yr (Table 5). For West Boggs Lake to be at the target value of 0.031 mg/L of Total Phosphorus, loading must be reduced by 21,668 pounds per year or a 816% reduction. The Total Nitrogen loading rate was 48.833 g/m$^2$/yr. For West Boggs Lake to be at the target value of 1.7 mg/L of Total Nitrogen, loading must be reduced by 133,088 pounds per year or a 91% reduction.

Table 5. Total Phosphorus and Total Nitrogen budgets for West Boggs Lake Watershed. Loading rates were calculated using the Vollenweider (1975) model.

| Parameter | Total Phosphorus | Units | Total Nitrogen |
|---|---|---|---|
| Concentration in Lake ([P]) | 0.284 | mg/L | 3.254 |
| Mean Depth (z) | 3.11 | m | 3.11 |
| Flushing Rate (*p*) | 1.61 | | 1.61 |
| Hydraulic Residency Time | 0.62 | years | 0.62 |
| | | | |
| L Areal Loading Rate | 4.262 | g/m2/yr | 48.833 |
| | | | |
| Surface area | 259.4 | ha | 259.4 |
| Surface area in Acres | 662 | Acres | 662 |
| Regional Target Value | 0.031 | mg/L | 1.70 |
| Target Areal Loading Rate | 0.465 | g/m2/yr | 25.512 |
| Target Areal Load (Metric) | 1,207 | kg/yr | 66,178 |
| Target Areal Load (English) | 2,655 | lbs/yr | 145,592 |
| Actual Areal Load (Metric) | 11,056 | kg/yr | 126,673 |
| Actual Areal Load (English) | 24,322 | lbs/yr | 278,681 |
| Reduction Needed to Achieve Goal (Metric) | 9,849 | kg/yr | 60,495 |
| Reduction Needed to Achieve Goal (English) | 21,668 | lbs/yr | 133,088 |
| Reduction Per Acre Needed to Achieve Goal (Metric) | 1.17 | kg/acre | 7.17 |
| Reduction Per Acre Needed to Achieve Goal (English) | 2.57 | lbs/acre | 15.77 |

**Task 5: Model nonpoint source pollution in lakes and subwatersheds and sediment basin assessment**

To fulfill modeling needs, ECI utilized data collected Indiana Department of Agriculture (ISDA) on best management practices (BMPs) that were installed in the West Boggs Lake watershed (HUC 12: 051202081102). In addition to tracking BMPs installed in the watershed, ISDA also estimates the resulting load reduction using EPA's Region 5 model. Using this methodology, it was found that BMP installation, acres under a BMP, and resulting load reductions annually varied (Table 6). It appears that in most instances, BMPs installed in the previous years did not carry over to the next year. This is common in ECI's experience with watershed restoration projects in agricultural areas where producers implement a BMP but stop implementation once finical assistance is terminated.

Since there was annual variability in the ISDA dataset, there wasn't a clear understanding on what load reductions could be expected under a "best case scenario". To estimate load reductions under this scenario, ECI utilized the Region 5 and STEPL model and estimated that 30% of the cultivated crop acreage in the watershed would be under cover crop or conservation tillage (60% coverage when combined). This resulted in 2057 acres being under cover crop or conservation tillage (Table 7). However, these results should be taken as provisional since the estimated phosphorus load reduction was calculated using only two sampling events (N=2). Additionally, it should be noted that in ECI's experience, the Region 5 model is inaccurate when compared to ECI's water quality datasets at other watersheds. A helpful saying to keep in mind when reviewing modeled data is that all models are wrong, but some models are useful.

Table 6. Annual best management practice installation and resulting load reductions in the West Boggs watershed (HUC 12: 051202081102). Data was gathered by the Indiana Department of Agriculture.

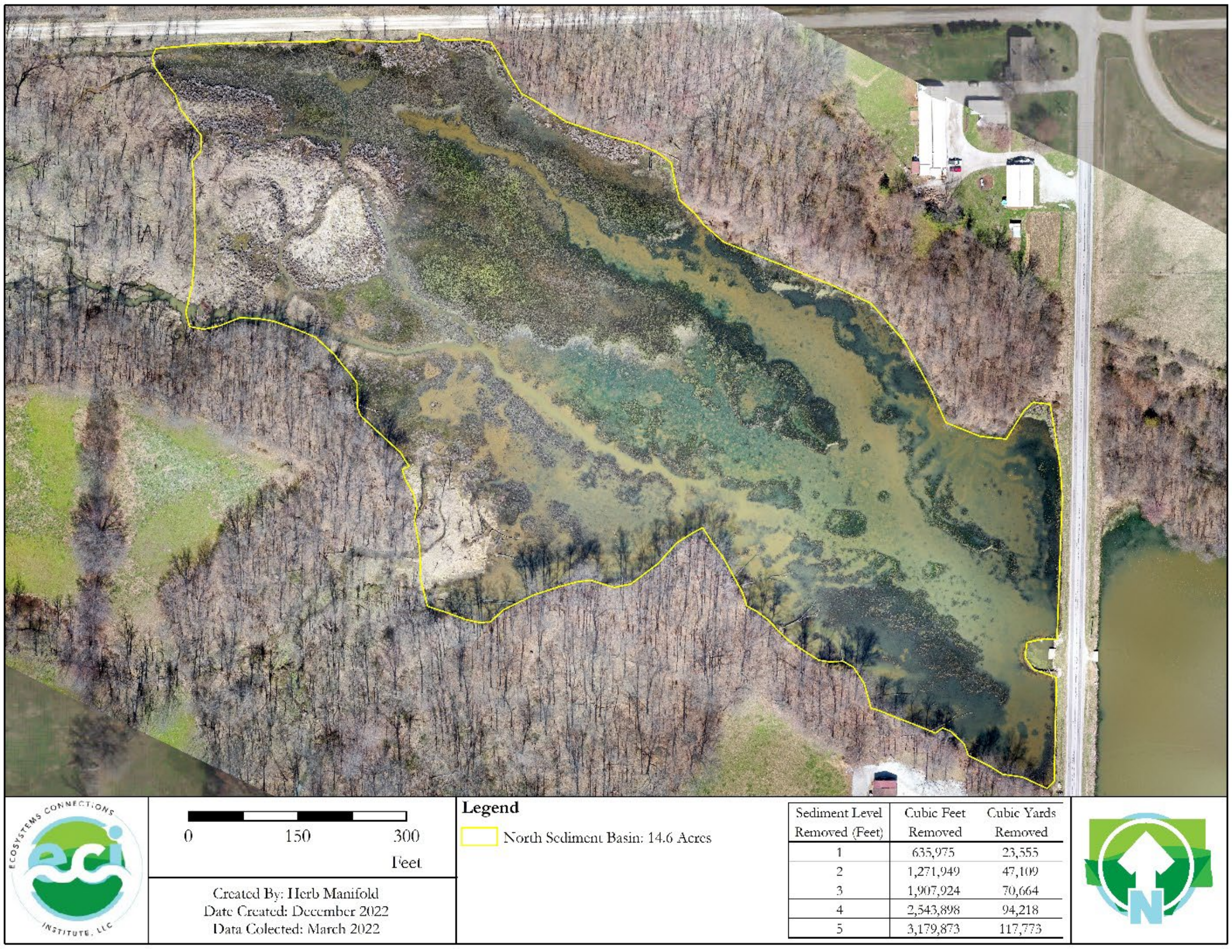
| Year | Most Frequent BMP | Installed BMPs | Active BMPs | Installed Acres | Active Acres | Percent HUC 12 in Conservation | Sediment Reduction (tons) | Phosphorus Reduction (lbs) | Nitrogen Reduction (lbs) |
|---|---|---|---|---|---|---|---|---|---|
| 2013 | Cover Crop | 19 | 19 | 31 | 31 | 0.2 | 18 | 16 | 33 |
| 2014 | Cover Crop | 2 | 5 | 28 | 50 | 0.4 | 27 | 27 | 55 |
| 2015 | Cover Crop | 3 | 6 | 29 | 51 | 0.4 | 334 | 337 | 674 |
| 2016 | | 0 | 4 | 0 | 22 | 0.2 | 213 | 218 | 436 |
| 2017 | Cover Crop | 9 | 13 | 288 | 310 | 2.2 | 1886 | 1764 | 3530 |
| 2018 | Cover Crop | 10 | 13 | 190 | 198 | 1.4 | 934 | 927 | 1855 |
| 2019 | Cover Crop | 15 | 20 | 292 | 301 | 2.1 | 1622 | 1541 | 3090 |
| 2020 | Cover Crop | 14 | 20 | 129 | 137 | 1.0 | 1053 | 1022 | 2047 |
| 2021 | Waste Storage Facility, Water and Sediment Control Basin | 1 | 10 | 0 | 2 | 0.0 | 545 | 525 | 1053 |

Table 7. Estimated load reductions under a best-case scenario for West Boggs Lake watershed (HUC 12: 051202081102). It was estimated both cover crop and conservation tillage practices were adopted at a rate of 30% of cultivated crop acreage (60% of total crop acreage is in a conservation practice).

| Conservation Practice | Pollutant of Concern | Estimated Load Reduction | Total Estimated Load Reduction |
|---|---|---|---|
| Cover Crop | Sediment | 3.6 tons/100 acres/year | 37.02 tons/year |
| | Phosphorus | 7 lbs/100 acres/year | 71.99 lbs/year |
| | Nitrogen | 57.4 lbs/100 acre/year | 590.30 lbs/year |
| Conservation tillage | Sediment | 27.8 tons/100 acres/year | 285.90 tons/year |
| | Phosphorus | 59.6 lbs/100 acres/year | 612.93 lbs/year |
| | Nitrogen | 147.3 lbs/100 acres/year | 1514.83 lbs/year |

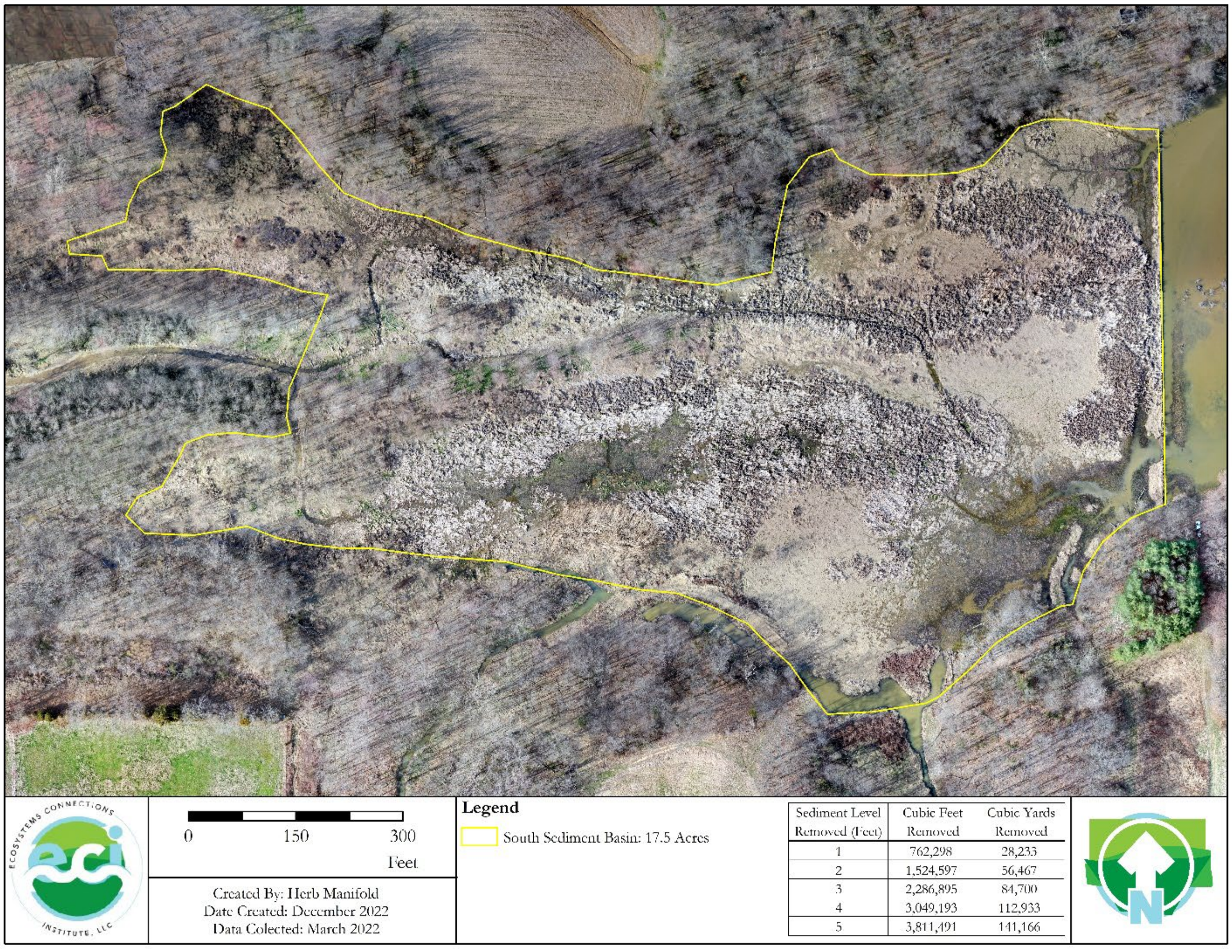
Sediment Basin Assessment

Sediment removal calculations were completed for the North and South basins (Figure 42 and Figure 43). These calculations are presented incrementally from one to five feet in depth (Table 8). The sediment basins have been functional as originally designed, but they have likely reached their capacities. One option for these basins would be to excavate out or dredge the sediment and restore them to some level based on economics. The second option would be to modify flows through each basin from "stream-like" to a more laminar of sheet-flow along with plantings to create a more functional wetland. Data would be helpful to understand sediment and nutrient loads passing through each basin as they exist. This data would be useful to understand and make the best management decision.




| Sediment Level Removed (Feet) | Cubic Feet Removed | Cubic Yards Removed |
|---|---|---|
| 1 | 635,975 | 23,555 |
| 2 | 1,271,949 | 47,109 |
| 3 | 1,907,924 | 70,664 |
| 4 | 2,543,898 | 94,218 |
| 5 | 3,179,873 | 117,773 |

Figure 42. North Sediment basin of West Boggs Lake with calculated cubic feet and cubic yards of sediment by one foot in increments from one to five feet. This sediment basin has an area of 14.6-Acres.




| Sediment Level Removed (Feet) | Cubic Feet Removed | Cubic Yards Removed |
|---|---|---|
| 1 | 762,298 | 28,233 |
| 2 | 1,524,597 | 56,467 |
| 3 | 2,286,895 | 84,700 |
| 4 | 3,049,193 | 112,933 |
| 5 | 3,811,491 | 141,166 |

Figure 43. South Sediment basin of West Boggs Lake with calculated cubic feet and cubic yards of sediment by one foot in increments from one to five feet. This sediment basin has an area of 17.5-Acres.

Table 8. Calculated sediment volume for the north and south basins in cubic feet and by incrementally from one to five feet.

| Sediment Removed Over Entire Basin (Cubic Feet) | | | | Basin Site | Surface Area (Acres) |
|---|---|---|---|---|---|
| Level Removed (Feet) | North Basin | South Basin | | North Basin | 14.6 |
| 1 | 635,975 | 762,298 | | South Basin | 17.5 |
| 2 | 1,271,949 | 1,524,597 | | | |
| 3 | 1,907,924 | 2,286,895 | | | |
| 4 | 2,543,898 | 3,049,193 | | | |
| 5 | 3,179,873 | 3,811,491 | | | |

**Task 6: Assess institutional resources**

Daviees-Martin Joint County Parks and Recreation Department (the Department) manages West Boggs Park which West Boggs Lake is a part of. The Park consists of a 10 member Park Board, Superintendent, and full and part-time employees. The Department has been proactive in planning and managing the resources they are responsible for and have recently published a Master Plan for 2021 – 2025 and a buffer zone management document for West Boggs Lake. The Master Plan acknowledges that blue green algal blooms, driven by excess nutrients, are a concern in West Boggs Lake and that water quality is a management concern for the lake. The Department has already begun outreach to farmers within the watershed. Outreach, combined with this report, which is specifically referenced in the Master Plan, are foundational efforts to mitigate blue green algal blooms on West Boggs Lake.

**Task 7: Prioritize management recommendations**

West Boggs Lake is an impounded waterbody that suffers very simply from acute and chronic effects of too much Phosphorus. The ecological condition of the lake clearly suggests large external and internal loads of Phosphorus well beyond the ability of the lake to assimilate. These loads foster an environment for excessive algae, hypoxia, and they have created a dangerous N:P ratio of 11:1 that facilitates frequent summer Harmful Algal Blooms (HAB). These HAB compromise property values, limit recreational opportunities, and affect local economies that are dependent on an ecologically clean lake. Conceptually, restoration of West Boggs Lake is simple, turn off the Phosphorus tap. While this particular LARE diagnostic study has shed a semi-quantitative light on the degree of the challenge, it is critical to invest in a more robust scientific watershed assessment that will identify accurately and based on data high priority sources of Phosphorus across the watershed. It would be especially helpful to better understand Site 7 sampled during the study. These data can be used to nurture collaboration among the agricultural community, lake property owners, and all other stakeholders. This then becomes less of scientific question and more of a social science set of questions that defines the will of stakeholders to work in partnership and follow the management prescription to reduce Phosphorus from entering the lake. The solution is knowable and the lake along with additional watershed assessment will verify and issue a "grade". There exist well known sets of soil and water conservation best management practices to reduce nutrient and sediment pollution and these practices are strategic and should be viewed within the context of a holistic watershed initiative. There is hope and there is the scientific knowledge to fix West Boggs Lake, and we hope this first step will lead to action. We hope this report will become a working document and not just one more report on a shelf.

**Task 8: Create a public information handout**

An informational brochure will be designed and distributed in early 2023.

**Task 9: Facilitate meetings**

One meeting was held to discuss outcomes of the project and to discuss how to "fix" the lake. The first meeting was held on 5 December 2022 from 10:00-12:30 at West Boggs Park Cedar Cabin. The meeting was attended by Park Board and Park Staff. The group decided to host a second public meeting in January 2023 and directed by ECI. There was agreement to organize a separate meeting to meet with the Amish Bishops. This meeting will be in January or February 2023 and directed by ECI.

**Task 10: Report project progress**

Progress reports were submitted to LARE staff.

**Task 11: Complete Lake Diagnostic Study report**

This report fulfills Task 11.

**Work Cited**


Donan Engineering. 1991. Lake Enhancement Feasibility Study West Boggs Lake.

Donan Engineering. 2002. Post Construction Monitoring Study for West Boggs Reservoir.

Johnson, C. 2020. Fishing revival at West Boggs. The Times-Mail. March 9, 2020.

King, D. 2011. West Boggs Creek Reservoir. 2010. Fish Management Report. Daviess and Martin Counties. Indiana Department of Natural Resources.

King, D. 2017. West Boggs 2016 Management Report. Indiana Department of Natural Resources.

Kittaka, D. S. 2016. West Boggs Creek Lake, Daviess and Martin Counties 2014 Lake Renovation Summary. Indiana Department of Natural Resources.

Kittaka, D. S. 2014. West Boggs Creek Reservoir, Daviess and Martin Counties 2013 Fish Management Report. Indiana Department of Natural Resources.

Kittaka, D. S. 2011. Fishing Pressure, Fish Harvest, and Economic Value of West Boggs Creek Reservoir Fishery: 2010 Fish Management Report. Indiana Department of Natural Resources.

**Appendix**

<u>Lake Profiles</u>

<u>Lake Profile 15 June 2021, North Sampling Site</u>

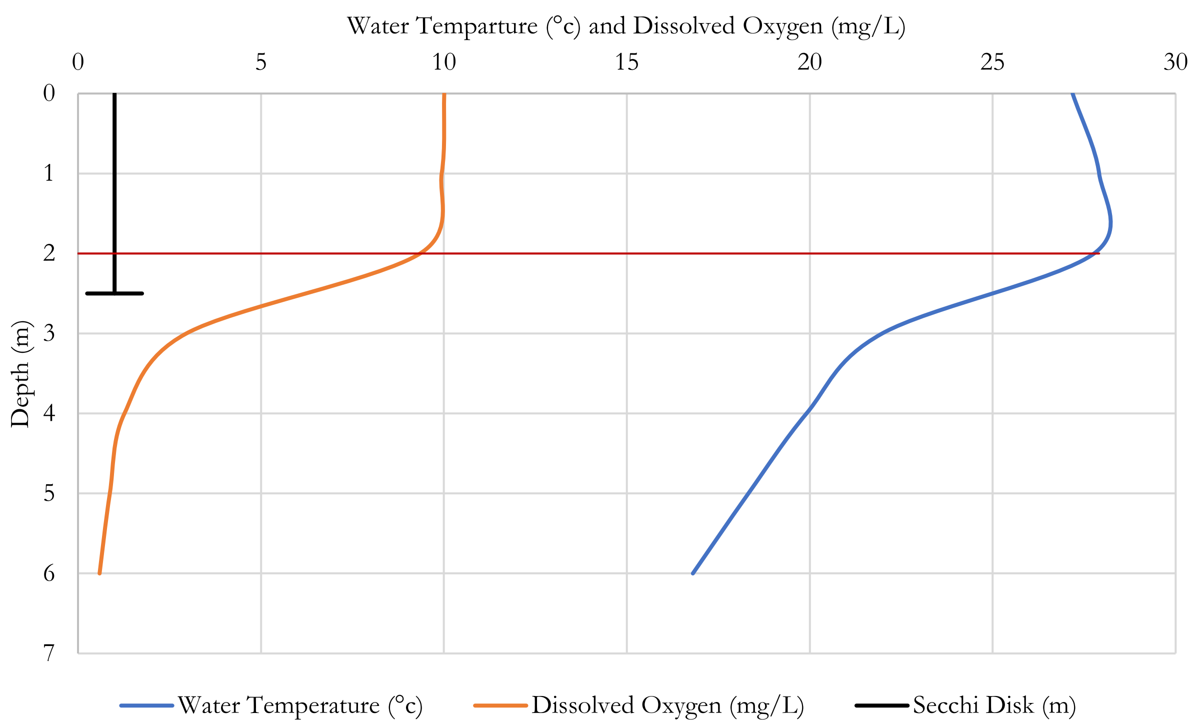



Figure 44. Vertical lake profile taken on 15 June 2021 at the North sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 02-meters. Dissolved oxygen exhibits a strong Clinograde oxygen curve that is typical for a productive lake. The decrease of oxygen in the hypolimnion (bottom-layer) at 02-meters results from respiration exceeding productivity. The hypolimnion becomes hypoxic and at 04-meters. Secchi depth was measured at 2.5 meters.

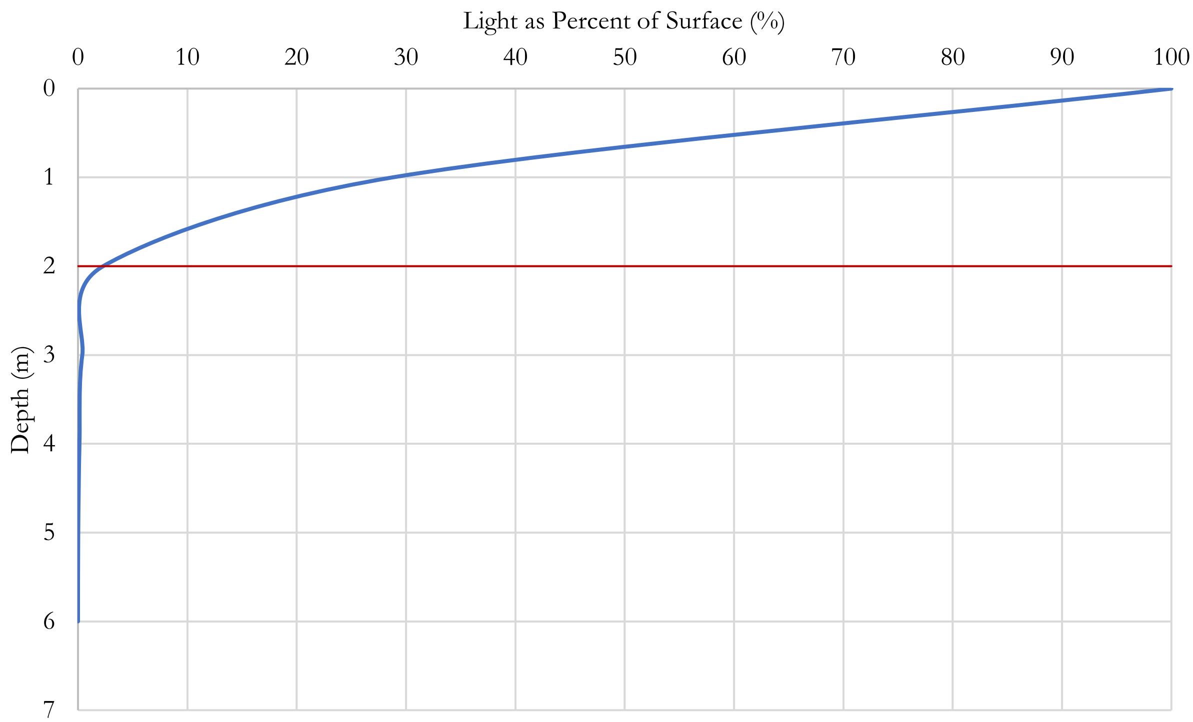



Figure 45. Light attenuation on 15 June 2021 at the North sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 02-meters. This is where the percent of light relative to the values at the surface equals 1%.  The water depth above this 1% level of light equals the photic zone for aquatic plant growth and is approximately 3 times the Secchi depth. Light is measured as Micromole per second and square meter (µmol/$m^{-2}$/$s^{-1}$).

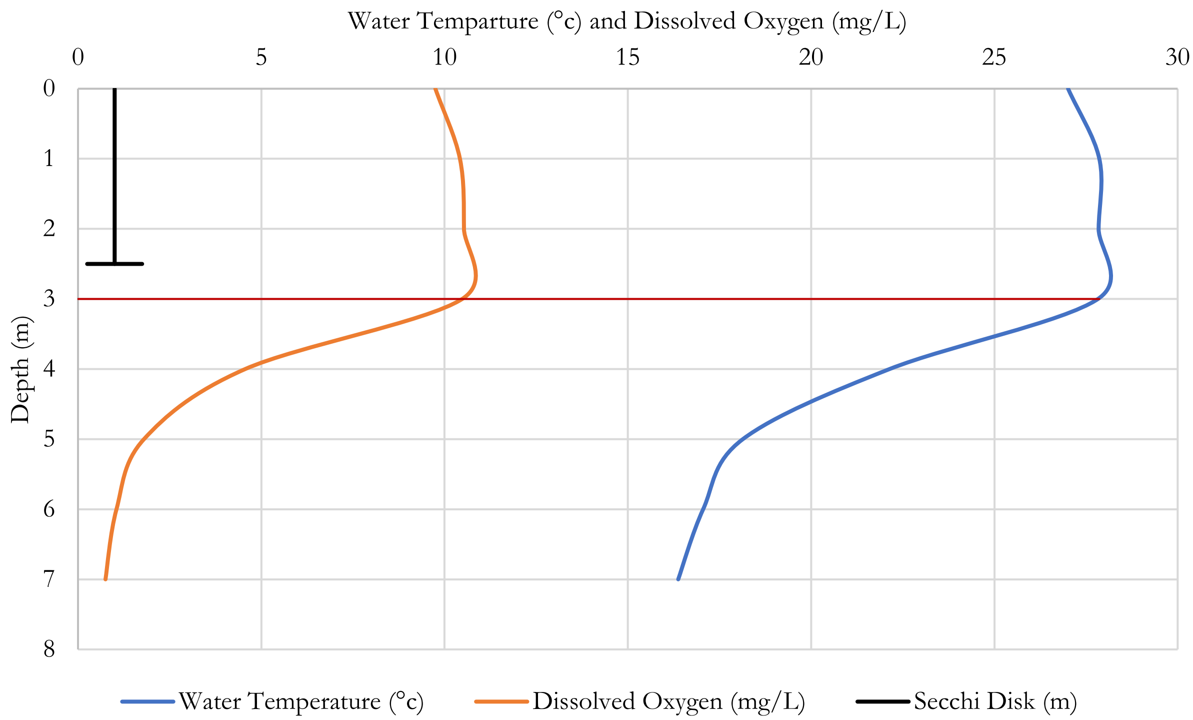



Figure 46. Vertical lake profile taken on 15 June 2021 at the South sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 03-meters. Dissolved oxygen exhibits a strong Clinograde oxygen curve that is typical for a productive lake.  The decrease of oxygen in the hypolimnion (bottom-layer) at 03-meters results from respiration exceeding productivity. The hypolimnion becomes hypoxic and at 05-meters. Secchi depth was measured at 2.5 meters.

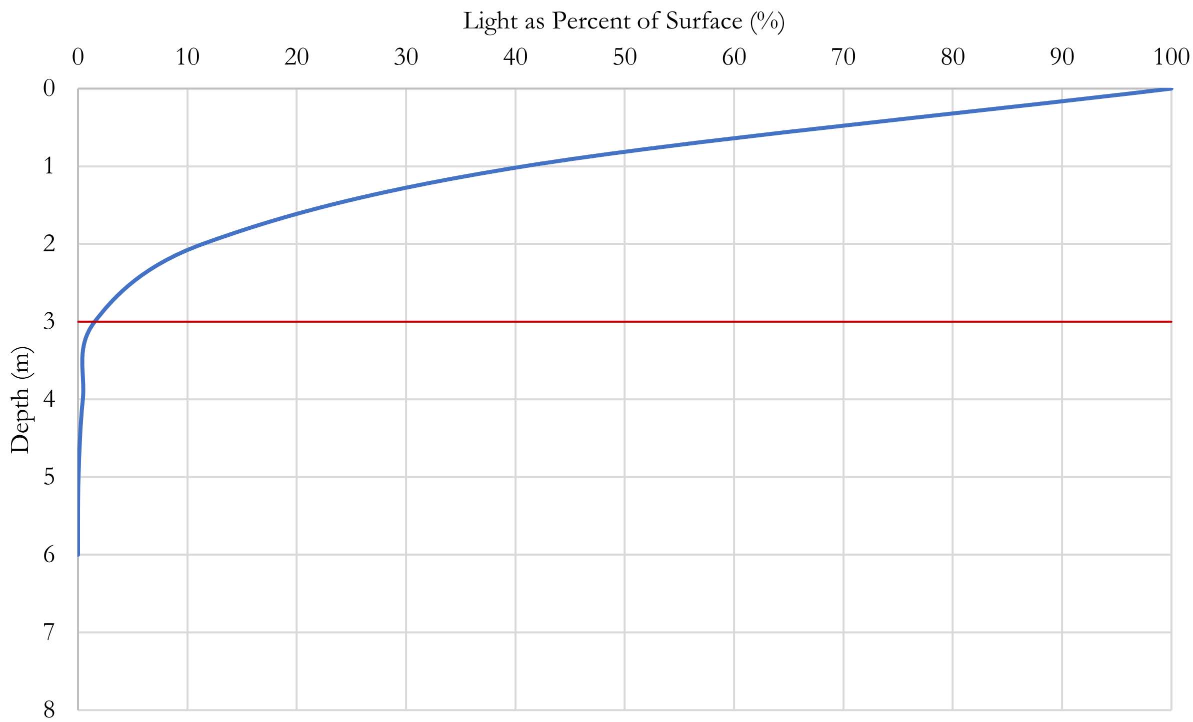



Figure 47. Light attenuation on 15 June 2021 at the South sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 03-meters. This is where the percent of light relative to the values at the surface equals 1%.  The water depth above this 1% level of light equals the photic zone for aquatic plant growth and is approximately 3 times the Secchi depth. Light is measured as Micromole per second and square meter (µmol/$m^{-2}$/$s^{-1}$).

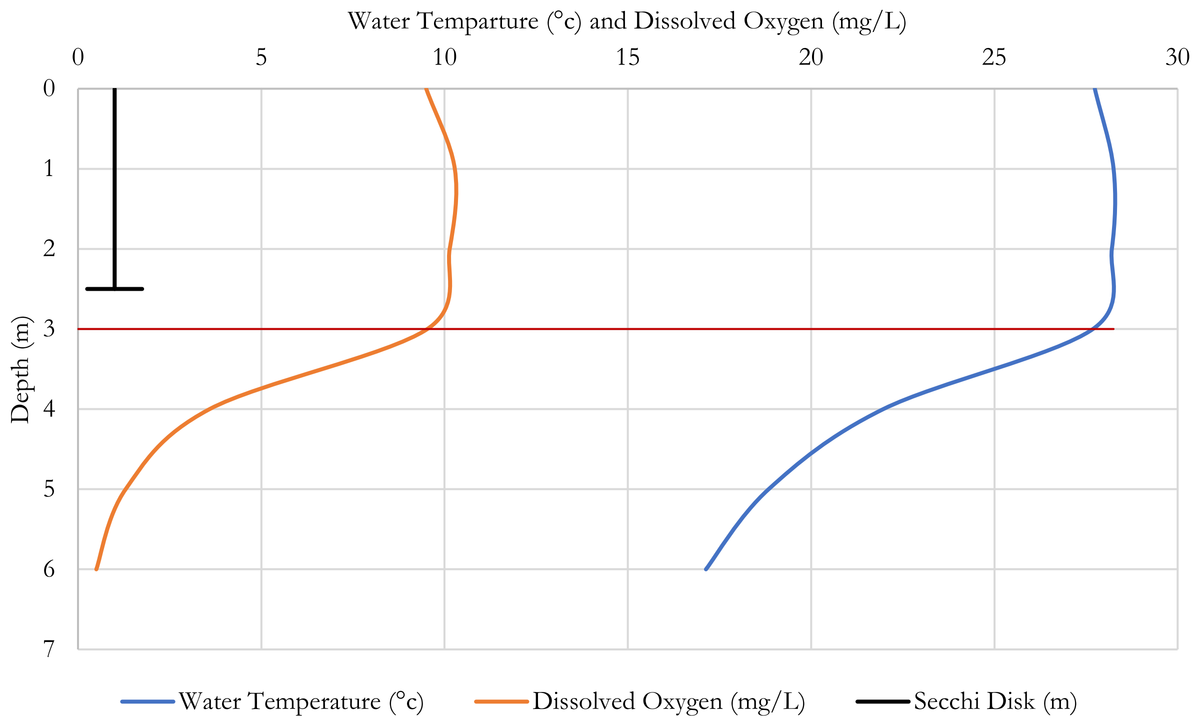



Figure 48. Vertical lake profile taken on 15 June 2021 at the West sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 03-meters. Dissolved oxygen exhibits a strong Clinograde oxygen curve that is typical for a productive lake.  The decrease of oxygen in the hypolimnion (bottom-layer) at 03-meters results from respiration exceeding productivity. The hypolimnion becomes hypoxic and at 05-meters. Secchi depth was measured at 2.5 meters.

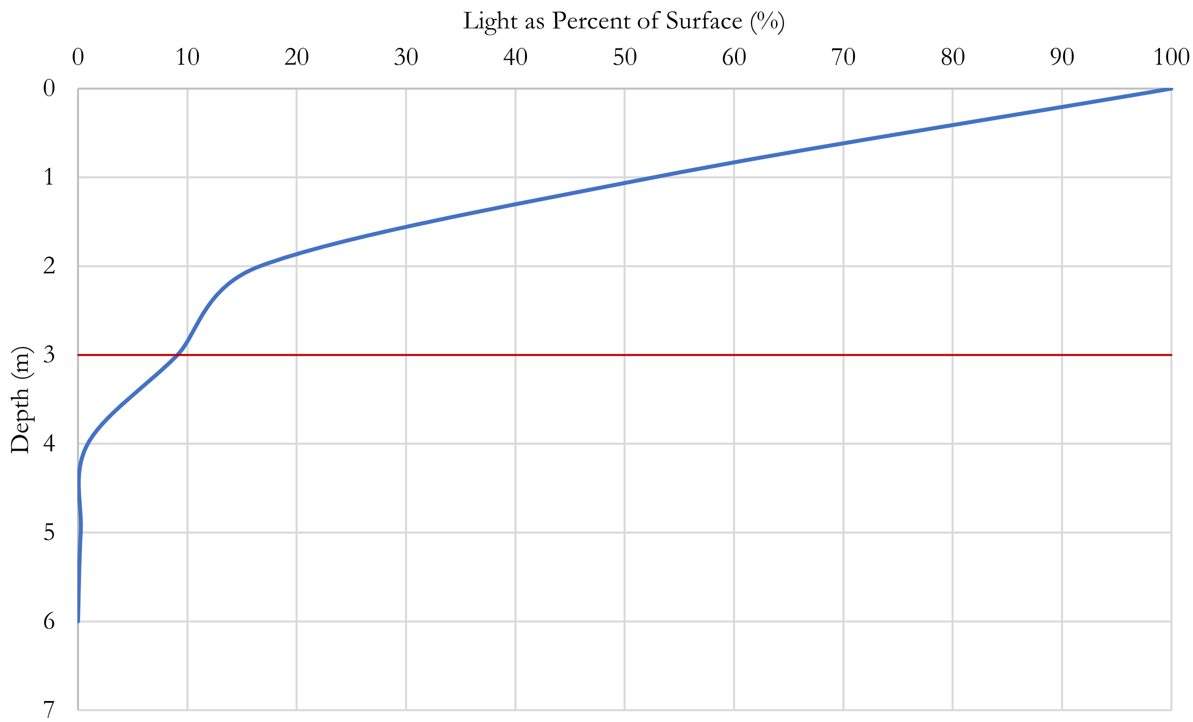



Figure 49. Light attenuation on 15 June 2021 at the West sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 03-meters. This is where the percent of light relative to the values at the surface equals 1%. The water depth above this 1% level of light equals the photic zone for aquatic plant growth and is approximately 3 times the Secchi depth. Light is measured as Micromole per second and square meter ($\mu mol/m^{-2}/s^{-1}$).

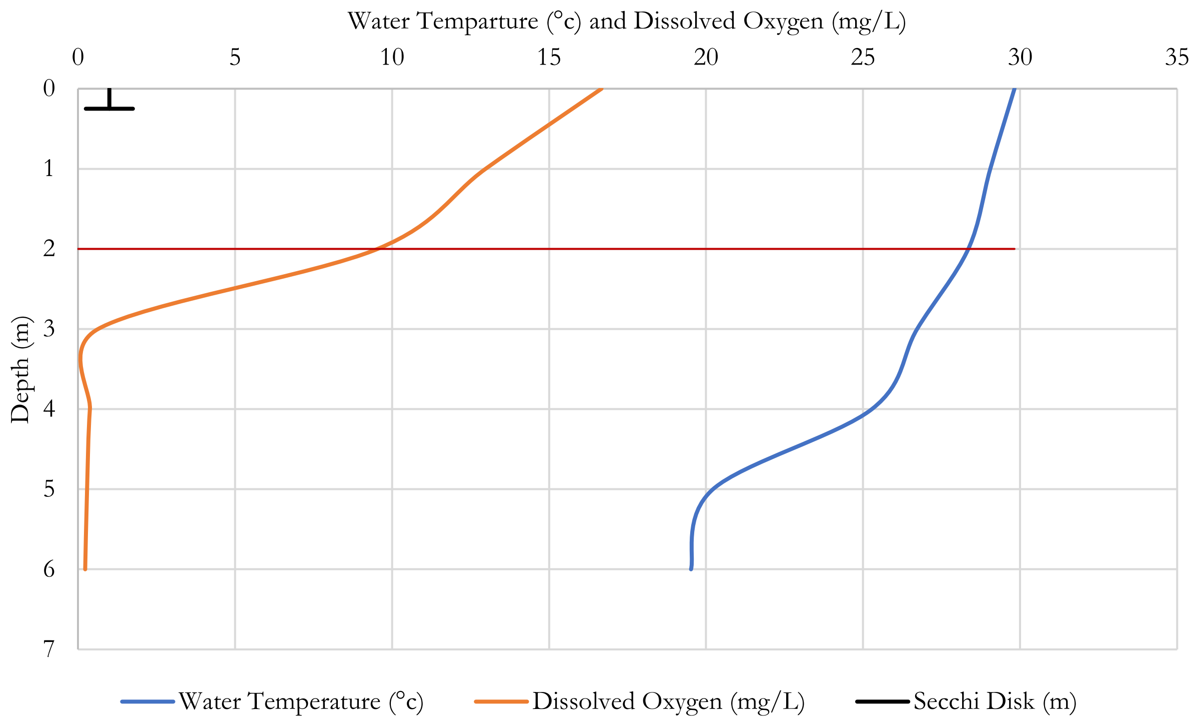



Figure 50. Vertical lake profile taken on 20 July 2022 at the North sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 02-meters. The hypolimnion becomes hypoxic and at 03-meters. Secchi depth was measured at 0.25 meters. The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.

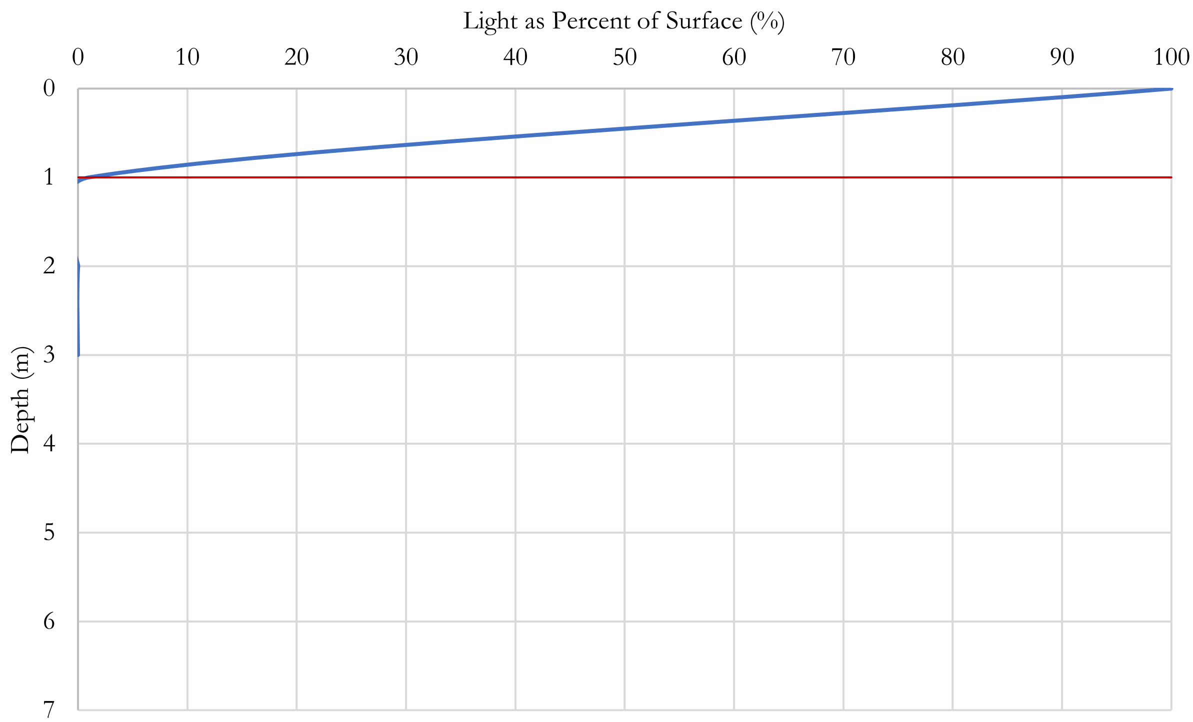



Figure 51. Light attenuation on 20 July 2022 at the North sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 01-meters. This is where the percent of light relative to the values at the surface equals 1%. The water depth above this 1% level of light equals the photic zone for aquatic plant growth and is approximately 3 times the Secchi depth. Light is measured as Micromole per second and square meter ($\mu mol/m^{-2}/s^{-1}$). The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.

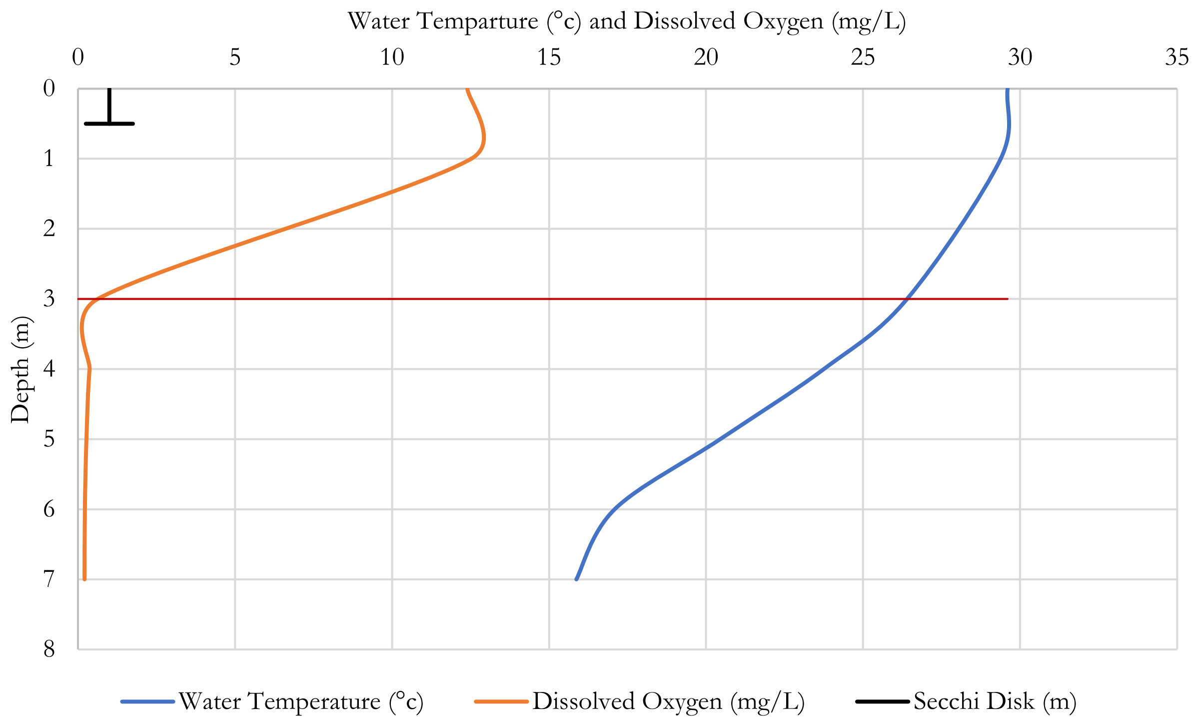



Figure 52. Vertical lake profile taken on 20 July 2022 at the South sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 03-meters. Dissolved oxygen exhibits a strong Clinograde oxygen curve that is typical for a productive lake. The decrease of oxygen in the hypolimnion (bottom-layer) at 03-meters results from respiration exceeding productivity. The hypolimnion becomes hypoxic and at 03-meters. Secchi depth was measured at 0.5 meters. The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.

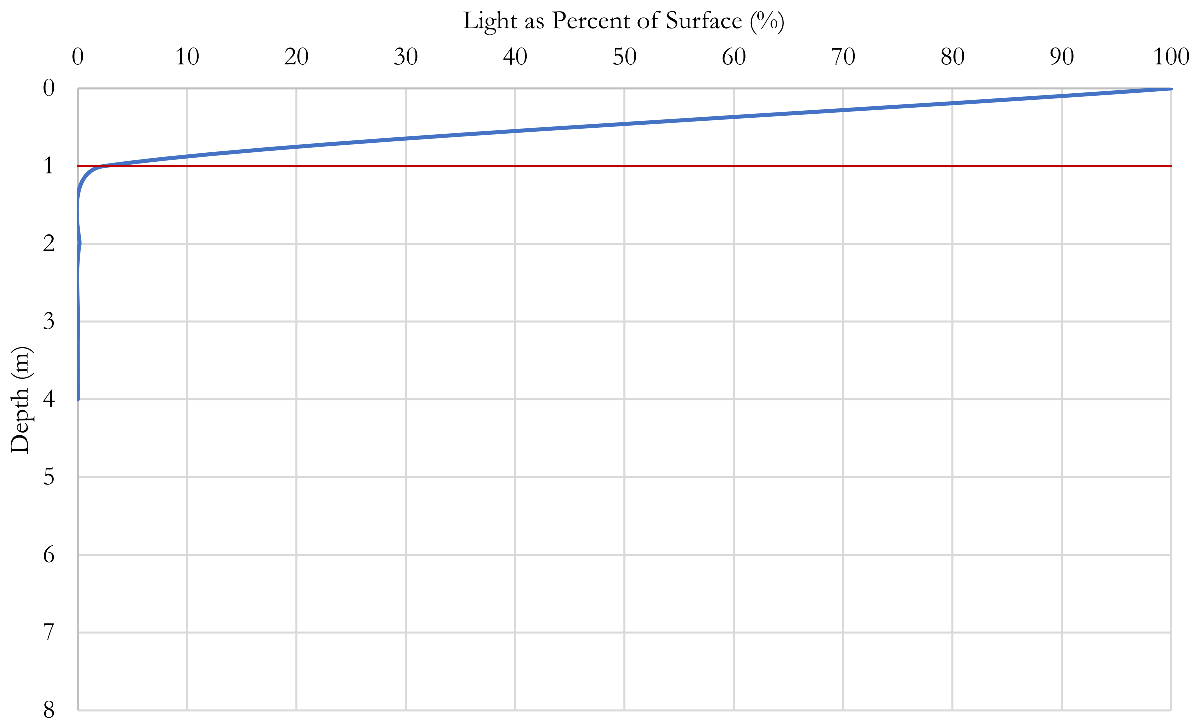



Figure 53. Light attenuation on 20 July 2022 at the South sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 01-meters. This is where the percent of light relative to the values at the surface equals 1%. The water depth above this 1% level of light equals the photic zone for aquatic plant growth and is approximately 3 times the Secchi depth. Light is measured as Micromole per second and square meter (µmol/$m^{-2}$/$s^{-1}$). The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.

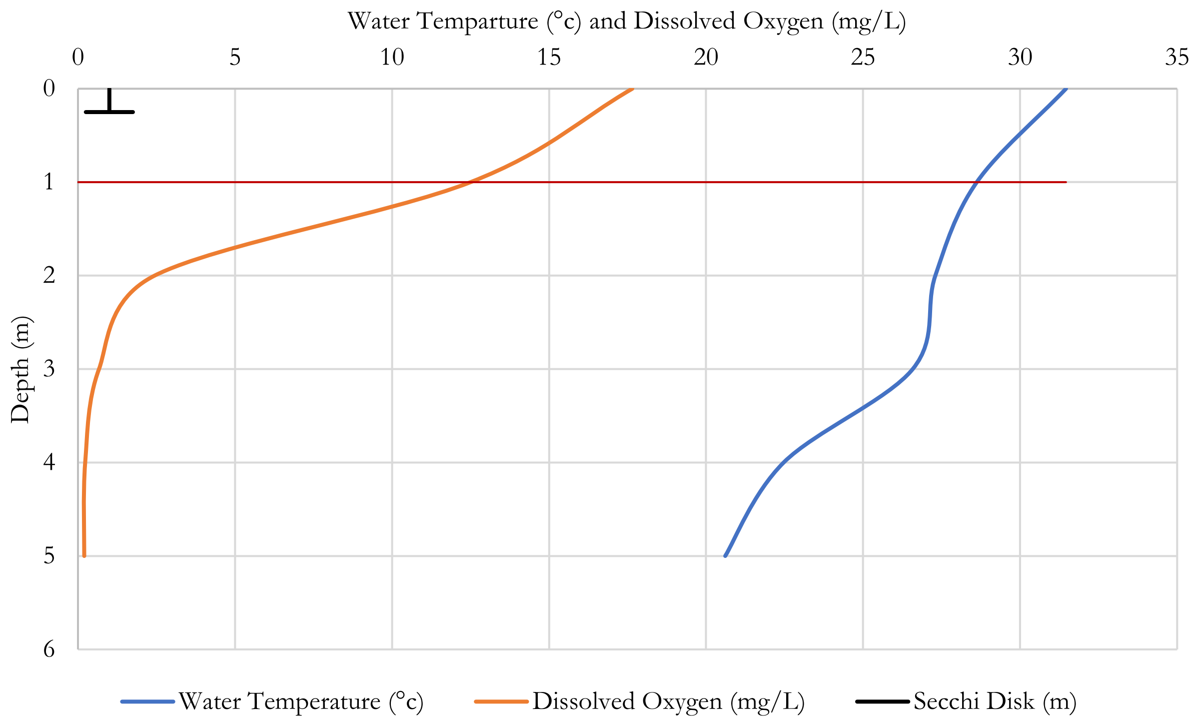



Figure 54. Vertical lake profile taken on 20 July 2022 at the West sampling site of West Boggs Lake. The lake was stratified, meaning there are distinct layers of water at different depths. The epilimnion (top-layer) extends to 01-meter. Dissolved oxygen exhibits a strong Clinograde oxygen curve that is typical for a productive lake. The decrease of oxygen in the hypolimnion (bottom-layer) at 01-meter results from respiration exceeding productivity. The hypolimnion becomes hypoxic and at 03-meters. Secchi depth was measured at 0.25 meters. The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.

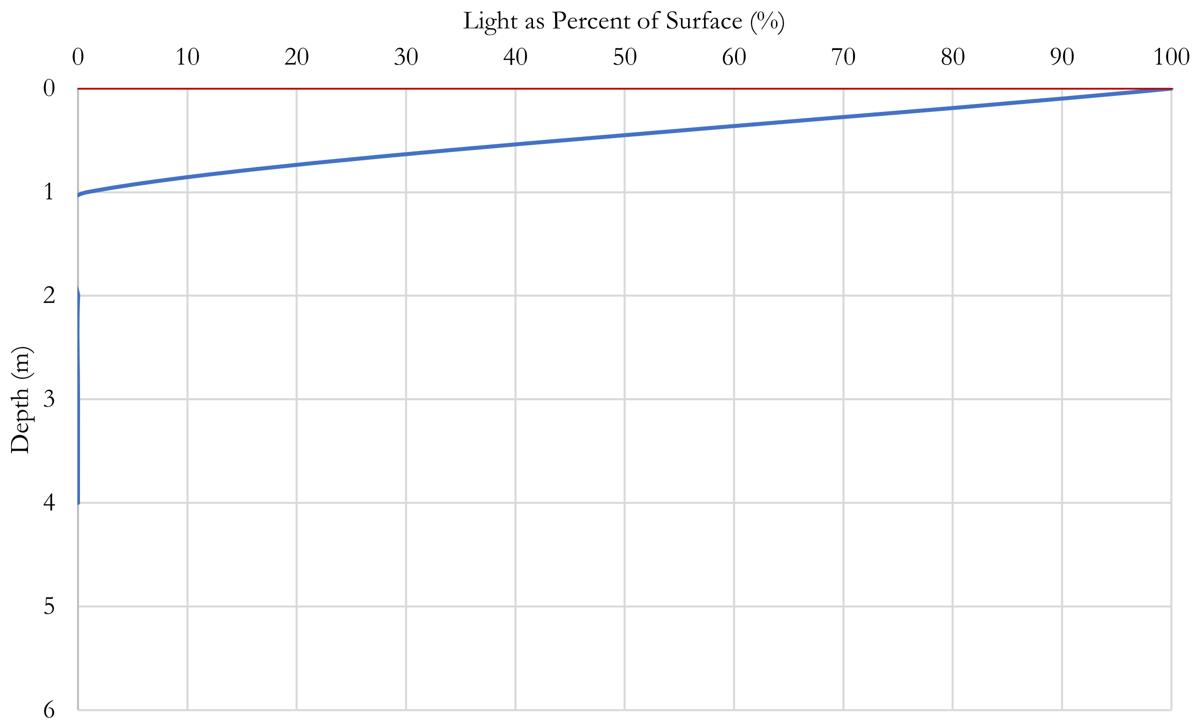



Figure 55. Light attenuation on 20 July 2022 at the West sampling site of West Boggs Lake. The horizontal line intersects the light attenuation at 00-meters. This means that photosynthesis cannot occur below the surface. This is a result of a large blue green algae bloom at the time the lake profile was done. Light is measured as Micromole per second and square meter (µmol/m$^{-2}$/s$^{-1}$). The lake profile was done while West Boggs Lake was experiencing a blue green algal bloom.