ASSESSMENT REPORT

BIG EAGLE LAKE WATER QUALITY ASSESSMENT AND LOAD SOURCE ASSESSMENT

ORROCK AND BIG LAKE TOWNSHIPS | MINNESOTA

JUNE 19, 2020

Prepared in collaboration with:
Big Eagle Lake Improvement Association
Sherburne Soil and Water Conservation District

A portion of the funding for this study came from the Clean Water Land and Legacy Amendment

WSB PROJECT NO. 013565-000

Table of Contents

1. EXECUTIVE SUMMARY

Throughout 2019 and early 2020, the Big Eagle Lake Improvement Association (BELIA) , Sherburne Soil and Water Conservation District (SWCD), and WSB, collaborated to collect and assess water quality data for Big Eagle Lake and its tributaries to determine if Big Eagle Lake is impaired by elevated nutrients, assess the source of the impairment (loads), and identify potential best management practices (BMPs) to implement to improve water quality.

Based on data collected in 2019 by BELIA and Sherburne SWCD, Big Eagle Lake is impaired for nutrients as the in-lake growing season average for total phosphorous was 46 µg/l, 6 µg/l higher than the state standard, secchi depth was measured at 1.3 meters, 0.1 meter shallower than the state standard, and chlorophyll-a concentration was 39.52 µg/l, 25.52 µg/l higher than the state average.

To determine the source of these impairments or loading of total phosphorous, WSB first used a P8 model to identify the contribution from five (5) subwatersheds surrounding Big Eagle Lake. This modeling effort shows that the largest amount of total phosphorous comes from the Northeast subwatershed which outlets into the east side of Big Eagle Lake after crossing under 183rd Avenue NW (station 100).

This subwatershed was further assessed by directly measuring flow and nutrient concentration (total phosphorous) at station 100 to develop a measured load using FLUX software. Monitoring found that the load from this subwatershed was 1,171 pounds of total phosphorous/year, 10 times the next highest subwatershed total and ~5 times the P8 modeled load. This may be due to the elevated amount of precipitation received in 2019 and nuances between the land use classification in the model. Backflow from the Big Eagle Lake outlet was also evident from data collected at station 700 and 100 and was accounted for in the FLUX analysis. A total phosphorous sample was taken in October 2019 in the outlet stream and near station 204. Results showed the in-lake total phosphorous concentration was much higher than the in-stream sample, indicating that backflow, while inhibiting the outlet, may not be contributing to the overall total phosphorous load.

To assess the entire load affecting Big Eagle Lake water quality, internal loading was also measured from anoxic sediment release and bioturbation from rough fish such as common carp. The load from anoxic sediment release was calculated by using a release rate measured from Big Eagle Lake sediment cores analyzed by the St. Anthony Falls Lab and dissolved oxygen profiles measured by BELIA volunteers that identified the depth of anoxia (no oxygen).

Loading from carp was calculated by developing a carp biomass estimate and using published rates from LaMarra.

Initial calculations showed that most of the total phosphorous load was coming from the northeast subwatershed; 1,171 pounds of the total load of 2,511 pounds (see Tables 12 and 13).

This analysis was further refined by using BATHTUB software to compare calculated loads with observed water quality values. Under this final analysis, Big Eagle Lake was receiving 3,058 pounds of Total Phosphorous in 2019, with external loading (all subwatersheds and atmospheric deposition) contributing 1,555 pounds and internal loading (carp and anoxic sediment release) contributing 1,502 pounds per year.

To address this a series of BMPs were identified and discussed in detail in section 6.0. These BMPs include both external and internal practices. BATHTUB was used as a predictive model to determine how much the total load would need to be reduced by and where those reductions would need to come from.

To meet water quality standards, the overall load to Big Eagle Lake will need to be reduced by 1,172 pounds per year or 65.1%. While there a number of external load reduction BMPs available, many of them account for only a small percentage of the total load reduction needed, with the exception of the wetland restorations. Internal load reduction, by sequestering anoxic total phosphorous release via an alum treatment, provides the largest load reduction and would be necessary to meet the load reduction required, but is also the single most expensive alternative.

Load Source	Existing Load (Pounds/Year)	Sum of Load Reduction From BMPs (Pounds)[1]	Sum of Load Reduction From BMPs (Pounds)[2]
Central Subwatershed	144.4	25.3	25.3
West Subwatershed	68.2	17.2	17.2
South (Direct) Subwatershed	24.8	21.9	21.9
Northwest Subwatershed	25.6	12.5	25
Northeast Subwatershed	1,168.9	62	124
Atmospheric	123.4	0	0
Septic Systems	18.8	0	0
Total External Load Reduction		138.9	229.9
Internal-Anoxic Sediment Release	1,140	912[3]	969[4]
Internal- Carp	362	259	259
Sum of Internal BMPs		1,171	1,228
Total Load Reduction		1,309	1,457

1- calculated using a 25% TP removal efficiency
2- calculated using a 50% removal efficiency
3- calculated by subtracting the internal carp load of 362 pounds TP, from the total internal load identified in Table 15 of 1,502 pounds TP and using an 80% removal efficiency.
4- calculated by subtracting the internal carp load of 362 pounds TP, from the total internal load identified in Table 15 of 1,502 pounds TP and using an 85% removal efficiency.

Next steps should include:

- Distribution of the report to members of BELIA and partner agencies.
- Complete 2020 in-lake sampling to satisfy MPCA surface water sampling data requirements for listing Big Eagle Lake as impaired.
- Prioritization of BMPs based on public and agency input.
- Refinement of cost estimates for top priority BMPs or those the BELIA and its partners plan on implementing or pursuing funding for in the near future. For example, the cost for the alum treatment is a conservative estimate. Additional analysis on dosing would need to be completed to provide a more exact estimate and the treatment area could potentially be decreased in size to reduce overall cost or the applications may be phased over a few years.
- Develop site specific plans for external BMPs.
- Further analysis of the Northeast subwatershed to determine if wetlands are a source or sink. This could include multi-year wetland hydrology monitoring during various precipitation cycle or adding water quality sampling stations further upstream within the northeast subwatershed.

2. PROJECT OVERVIEW

2.1 Background and Project Purpose

Eagle Lake, locally referred to as Big Eagle Lake, is located in Orrock Township, Sherburne County, Minnesota. The nearest city is the City of Big Lake roughly 0.77 miles to the south-southwest of the lake.

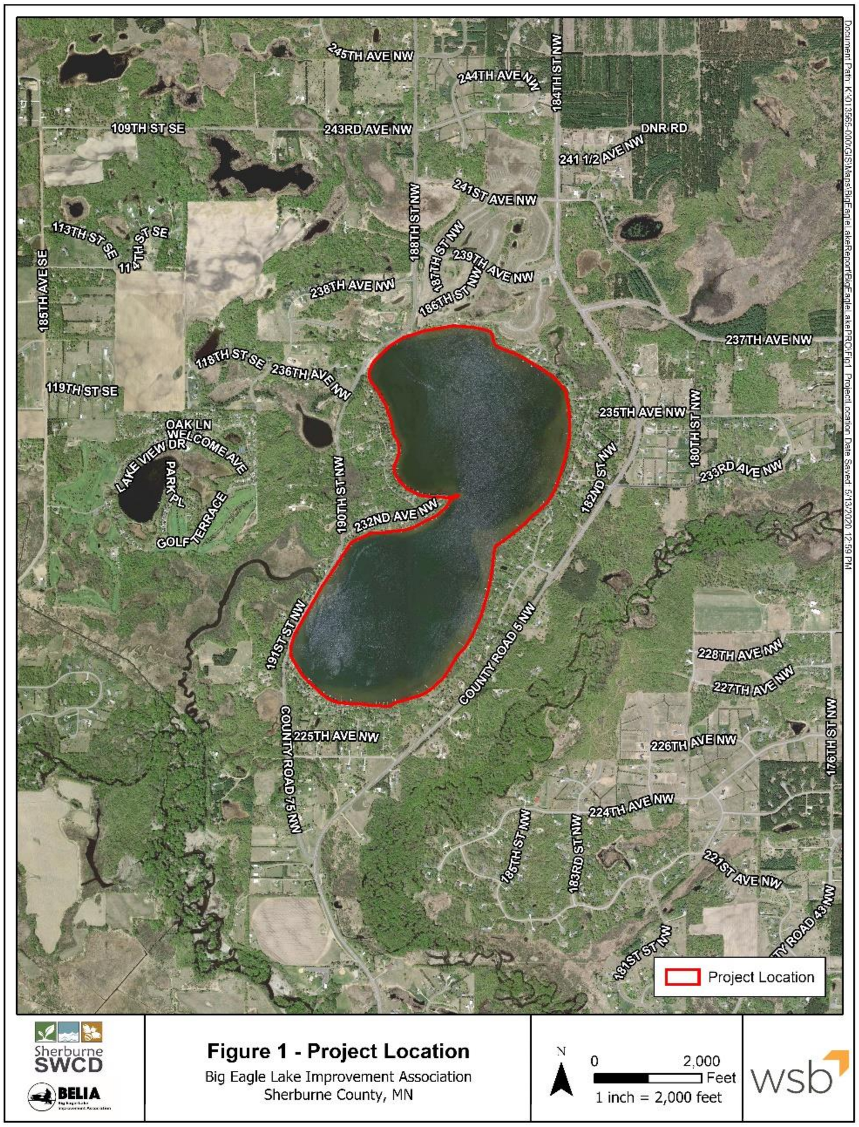

Figure 1. Big Eagle Lake Location

Historical data and anecdotal information suggest that Big Eagle Lake is not meeting water quality standards due to elevated total phosphorus concentrations and regularly experiences algal blooms due to this. This project provides the Big Eagle Lake Improvement Association (BELIA) with analysis to identify and quantify the sources of total phosphorous (TP) and develop an implementation plan to address those sources to reduce loading and rehabilitate Big Eagle Lake so it may meet water quality standards.

Big Eagle Lake is not currently listed as impaired for nutrients due to a lack of water quality data to request listing. Work completed under this project and efforts by the Sherburne Soil and Water Conservation District (SWCD), Minnesota Pollution Control Agency (MPCA), and BELIA generated the necessary data to determine if Big Eagle Lake is impaired.

To complete this project, the project team implemented eight (8) tasks identified below and discussed in detail in this report.

1. Aggregate and Assess Existing Spatial, Fisheries, Water Quality, and Previous Best Management Practices Implementation Data
2. Calculate loading based on existing watershed map (direct and indirect) as a modeling exercise
3. Collaborate with BELIA, Sherburne SWCD, and MPCA on water quality sampling for 2019-2020
4. Analyze Sediments for Phosphorus Release Rates in 2019
5. Assess fishery in 2019 and calculate load contribution from rough fish
6. Develop a sampling plan for inlet and outlet to assess flow-based load for both
7. Development of a Big Eagle Lake Phosphorus Budget
8. Draft list of potential implementation activities to address loading

2.2 Identification of Waterbodies

Waterbodies within the project area include Big Eagle Lake, and two (2) unnamed stream sections, one of which is the inlet to Big Eagle Lake and the other forms the outlet of Big Eagle Lake and eventually flows into the Snake River. The Snake River drains into the Elk River shortly after the confluence of the Big Eagle Lake Outlet and the Snake River. Elevated water levels in the Elk and Snake Rivers contribute to periodic backflows in Big Eagle Lake.

Affected Use: Pollutant/ Stressor	Aquatic Unit Identification # (AUID)	Stream or Lake Name	Location/Reach Description	Designated Use Class	Listing Year
Aquatic recreation: Nutrient/Eutrophication Biological indicators (Phosphorus)	71-0067-00	Eagle (Big Eagle) Lake	3 Mi N of Big Lake	2B, 3C	Not Listed
	07010203-692	Unnamed Stream (Outlet)	Eagle Lake to Snake River	2B, 3C	Not Listed
	07010203-999	Unnamed Stream (Inlet)	Unassessed; tributary to Eagle Lake	2B, 3C	Not Listed

Table 1. Waterbody Identification

Water quality data and supporting documentation are available for Big Eagle Lake and the outlet stream (AUID 07010203-692) on the MPCA Surface Water Dashboard, but there is no supplemental data available for the inlet stream (AUID 07010203-999) beyond what is presented in this report from 2019 data collection activities.

None of the waterbodies identified are listed as impaired, and the inlet stream is unassessed.

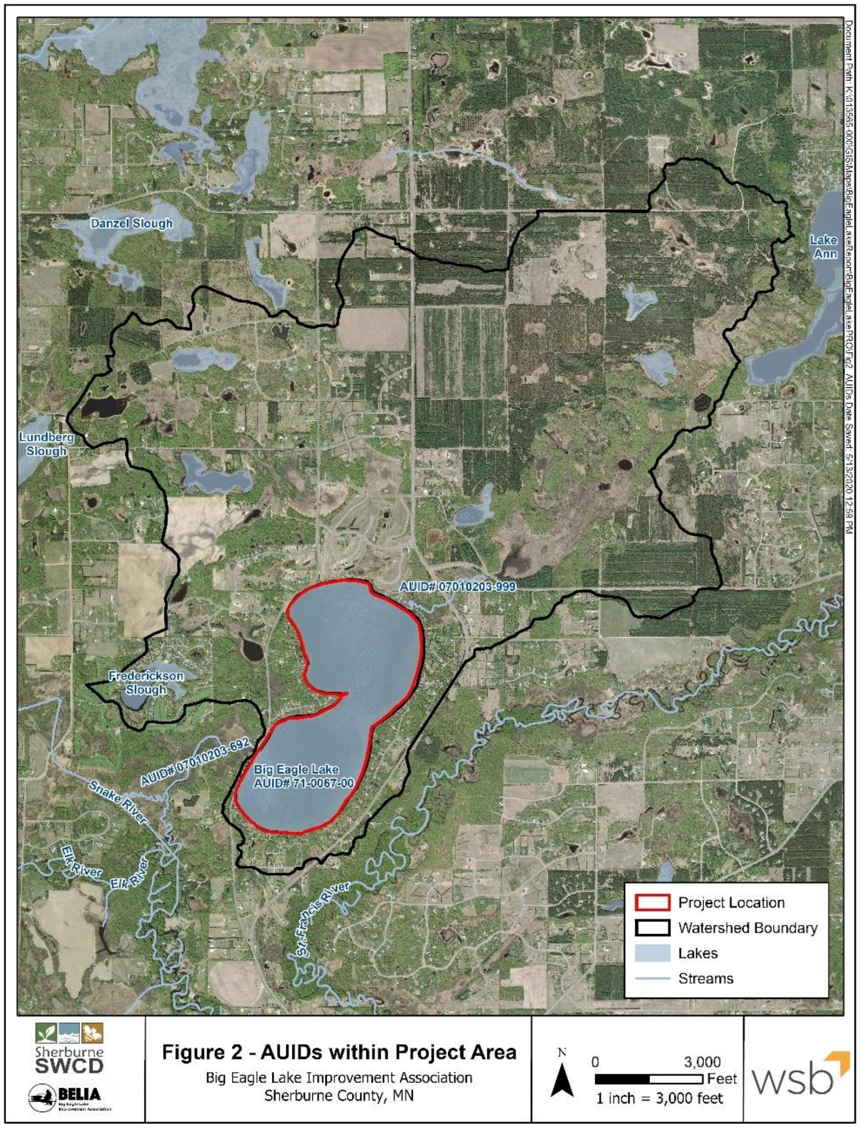

Figure 2. AUIDs within the Project Area

2.3 Priority Ranking

The Prioritization Plan for Minnesota 303(d) Listings to Total Maximum Daily Loads Minnesota Pollution Control Agency September 2015 indicates that intensive watershed monitoring was scheduled to begin in 2009. Intensive Watershed Monitoring (IWM) was completed in the Mississippi River-St. Cloud Watershed in 2009 and 2010, but due to the number of impaired waterbodies in this project area, some were deferred until 2019; including Big Eagle Lake. Big Eagle Lake is included in the 2019/2020 IWM effort.

3. APPLICABLE WATER QUALITY STANDARDS AND NUMERIC WATER QUALITY TARGETS

3.1 Numeric Water Quality Criteria

The pollutant of concern for this report is total phosphorous (TP). Total phosphorous is a nutrient found in aquatic environments that drives productivity (algae production) and subsequently impacts water clarity and the ability of the waterbody to provide designated uses and meet water quality standards.

In addition to meeting phosphorus limits, chlorophyll-a (Chl-*a*) and Secchi transparency standards must be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor total phosphorus and the response variables Chl-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will likewise be met.

While Big Eagle Lake and the connected inlet and outlet stream reaches are not currently listed as impaired for aquatic recreation/nutrients, available data suggests that Big Eagle Lake is impaired for nutrients and is not currently meeting established numeric water quality standards or providing designated beneficial uses.

	Water Quality Parameter		
	TP (µg/L)	Chl-a (µg/L)	Secchi (m)
North Central Hardwoods Forest Ecoregion (Class 2B Lakes)	40	14	Not less than 1.4
Central Rivers (Class 2B Streams)	100	18	NA

Table 2. Numerical Water Quality Standards

There are different applicable numeric water quality standards for lakes, shallow lakes, and reservoirs. A shallow lake is defined as a lake having a maximum depth of 15' or a lake with > 80% littoral area (area shallow enough for aquatic vegetation to grow). For purposes of this report, Big Eagle Lake is classified as a lake, not a shallow lake, based on maximum depth (20'), and that only 71% of the Big Eagle Lake is considered littoral (MN DNR Lakefinder). Big Eagle lake also stratifies, as is evident from the 2019 growing season temperature and dissolved oxygen profiles.

The Central Rivers numeric criteria for TP and Chl-a is applied to both stream reaches within the project area. While not listed, there is a total suspended solids (TSS) numeric criteria for streams within the Central Rivers Ecoregion of 30 mg/L or 30,000 µg/L.

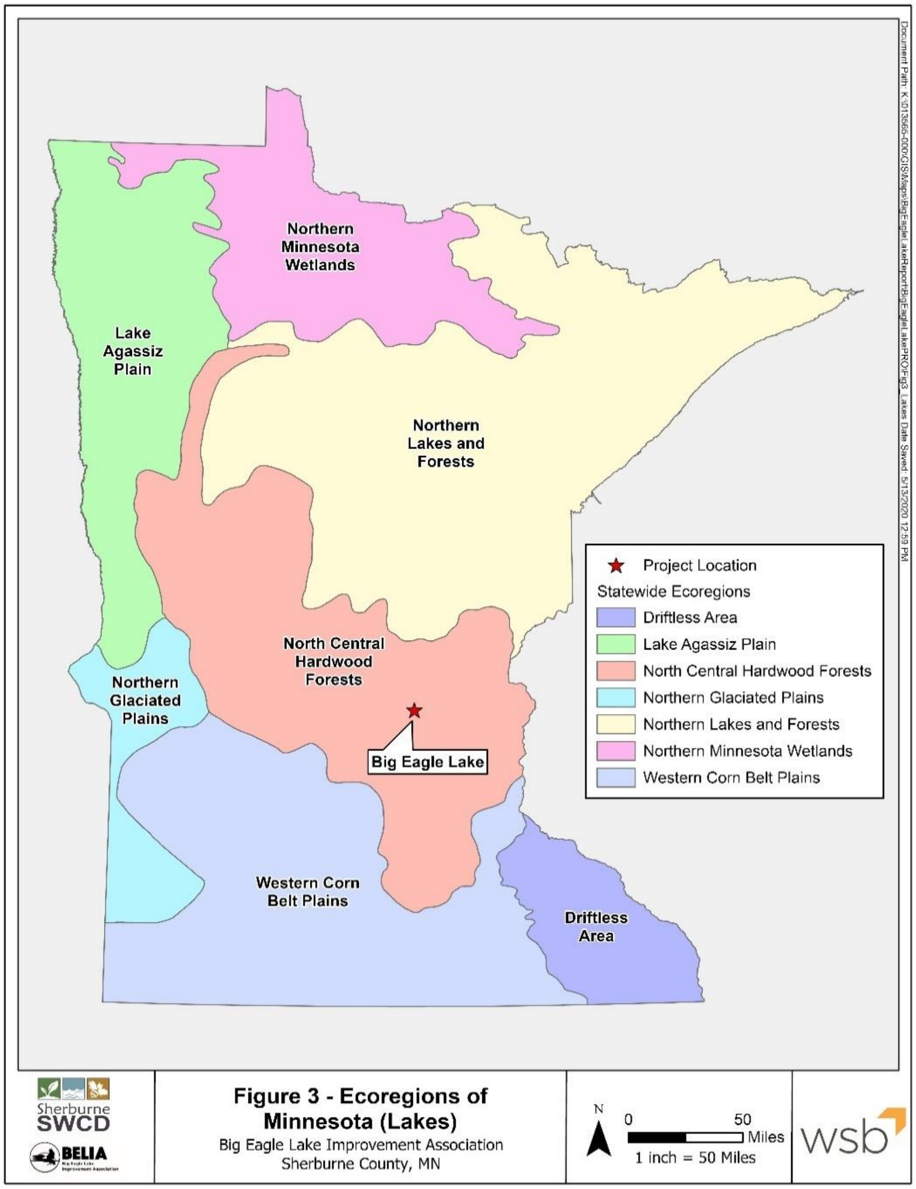

Figure 3. Ecoregions of Minnesota (Lakes)

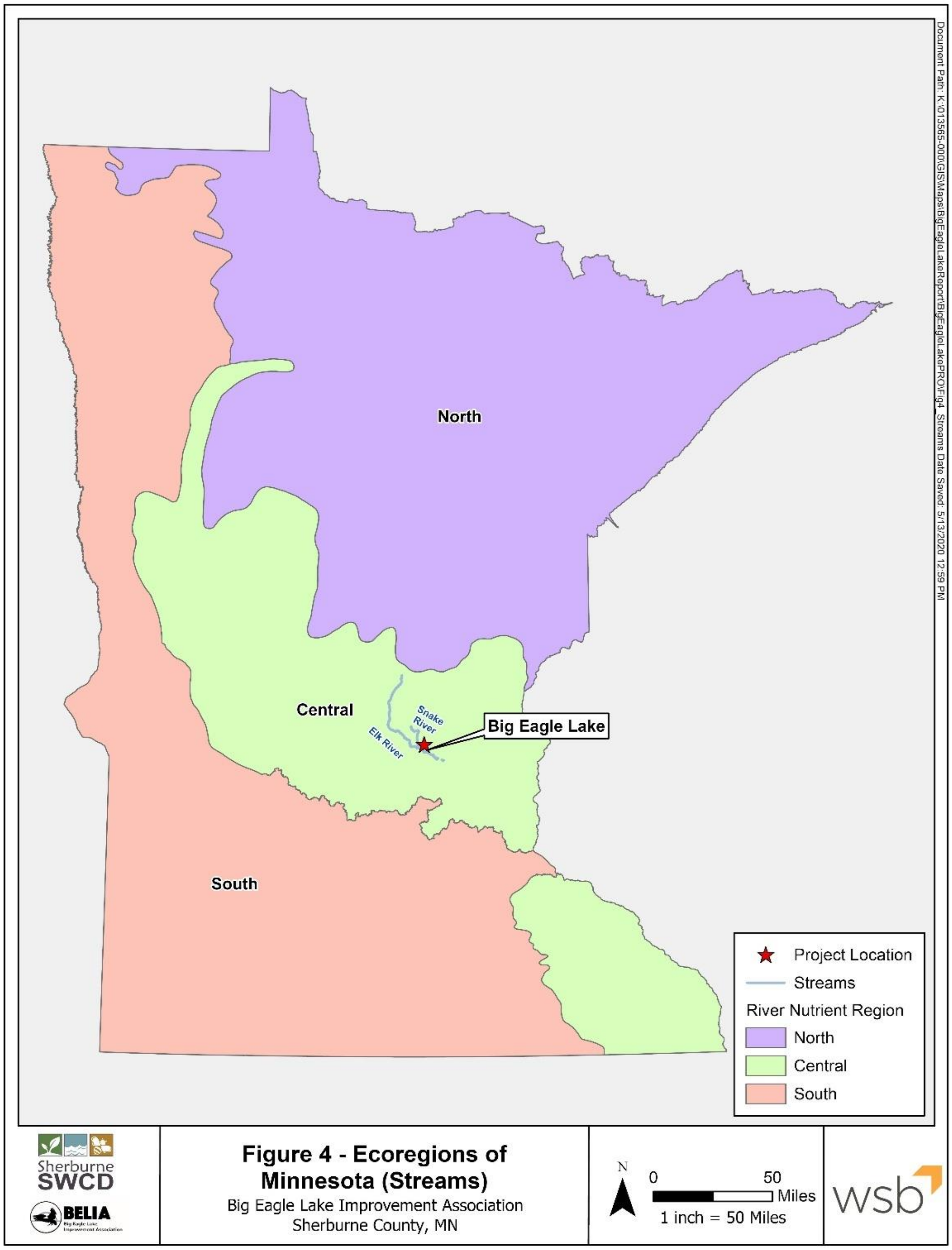

Figure 4. Ecoregions of Minnesota (Rivers)

3.2 Designated Uses

Listed designated uses for Big Eagle Lake and the two (2) identified steam reaches are class 2B and 3C.

Class 2B Designated Use Waters are “waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water aquatic biota, and their habitats” and “These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water” (MN Rule 7050.0222 SPECIFIC WATER QUALITY STANDARDS FOR CLASS 2 WATERS OF THE STATE; AQUATIC LIFE AND RECREATION)

Class 3C Designated Use Waters are “waters of the state shall be such as to permit their use for industrial cooling and materials transport without a high degree of treatment being necessary to avoid severe fouling, corrosion, scaling, or other unsatisfactory conditions”. (MN Rule 7050.0223 SPECIFIC WATER QUALITY STANDARDS FOR CLASS 3 WATERS OF THE STATE; INDUSTRIAL CONSUMPTION).

4. WATERSHED AND WATERBODY CHARACTERIZATION

Pre-settlement land cover/vegetation within the Sherburne County and the Big Eagle Lake Watershed largely consisted of oak openings and barrens, with smaller amounts of wet prairie, conifer bogs and swamps, and brush prairie cover types composing the remainder of the cover types.

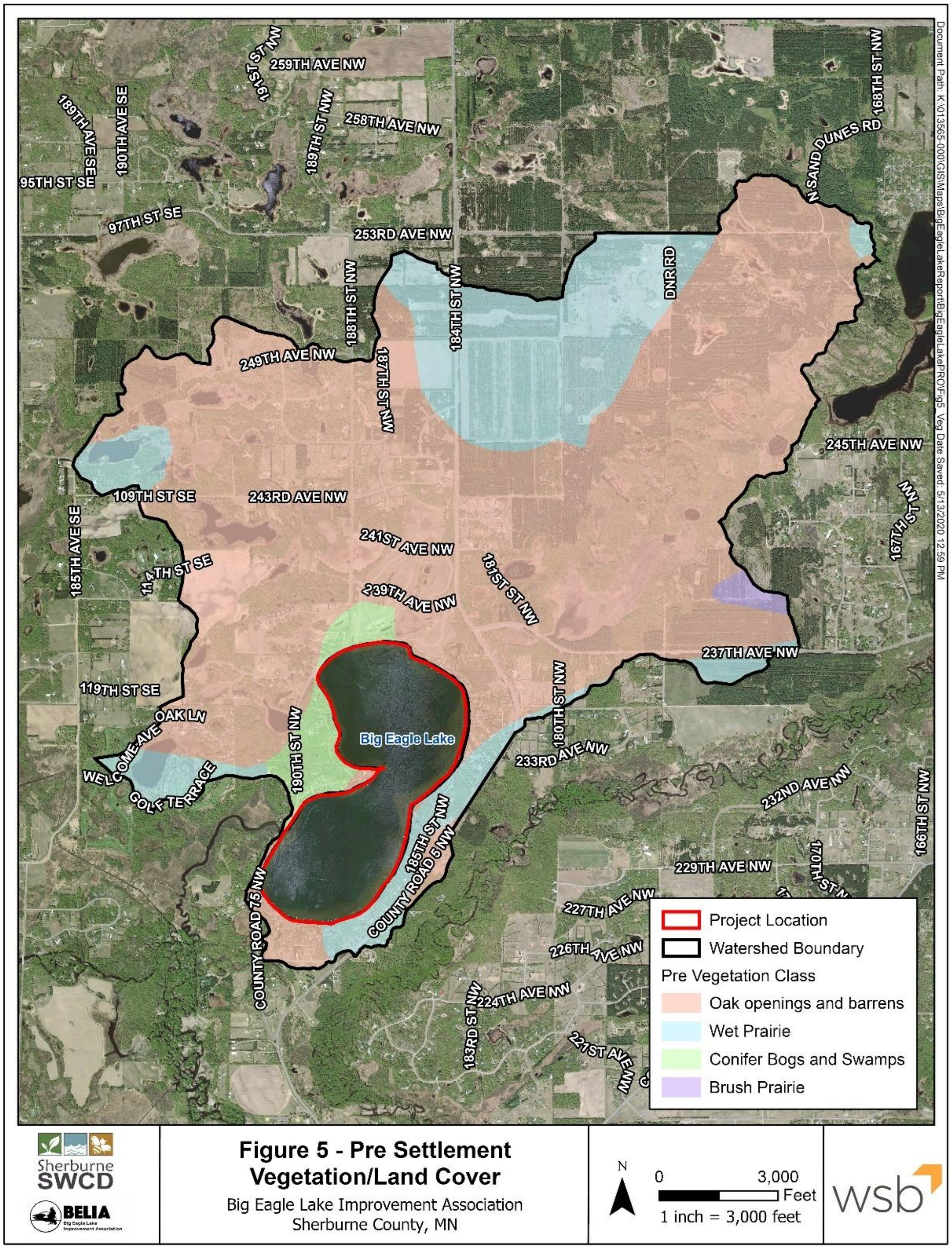

Figure 5. Pre-Settlement Vegetation/Land Cover

Data used for Figure 5 is from the statewide MN DNR Pre-settlement vegetation of Minnesota based on Marschner's original analysis of Public Land Survey notes and landscape patterns.

No part of the Big Eagle Lake Watershed is located within the boundary of a Native American Reservation Boundary. The area surrounding Big Eagle Lake appears to be included in the 1851 land cession treaty between the U.S. Government and the Sioux or Dahcotahs.

4.1 Lakes

Big Eagle Lake is the only lake that falls within the project area. The total surface area of the lake is 462.42 acres with 71% or 330 acres of littoral area. The shoreline is 4.2 miles in length. The average depth is 10.7 feet and the maximum depth is 20 feet.

Five-foot contour intervals were readily available from the MN DNR GIS Portal. WSB created 1-foot contour intervals through interpolation. See Figure 6 below.

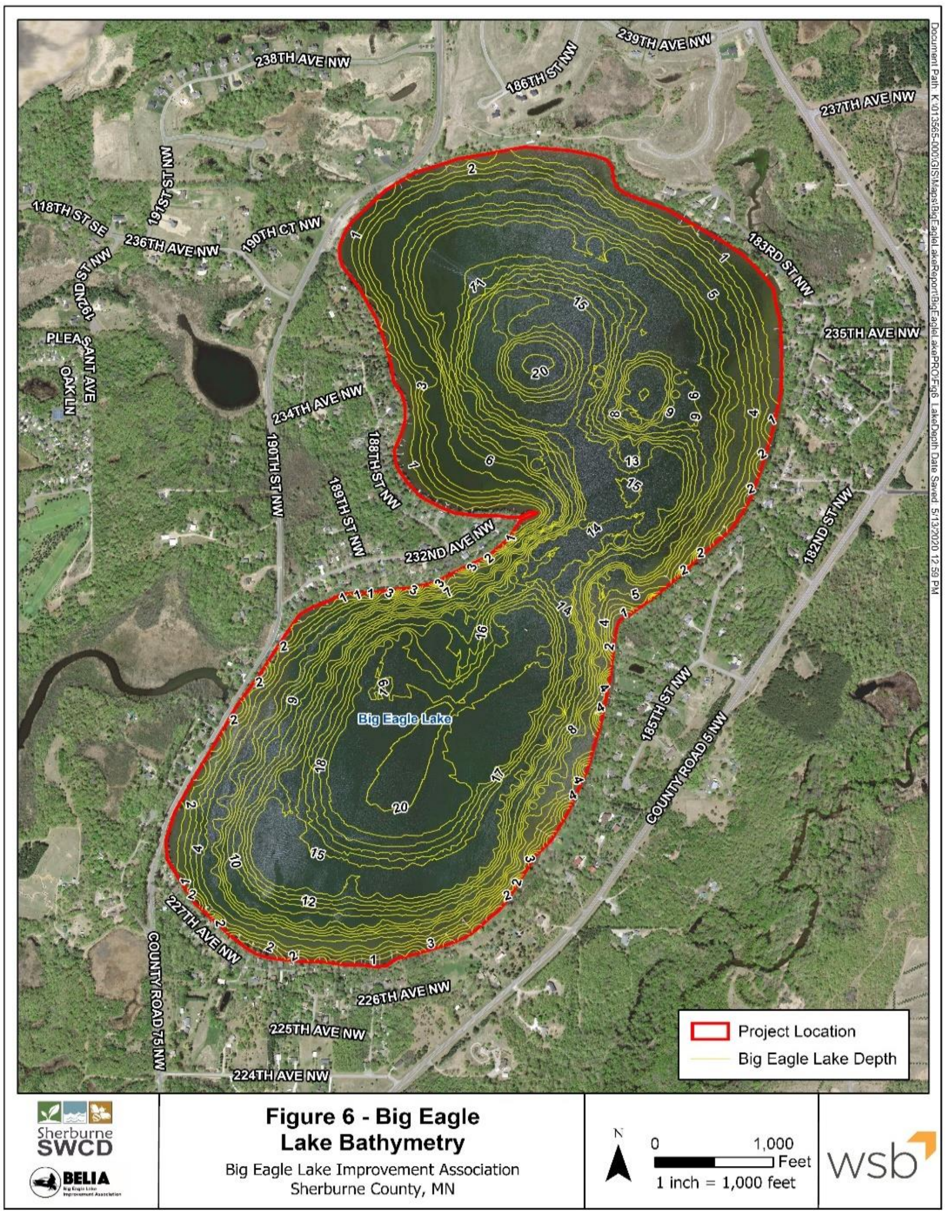

Figure 6. Big Eagle Lake Bathymetry

The ordinary high-water level (OHW) for Big Eagle Lake is 924.5'. Between December 22, 1941, and November 8, 2019 a total of 185 water level readings have been taken. The highest reading recorded is 924.95' on April 8, 1956 and the lowest recorded reading was 922.45' on August 31, 2019; resulting in a recorded water elevation range of 2.5'.

4.2 Streams

The project area includes two (2) stream segments that are identified by unique AUIDs.

Unnamed Creek (Stream) 07010203-692: This stream is considered the outlet of Big Eagle Lake. It starts at the outlet of Big Eagle Lake (crossing of county highway 75) and ends 1.25 miles downstream at the confluence with the Snake River, which drains into the Elk River shortly after.

Unnamed Creek (Stream) 07010203-999: This stream is a tributary to Big Eagle Lake and forms the one (1) major inlet. MPCA maps show the stream segment starting 0.6 miles upstream of Big Eagle Lake near the Sand Dunes State Forest. The segment is also identified to the west of Big Eagle Lake as a tributary to the unnamed outlet to Big Eagle Lake. This is a separate segment.

4.3 Wetlands

There are 207 wetland basins identified by the National Wetland Inventory (NWI) within the Big Eagle Watershed totaling 644 acres of wetlands within the watershed. 125 or 60% of these wetlands are freshwater emergent, which may provide some nutrient transformation functions. Another 46 or 22% are freshwater forested/shrub wetlands providing additional stormwater retention and nutrient transformation functions among others.

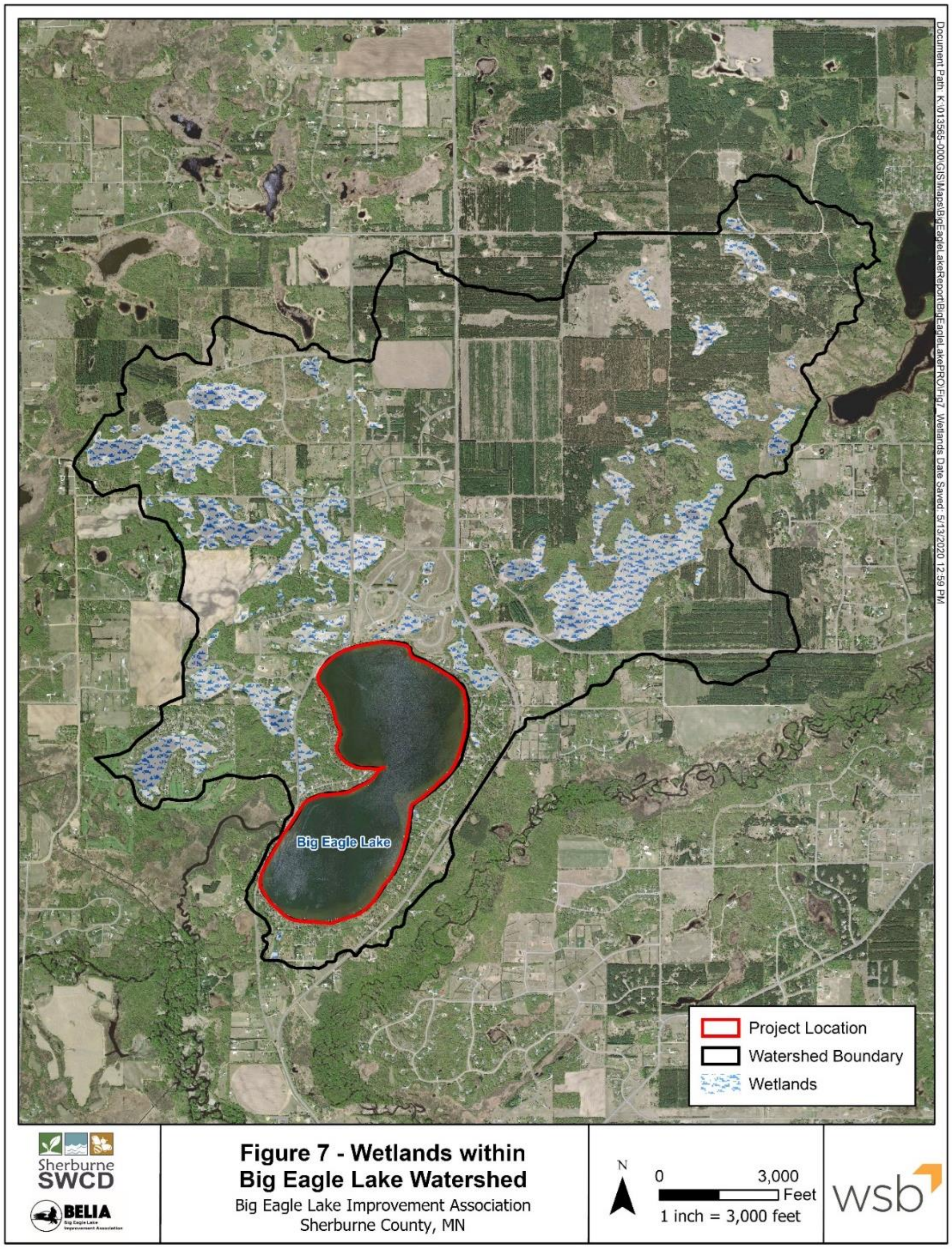

Figure 7. Wetlands within the Big Eagle Lake Watershed

4.4 Subwatersheds

The watershed boundaries were delineated for Big Eagle Lake through use of satellite topographic imagery, LIDAR contours, the National Wetland Inventory, and the Minnesota DNR Public Waters Inventory. The total watershed size analyzed is 4,330 acres this area excludes the actual area of Big Eagle Lake.

The watershed can be split into five subwatersheds. Four subwatersheds include ponds and wetlands that filter the water prior to discharging to the lake. These four subwatersheds are considered to have a "long hydraulic time" because of the indirect pathway water flows. The south watershed is considered to have a "short hydraulic time" as it includes the area immediately around the lake that flows directly into the lake.

Subwatershed	Acres (% of total Watershed)
Northwest	364 (8)
Central	867 (20)
Northeast	1,814 (42)
West	952 (22)
South (Direct)	333 (8)
Total	4,330 (100)

Table 3. Subwatersheds and associated Acreages

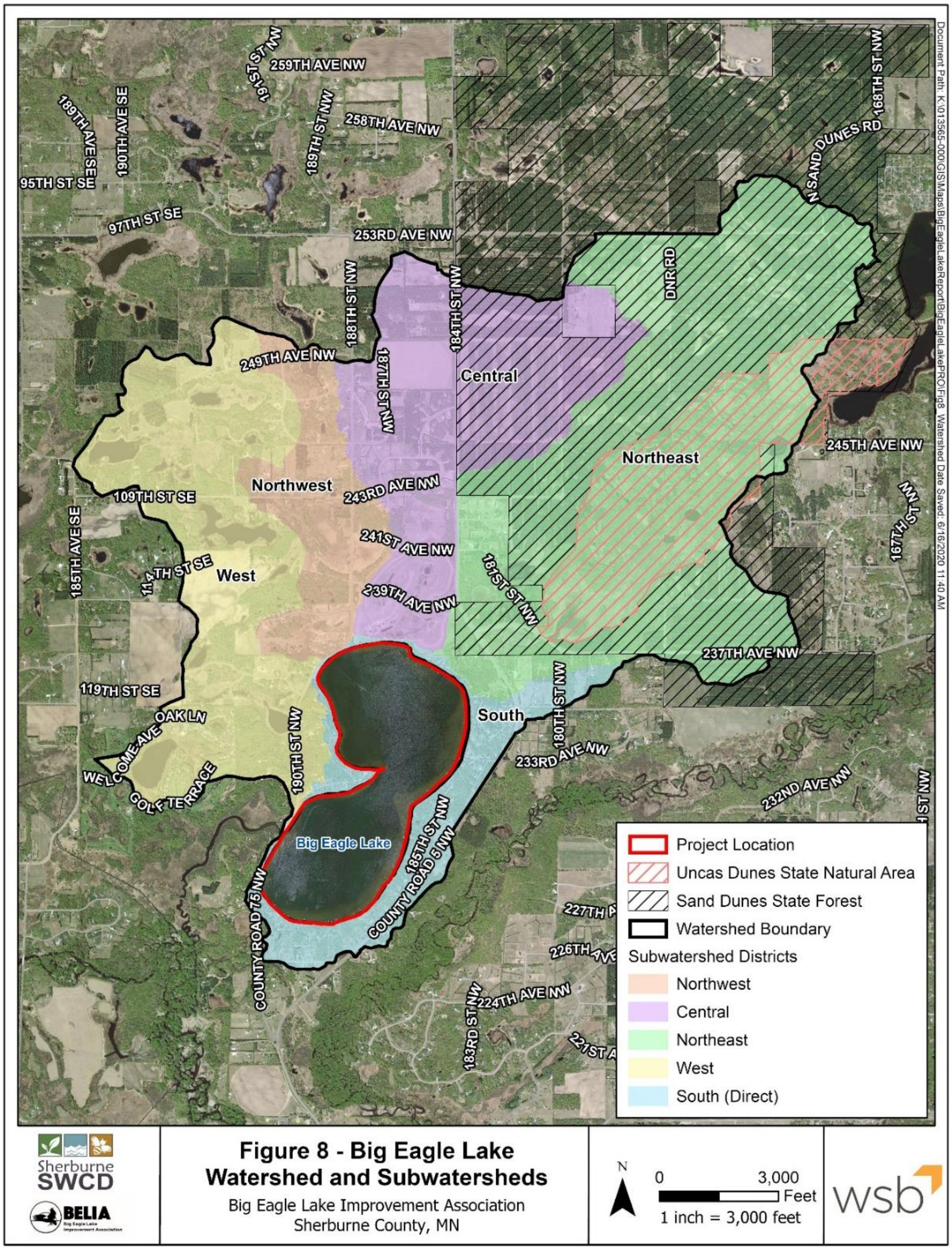

Figure 8. Big Eagle Lake Watershed and Subwatersheds

Northwest Subwatershed: The Northwest Subwatershed is approximately 364 acres (8.4% of the watershed area) and includes two major inlets:

- The first inlet includes two wetlands approximately ½ mile north of Big Eagle Lake. The area on the east side of County Road (CR) 75 drains through a culvert to the west side. The Subwatershed area on the west side then drains to the south via an underground storm drain to “The Woods” development and discharges into a small pond. The water flows out of this pond, through an open ditch running south, and in to a 24” culvert. The culvert crosses CR 75 and discharges into an open lake ditch, where the water is carried to Big Eagle Lake.

- The second major inlet includes an additional wetland on the northwest side of CR 75 that also collects water from the curve to the north. A 24” culvert carries the water to the southeast side of CR 75 and discharges into an open ditch. The ditch carries to the water into Big Eagle Lake.

Central Subwatershed: The Central Subwatershed is approximately 867 acres (20.0% of the watershed area). Various storm sewers, drains, and culverts collect water from the roadways and land of the “Shores of Eagle Lake” addition. The water is collected in small ponds or open ditches, which then discharge into an open wetland. The flowage then directs all water to Big Eagle Lake.

Northeast Subwatershed: The Northeast Subwatershed is approximately 1,814 acres (42% of the watershed area). Water collection begins north of 253rd Ave NW and begins to flow southwest through various wetlands. A larger wetland east of CR 5 collects water, which then crosses under CR 5 through a culvert. The culvert drains into an open ditch on the west side of the road, and the open ditch then carries the water into Big Eagle Lake. This subwatershed drains large portions of the Uncas Dunes State Natural Area and Sand Dunes State Forest.

West Subwatershed: The West Subwatershed is approximately 952 acres (22.0% of the watershed area). Water flows through various ponds as it heads from the north to the south. Water eventually flows to a small lake located south of the DNR Public Access and west of County Road 75. This water heads into a drainage ditch and goes south until it reaches 232 Avenue. The ditch on the west side eventually flows through a culvert pipe under 232 Avenue that empties into an open ditch. This ditch carries the water to the lake.

South Subwatershed (Direct): The south watershed includes the immediate area surrounding the lake and the septic systems installed on Big Eagle Lake. The south watershed is estimated to be 333 acres (8% of the watershed area). The water that flows through this subwatershed is not filtered through any additional ponds or wetlands before discharging into Big Eagle Lake.

4.5 Land Use

Big Eagle Lake is found entirely within the North Central Forest Hardwoods Ecoregion (NCHF). This ecoregion is a transition from the Northern Lakes and Forest Ecoregion to the north and the North Glaciated Plains, Western Corn Belt Plains, and Driftless area to the south. It is a transitional landscape from forested to agriculture.

The major land use in this region is agriculture (49.5%), with grassland (15.2%) and deciduous forests (10.9%) being subdominant land uses. The remaining land uses/land cover types include conifer forests, water, wetlands, shrubland, and urban, but all are less than 6.5% individually.

The 2011 National Land Cover Database was used to identify the major land use types and areas within the Big Eagle Lake Watershed. Figure 8 shows land use data for the Big Eagle Lake Watershed based on the 2011 National Land Cover Database.

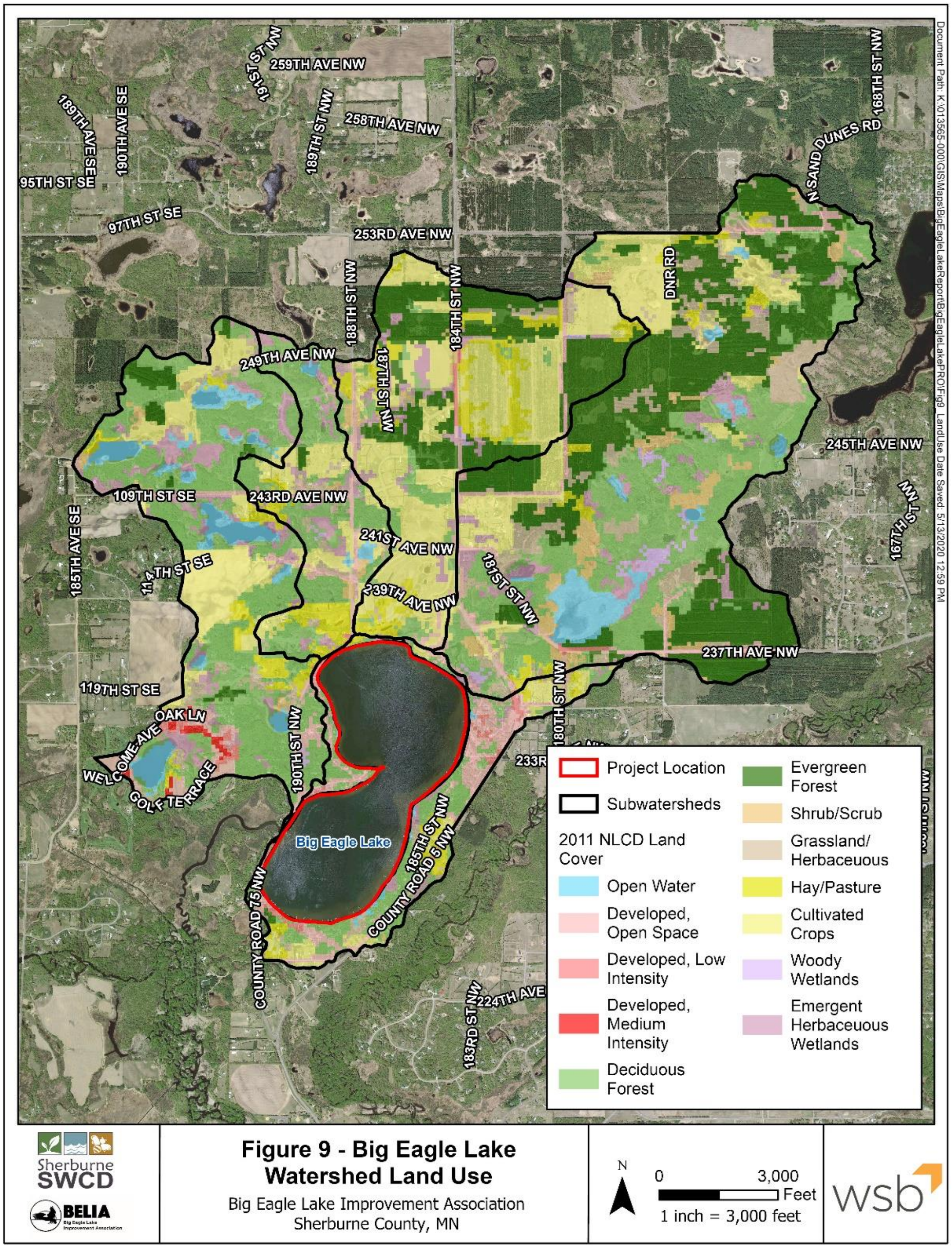

Figure 8. Big Eagle Lake Watershed Land Use. Source: 2011 National Land Cover Database.

	Subwatershed					
Land Use	Northwest (Acres)	Central (Acres)	Northeast (Acres)	West (Acres)	South-Direct (Acres)	Total Acres (%)
Cultivated Crops	66.31	367.97	209.11	149.83	43.11	836.33 (19)
Deciduous Forest	155.55	51.78	463.20	402.05	107.00	1179.58 (27)
Developed, Low Intensity	1.23	6.67	4.63	15.63	17.75	45.91 (1)
Developed, Open Space	23.93	33.28	68.67	9.84	82.97	218.69 (5)
Emergent Herbaceous Wetlands	36.94	45.03	80.91	63.50	17.76	244.14 (6)
Evergreen Forest	2.94	230.24	592.65	86.25	1.89	913.97 (21)
Hay/Pasture	38.55	98.95	37.58	29.18	29.17	233.43 (5)
Herbaceous	21.78	18.09	164.40	42.48	12.74	259.49 (6)
Open Water	8.01	0.05	77.46	35.92	7.84	129.28 (3)
Shrub/Scrub	6.90	10.13	83.83	96.71	1.24	198.81 (5)
Woody Wetlands	1.11	2.67	24.04	10.54	43.11	81.47 (2)

Table 4. Land Uses within the Big Eagle Lake Watershed and associated acreages

4.6 Current/Historical Water Quality

There are six (6) MPCA identified sampling locations in Big Eagle Lake and one (1) sampling station on the Unnamed Stream outlet. These are shown in Figure 9 below.

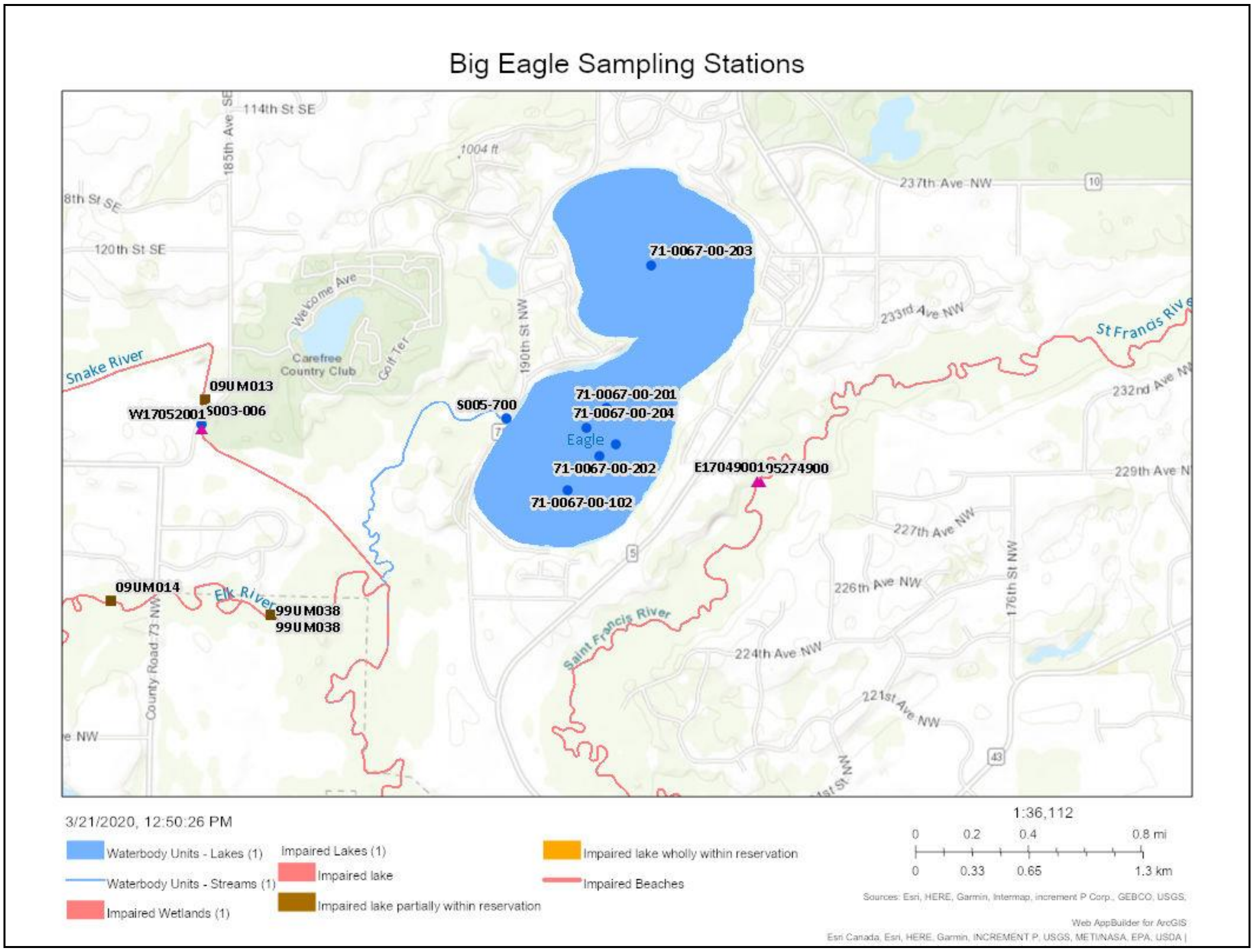

Figure 9. MPCA Big Eagle Sampling Stations

For the purposes of this analysis and report, only data from stations 71-0067-00-203, 71-0067-00-204, and S005-700 are summarized as these station locations were utilized as sampling stations in 2019.

A variety of water quality parameters were available for all stations, but this analysis focuses on TP, Secchi depth, and Chlorophyll-a for lake stations and total suspended solids and total phosphorous for the stream station.

4.6.1 Station 71-0067-00-203 Historical Data

The period of record for historical data (available from MPCA) is 1978 through 2009. Data for TP, secchi depth, and chlorophyll-a were extracted from the master station file and segregated by year and parameter. A seasonal average was then calculated for all results between June and September of the calendar year (based on MPCA Guidance Manual for Assessing Quality of Minnesota Surface Waters). Historical data presented in the following sections are surface water grab samples; not hypolimnetic values.

4.6.1.1 Station 71-0067-00-203 Historical TP

The period of record for TP data at this station is 1981 through 2009 with no data available in 2000, 2001, and 2002.

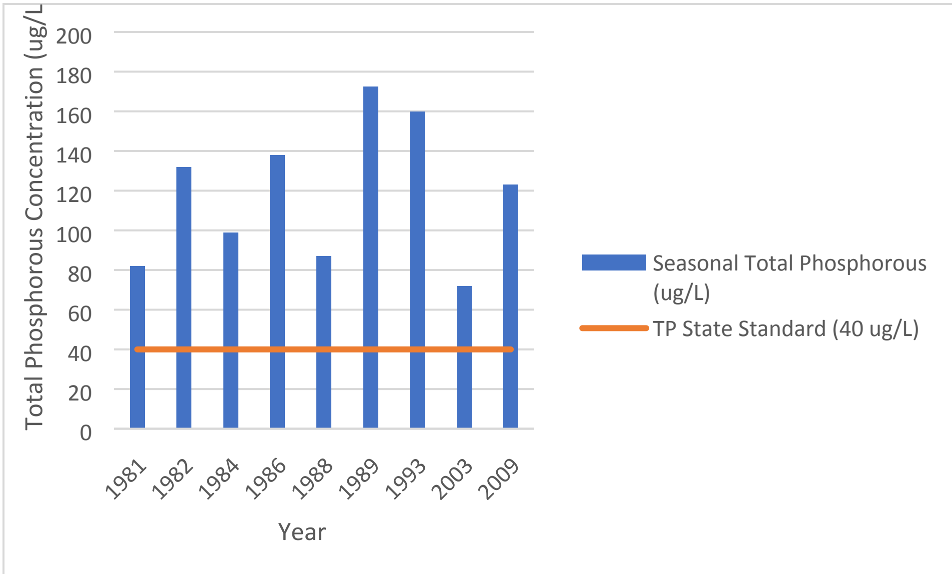

Figure 10. Station 71-0067-00-203 Historical Seasonal TP Average

Total phosphorous concentrations for station 71-0067-00-203 were documented to exceed the state standard for the entire period of record. In all years, but 2003, the TP concentration was at least twice the state standard concentration of 40 µg/L.

4.6.1.2 Station 71-0067-00-203 Historical Chl-a

The period of record for Chl-a data is 1978 through 2009, with no data available in 1981, 2000, 2001, and 2002.

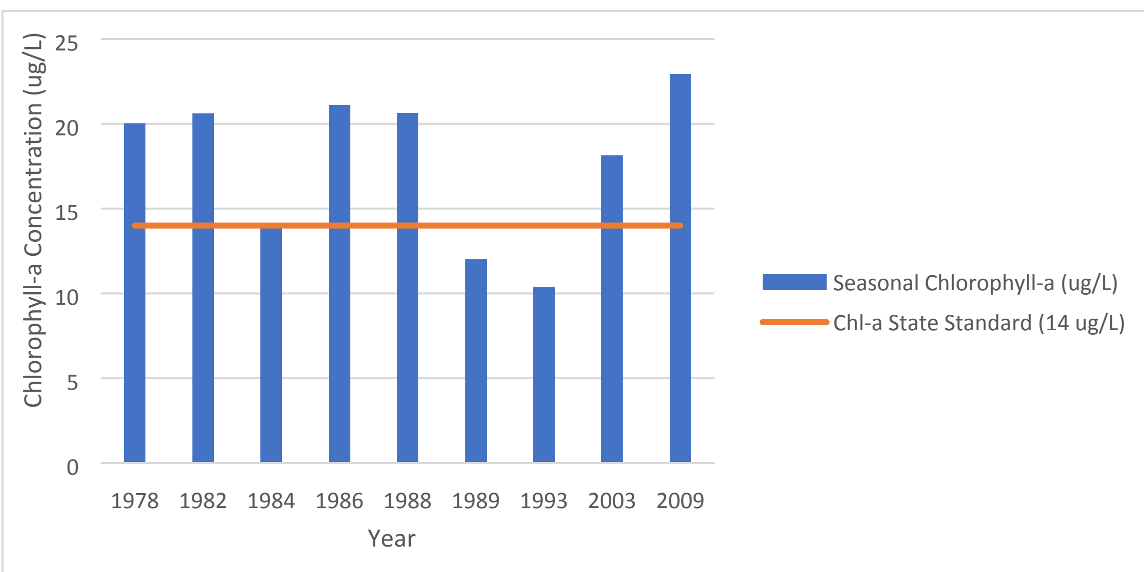

Figure 11. Station 71-0067-00-203 Historical Seasonal Chl-a Average

Chlorophyll-a concentration exceeded the state standard in six (6) of the nine (9) years were data was available or 66% of the time. Only in 1984, 1989, and 1993 were chlorophyll-a concentrations below the state standard of 14 µg/L.

4.6.1.3 Station 71-0067-00-203 Historical Secchi Data

The period of record for Secchi data is 1978 through 2009. All years are represented in the dataset.

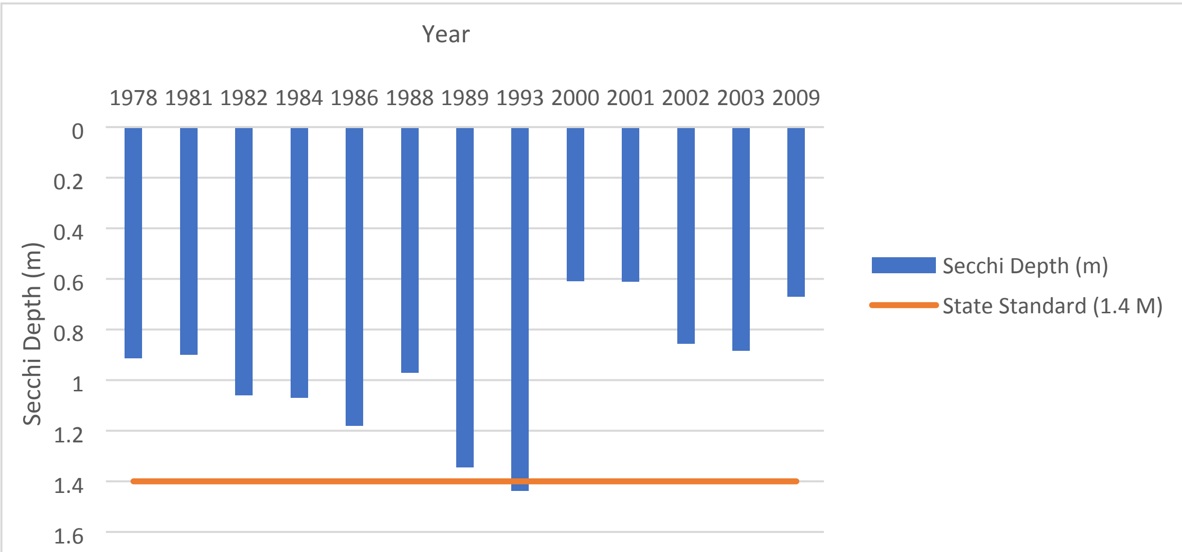

Figure 12. Station 71-0067-00-203 Historical Seasonal Secchi Average

Historical data shows that this secchi depth at tis station met state standard one (1) year during the period of record (1993). This correlates to lower chlorophyll-a concentration data but is actually inverse to TP concentrations as they were highest in 1989 and 1993.

<u>4.6.2 Station 71-0067-00-204 Historical Data</u>

4.6.2.1 Station 71-0067-00-204 Historical TP

The period of record for TP data at this station is 1982 through 2009 with data available for all years.

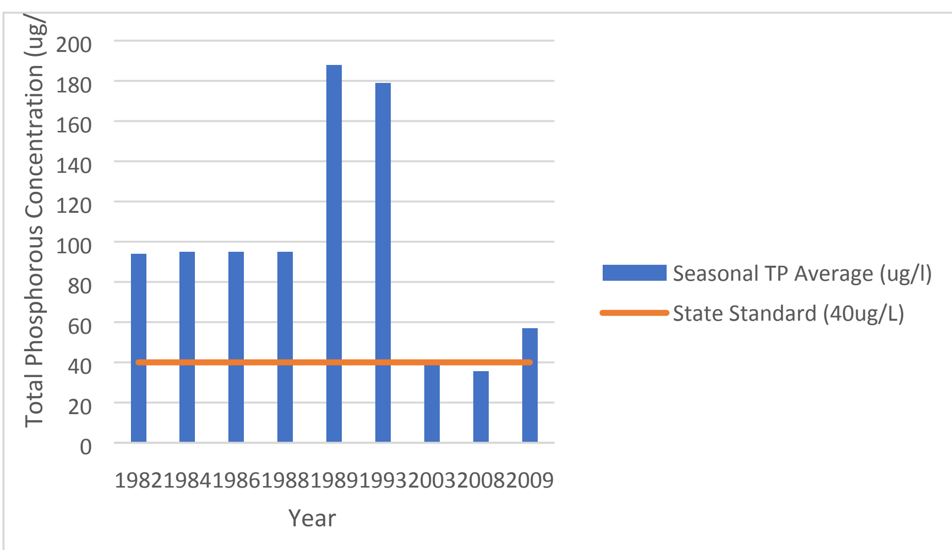

Figure 13. Station 71-0067-00-204 Historical Seasonal TP Average

TP concentrations were consistently similar between 1982 and 1988, spiked in 1989 and 1993, similar to station 203, and met the state TP standard in 2003 and 2008. This data deviates from station 203 as concentrations were lower at station 204 and actually met standards for a portion of the period of record unlike station 203 which did not meet the state standard in any year.

4.6.2.2 Station 71-0067-00-204 Historical Chl-a

The period of record for chlorophyll-a data at this station is 1982 through 2009 with data available for all years.

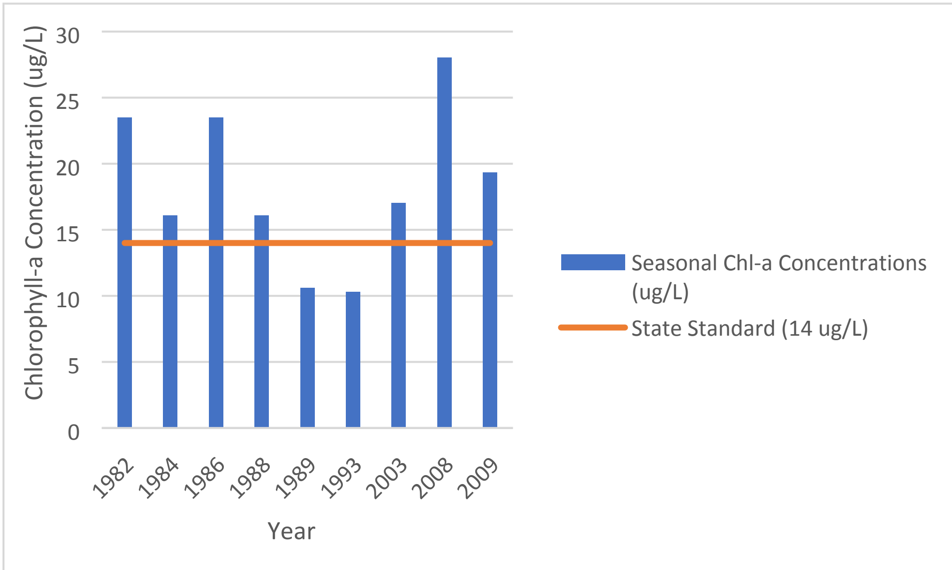

Figure 14. Station 71-0067-00-204 Historical Seasonal Chl-a Average

Similar to station 203, Chl-a concentrations only met the state standard for the same two (2) year period 1989 and 1993, with chlorophyll-a concentrations exceeding the state standard in all remaining years.

4.6.2.3 Station 71-0067-00-204 Historical Secchi Data

The period of record for secchi depth data is 1978 through 2009 with all years represented in the dataset.

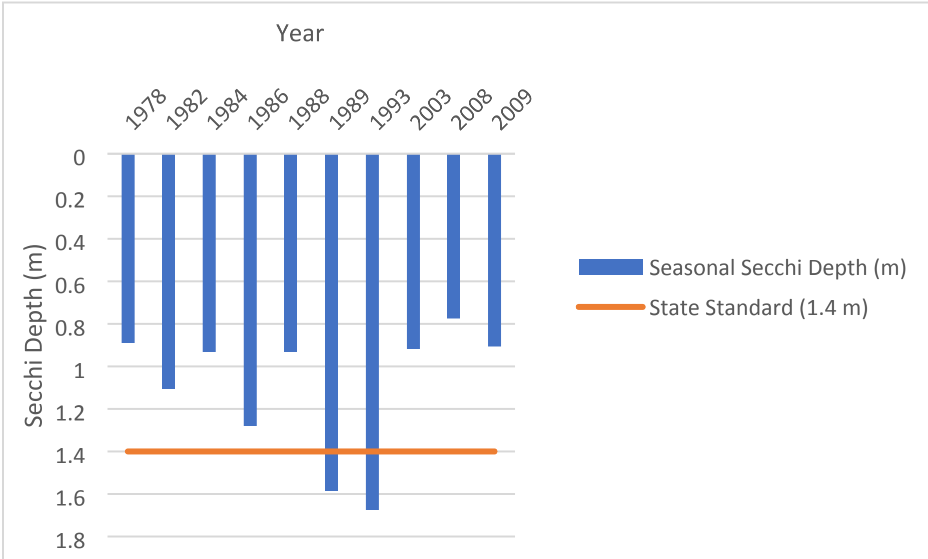

Figure 15. Station 71-0067-00-204 Historical Seasonal Secchi Depth Average

Secchi depth met the state standard in two (2) years, 1989 and 1993, unlike station 203 which only met the standard in one (1) year 1993 but follows a similar trend.

4.6.3 Station S005-700

Historical data is only available for 2009 at station S005-700. There are five (5) discreet sampling datapoints all occurring in June 2009 for total suspended solids. The average value for this dataset is 0.604 mg/l well below the state standard of 30 mg/l.

There was one TP sample taken on July 15, 2009 which returned a result of 6.4 mg/l, which exceeds the state standard of 0.1 mg/l.

Flow data is also available for this station between March 23, 2009 and June 2, 2009. The average flow as 6.81 cfs, with maximum of 7.47 cfs recorded on May 19, 2009 and a minimum value of 5.3 cfs recorded on April 2, 2009.

4.6.4 Current Water Quality Data

In 2019, the Big Eagle Lake Improvement Association, Sherburne Soil and Water Conservation District, and WSB collaborated to develop a water quality sampling plan and implement that plan to update the Big Eagle Lake Water Quality dataset, assess the current water quality of inlets and the Big Eagle Lake basin against established state water quality standards, and develop loading estimates for both internal and external sources.

A series of seven (7) water quality stations were established within Big Eagle Lake and the inlets and outlet channel. These stations are displayed in the figure below.

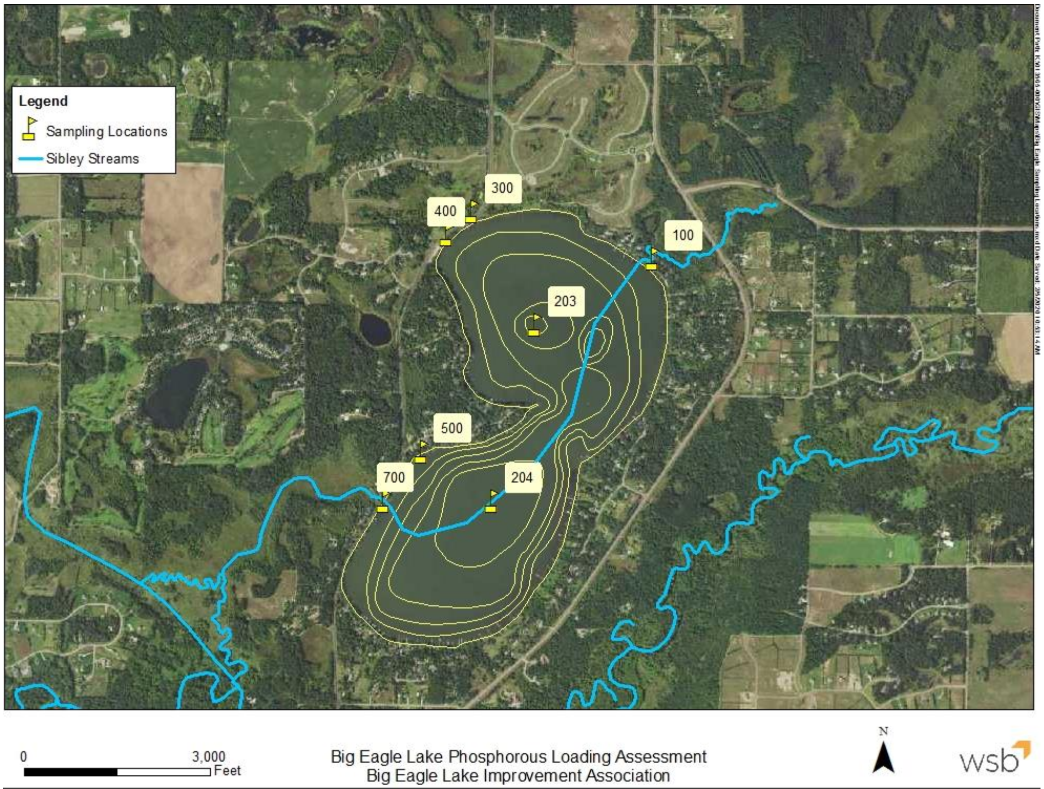

Figure 16. 2019 Big Eagle Lake Water Quality Sampling Stations

Stations 203, 204, and 700 (outlet) were selected since they replicate existing MPCA water quality stations. The remaining stations were established based on consultation with members of the BELIA and Sherburn SWCD.

Stations 100, 300, 400, and 500 are all inlets to Big Eagle Lake, but only station 100 is located within a stream that flows continuously throughout the growing season and can typically be measured (velocity and water depth) accurately enough to develop a rating curve and flow measurements. Station 400 flows intermittently and stations 300 and 500 are located with watercourses that typically flow intermittently but had continuous flow in 2019 (wet year). Station 100 is located just downstream of a culvert crossing along the inlet that flows into Big Eagle Lake from the Northeast under 183rd St. NW.

Figure 17. Station 100 Looking downstream.

Sampling methodology included automated collection of water level data at stations 100 and 700. A non-vented, Rugged Troll 100 (In-Situ) data logger was installed at both station 100 and 700 and set to record water levels at 1-hour intervals starting May 4, 2019 and continuing through September 19, 2019. These water level readings were tied to surveyed elevations completed by WSB on May 3, 2019 along with structural components of each station such as the culvert invert, top of culvert, top of loggers, and top of weir (station 700).

Members of the BELIA visited station 100 every two (2) weeks to collect grab samples for lab assessments which included total phosphorous, orthophosphorous, and total suspended solids. Water level data was downloaded from the logger monthly and provided to WSB for retention. The Sherburn SWCD would collect station 100 velocity readings and water level twice per low flow, normal flow, and high flow, for a total of at least six (6) discreet velocity measurements that could be tied to water level from the data logger and used to calculate flow and loading.

Station 700 was monitored for water level similar to station 100, except that there was also a MN DNR staff gauge deployed at the site and no discreet water quality sampling was planned to be completed (but one (1) sample was collected at the end of the growing season). Station 700 was also observed for backflow periods which were documented throughout the growing season.

A total of three (3) grab samples were planned to be completed for stations 300, 400, and 500 throughout the growing season for total phosphorous only.

In-lake sampling at stations 203 and 204 was completed by BELIA and Sherburne SWCD staff. BELIA volunteers sampled both stations for secchi depth, temperature, and dissolved oxygen on a weekly basis from the end of May 2019 through September 18, 2019 using a YSI Pro20. Measurements were taken at 1-foot intervals from the top of the water column to the sediment. Sherburne SWCD staff collected grab samples for lab analysis for chlorophyll-a and total phosphorous on a monthly basis; May through September.

4.6.4.1 2019 Inlet Station Sampling Results

Throughout 2019, a total of 11 lab samples were collected and processed for Station 100. The graphs below illustrate the lab results compared to the state standard for 2B-Central Rivers total suspended soils (30 mg/l) and total phosphorous (0.1 mg/l).

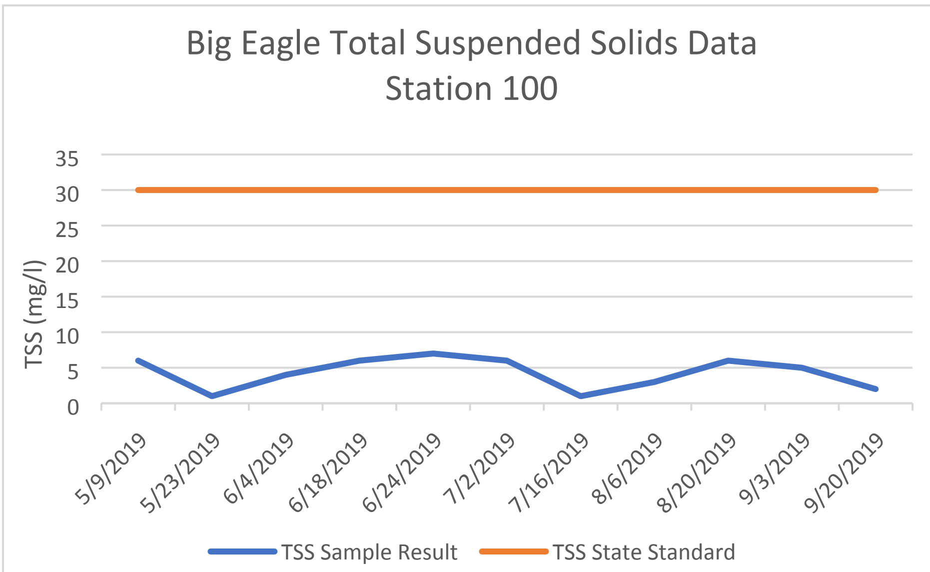

Figure 18. Station 100 TSS Results (2019).

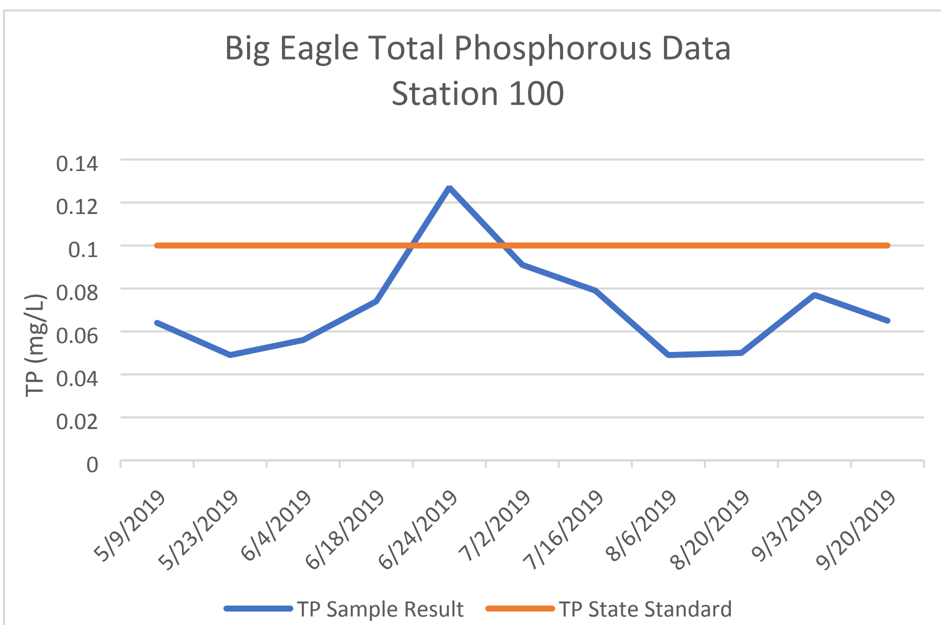

Figure 19. Station 100 TP Results (2019).

Total suspended solids (TSS) results were quite low all growing season when compared to the state standard of 30 mg/l. The maximum concentration was 7 mg/l on June 24, 2019. Two (2) sample concentrations were reported to be below the limit of detection which was 2 mg/l; these were taken on May 23 and July 16, 2019. These concentrations were recorded as 1 mg/l (1/2 the limit of detection). The average TSS concentration at station 100 for 2019 was 4.27 mg/l.

Similar to TSS, total phosphorous (TP) concentrations remained below the state standard of 0.1 mg/l for all but 1 sample taken on June 24, 2019 which resulted in a TP concentration of 0.127 mg/l. This was the maximum concentration documented at station 100 in 2019. The average value was 0.0717 mg/l.

All growing season results for 2019 are aggregated across the remaining stations and presented for comparison in the graph below.

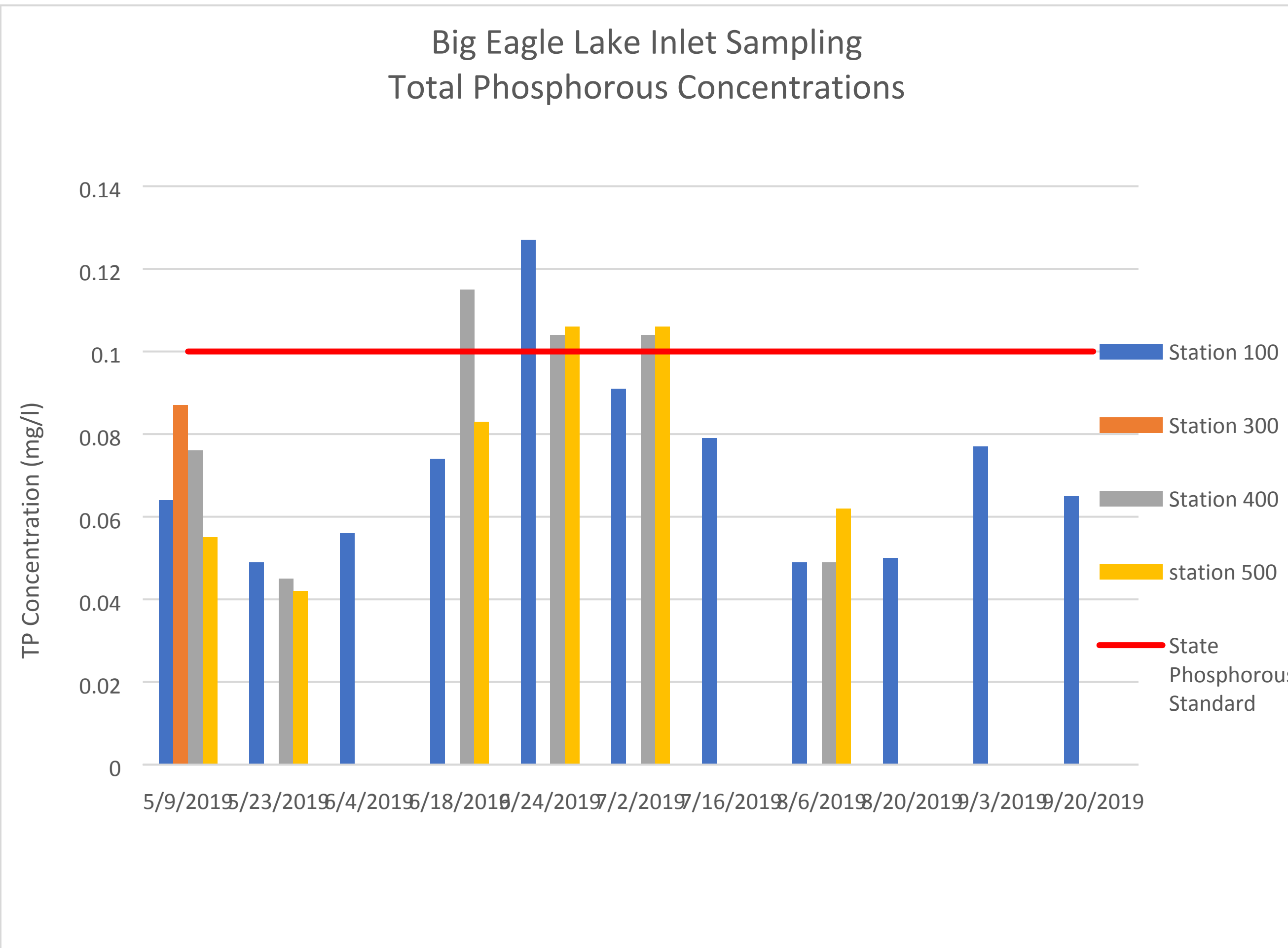

Figure 20. 2019 Big Eagle TP Inlet Concentrations

As can be seen, TP concentrations for station 400 exceeded the state standard on three (3) sampling occasions on June 18 and 24, and July 2, 2019. Station 500 TP concentrations exceeded the state standard on June 24 and July 2, 2019, while the only sample taken at station 300 (early in the season did not exceed the state standard.

Station 700 acts as the outlet for Big Eagle Lake and flows into the Snake River, which eventually flows into the Elk River. Observations between May 6, 2019 and September 26, 2019 show that the outlet was "backflowing" into Big Eagle Lake on 3 separate occasions; May 23-27, July 9-11, and September 22-25, 2019. There is also some correlation between these backflow events and a rise in the gage height of the Elk River at County Road 15 (USGS Station 05275000). One (1) lab sample was collected near the beaver dam downstream of station 700 for comparative analysis to in-lake TP concentrations. This was done to determine if TP concentrations downstream of station 700 were higher than in-lake TP concentrations and were contributing to increased loading of TP. The sample, collected on October 8, 2019, showed that the TP concentration at station 204 was 0.093 mg/l while the TP concentration downstream of station 700 was only 0.04 mg/l. TSS at this location was less than the limit of detection of 2 mg/l while station 204 TSS was 11 mg/l. However, soluble reactive phosphorous concentrations were similar; station 700 was 0.011 mg/l while station 204 was 0.012 mg/l. Based on this one (1) sample, it appears that backflow may not be contributing directly to phosphorous loading into Big Eagle Lake. Additional sampling in the future would need to be completed to ensure this is accurate.

4.6.4.2 In-Lake Sampling

Two (2) sampling stations were utilized for in-lake monitoring in 2019; station 203 and station 204. These stations were established by the MPCA and utilized in this project as they occur in the deepest portions of Big Eagle Lake and provide redundancy.

Both stations were sampled weekly by volunteers from the BELIA for temperature, dissolved oxygen, and secchi depth. The Sherburne SWCD sampled station 204 monthly for laboratory analysis of total phosphorous and chlorophyll-a. This sampling was completed through coordination with the MPCA IWM program for the Mississippi River-St. Cloud watershed and will be continued in 2020.

A sediment core was taken at both stations to determine the phosphorous release rate from the sediments as part of an internal loading assessment; that information is reported later in this document.

4.6.4.3 Station 203 2019 Sampling Results

Data for station 203 consists of profile data for temperature and dissolved oxygen along with secchi depth.

Temperature profile data shows that Big Eagle Lake does stratify over the growing period and become anoxic in the hypolimnion or the lowest layer of water that is generally cooler than the top layer in the summer.

The maximum temperature recorded was 82.4°F on July 17, 2019 at 5 feet water depth. The lowest temperature recorded (54.32°F) was on May 15, 2019 at the 19 ft. water depth.

Big Eagle Lake became mixed (spring turnover) near the May 25, 2019 sampling date indicated by the range (or lack thereof) in water temperature on that sampling date; 57.38 °F at the top of the water column to 57.02 °F at the 19 ft. water depth. By the next sampling date on May 29, 2019, the water column had stratified as indicated by a surface water temperature of 71 °F and a water temperature 19 feet of 55.58 °F. The difference in water temperature between the surface and the bottom of the profile when Big Eagle was stratified varied from a minimum of 7°F to a maximum of 25°F with 12-14°F separation between common. The water column remained thermally stratified until the August 21, 2109 sampling date when the water column was mixing and there was only a 4°F difference between the surface and the bottom of the profile. The water column remained weakly mixed until September 18, when it weakly stratified, then became completely mixed by the September 26, 2019 sample date. The last sampling date on October 3, 2019, showed the water column remained completely mixed at 58°F water temperature from top to bottom.

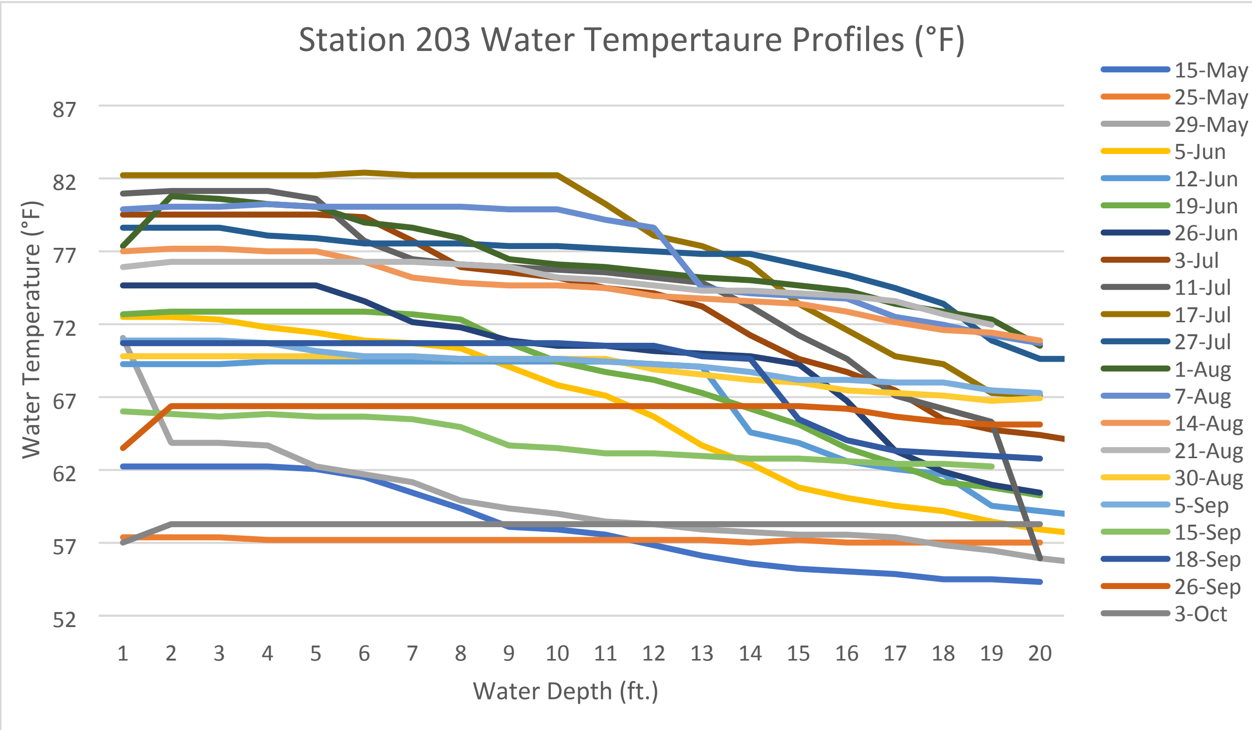

Figure 21. Temperature Profiles at Station 203.

Low levels of DO can be harmful to aquatic organisms; specifically, fish and invertebrates. Exposure to DO concentrations of less than 3 mg/l can be harmful to fish and the MPCA water quality standard for DO in Class 2 waters is 7 mg/l as a daily minimum. In addition, anoxic conditions can lead to the release of phosphorous from nutrient rich sediments leading to increased phosphorous loading for waterbodies. Phosphorous release from anoxic sediments is discussed in more detail later in the document, while this section provides a more general description of DO conditions in Big Eagle Lake as observed during the 2019 growing season.

Dissolved oxygen (DO) concentrations followed a similar pattern to water temperatures, with Big Eagle Lake being stratified on the May 15, 2019 sampling date where DO ranged from 11.17 mg/l at the surface to 5.77 mg/l at the bottom. By the next sampling date on May 25, 2019, the water column DO concentration was mixed; ranging from 10.46 mg/l at the surface to 9.72 mg/l at the bottom. By May 29, 2019, the water column had stratified with DO concentrations ranging from 11.1 mg/l at 1 foot below the surface to 3.05 mg/l at the bottom. This stratification remained until the August 30, 2019 sampling date where DO concentrations were mixed from the top (15.37 mg/l) to the bottom (10.95 mg/l). Similar to water temperature, the water column weakly stratified again until the September 26, 2019 sample (9.5 mg/l to 5.42 mg/l) and became further mixed on the last sampling date of 2019 (October 3); ranging from 7.86 mg/l to 5.62 mg/l.

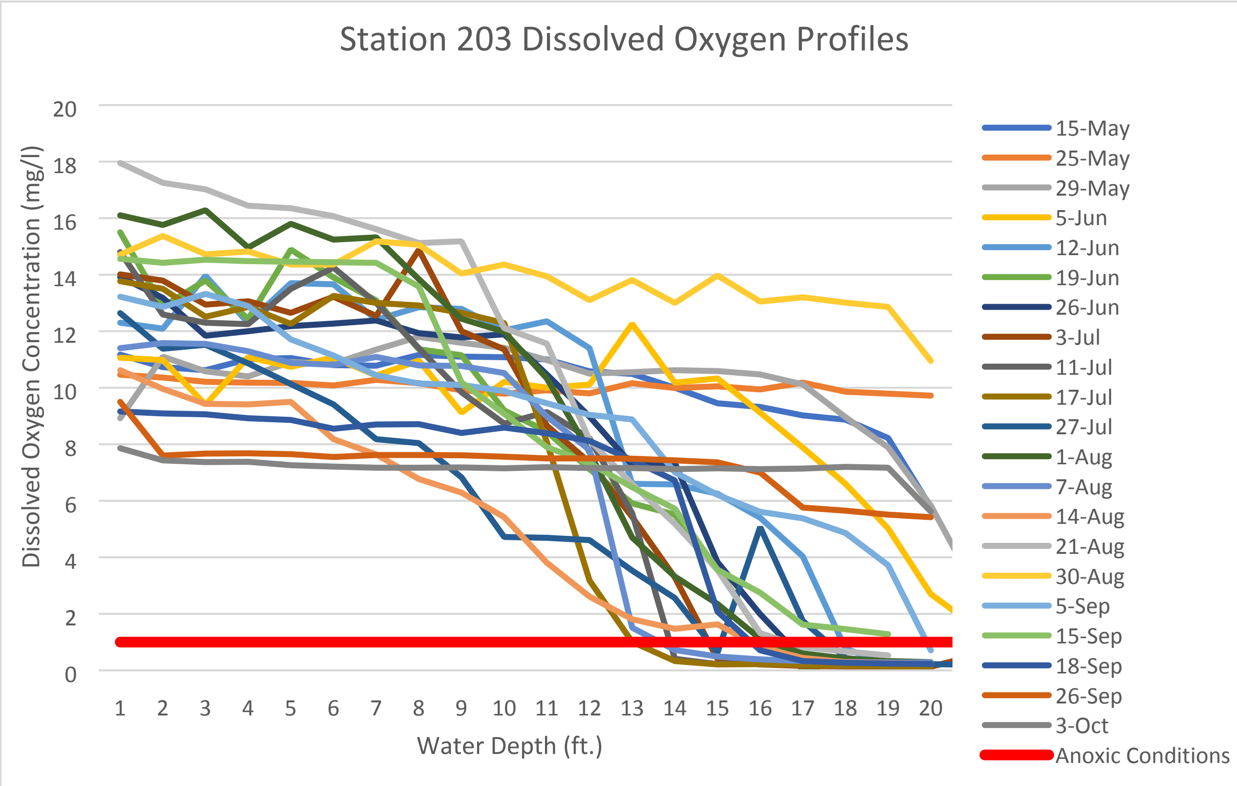

Figure 22. Dissolved Oxygen Profiles at Station 203

DO concentrations above 5 mg/l were maintained throughout the sampling period (May-October) in a majority of the water column. On July 27 and August 14, the DO concentration was ~5 mg/l at the 9 foot water depth. However, DO concentrations were at or above 7 mg/l for most of the rest of the water column. Profile sampling showed that DO concentrations were adequate for warm and cool water aquatic life the remainder of the growing season.

Anoxic conditions, or conditions where there is a lack of oxygen, are defined as when DO concentrations are below 1.5 mg/l for this report. At station 203, these conditions were present starting with the June 5, 2019 sample and continuing until August 21, 2019. They became present again on September 5 and remained until mixing on September 26, 2019. While these DO concentrations are harmful, they are generally limited to the lowest portion of the water column where aquatic life can avoid them.

Secchi depth was measured during each sampling event; May-October by BELIA volunteers. Results for those measurements are shown in Figure 23 below.

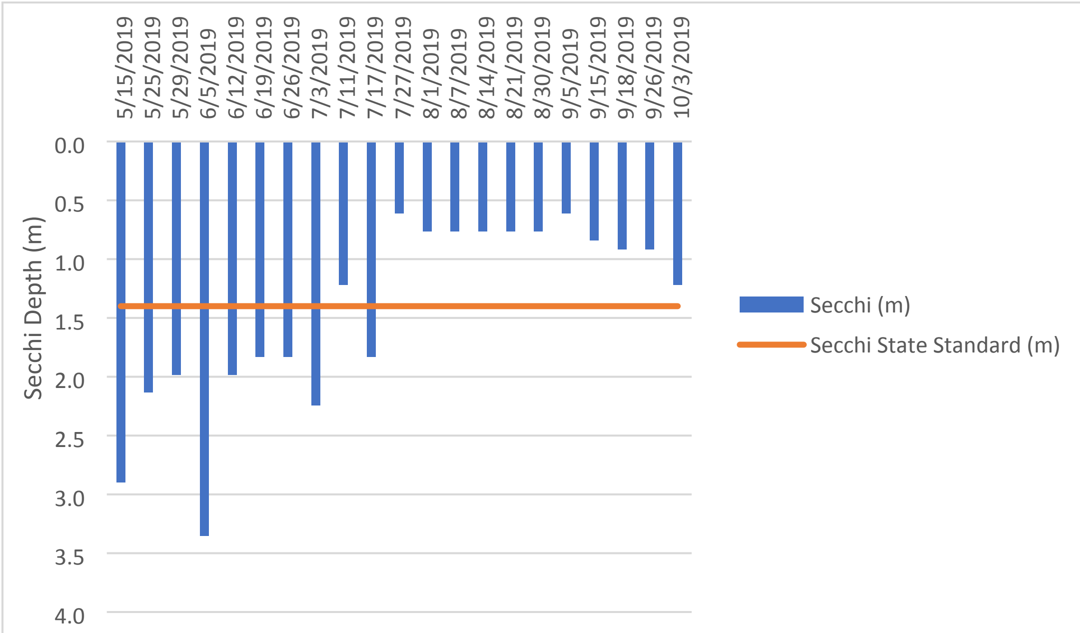

Figure 23. Secchi Depth Results for Big Eagle Lake Station 203 (2019 data).

Secchi depth met the state standard for 9 out of the 20 sampling events (45%) for the entire sampling period. The average secchi depth was 1.4 m when calculated across the entire sampling period; May to October. However, MPCA guidance requires that only data between June and September be used for assessment. The average, when adjusted for this period, is 1.3 m; just below the state standard of 1.4 meters.

4.6.4.4 Station 204 2019 Sampling Results

Data for station 204 consists of profile data for temperature and dissolved oxygen along with secchi depth and lab results for total phosphorous and chlorophyll-a. Both temperature and dissolved oxygen profiles are very similar to station 203; figures 21 and 22 are reflective of station 204 profile data.

Temperature profile data shows that Big Eagle lake does stratify over the growing period and become anoxic in the hypolimnion or the lowest layer of water that is generally cooler than the top layer in the summer.

The maximum temperature recorded was 82.04°F on July 17, 2019 at 0-7 feet water depth. The lowest temperature (53.96°F) recorded was on May 15, 2019 at the 18 ft. water depth.

Big Eagle Lake became mixed (spring turnover) near the May 25, 2019 sampling date indicated by the range (or lack thereof) in water temperature on that sampling date; 57.2 °F at the top of the water column to 56.66 °F at the 19 ft. water depth. By the next sampling date on May 29, 2019, the water column had stratified as indicated by a surface water temperature of 63.5 °F and a water temperature 19 feet of 57.02 °F. The difference in water temperature between the surface and the bottom of the profile when Big Eagle Lake was stratified varied from a minimum of 5°F to a maximum of 25°F with 8-12°F separation between common. The water column remained thermally stratified until the August 14, 2109 sampling date when the water column was mixing and there was only a 3°F difference between the surface and the bottom of the profile. The water column remained weakly mixed until September 18, after which it became completely mixed. The last sampling date on October 3, 2019, showed the water column remained completely mixed at 58°F water temperature from top to bottom.

Dissolved oxygen (DO) concentrations followed a similar pattern to water temperatures, with Big Eagle Lake being stratified on the May 15, 2019 sampling date where DO ranged from 11.5 mg/l at the surface to 7.32 mg/l at the bottom. By the next sampling date on May 25, 2019, the water column DO concentration was mixed; ranging from 10.44 mg/l at the surface to 9.61 mg/l at the bottom. By May 29, 2019, the water column had stratified with DO concentrations ranging from 11.1 mg/l at 1 foot below the surface to 5.88 mg/l at the bottom. This stratification remained until the August 30, 2019 sampling date where DO concentrations were mixed from the top (16.66 mg/l) to the bottom (10.19 mg/l). The water column became stratified again until the September 26, 2019 sample (6.71 mg/l to 4.72 mg/l) and became further mixed on the last sampling date of 2019 (October 3); ranging from 7.42 mg/l to 6.62 mg/l. This data shows that the early season mixing and stratification is similar to station 203, but late season "re-stratification" was more intense.

DO concentrations above 5 mg/l were maintained throughout the sampling period (May-October) in a majority of the water column. On July 17 and August 1, the DO concertation was ~5 mg/l at the 10 foot water depth. However, DO concentrations were at or above 7 mg/l for most of the rest of the water column. Profile sampling showed that DO concentrations were adequate for warm and cool water aquatic life the remainder of the growing season.

Anoxic conditions, or conditions where there is a lack of oxygen, are defined as when DO concentrations are below 1.5 mg/l for this report. At station 203, these conditions were present starting with the June 5, 2019 sample and continuing until August 21, 2019. They became present again on September 5 and remained until mixing on September 26, 2019. While these DO concentrations are harmful, they are generally limited to the lowest portion of the water column where aquatic life can avoid them.

Secchi depth was measured during each sampling event; May-October by BELIA volunteers. Results for those measurements are shown in Figure 24 below.

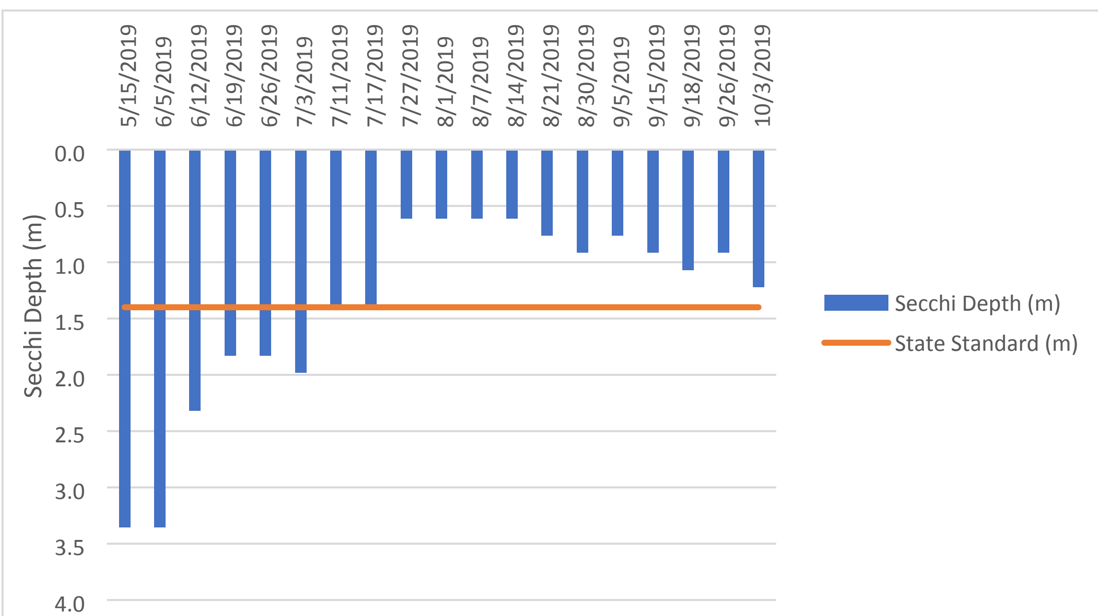

Figure 24. Secchi Depth Results for Big Eagle Lake station 204 (2019 data)

Secchi depth results for station 204 were very similar to those of station 203; meeting the standard in 8 out of 21 sampling events (38%). The average secchi depth was 1.4 m when calculated across the entire sampling period; May to October. However, MPCA guidance requires that only data between June and September be used for assessment. The average, when adjusted for this period, is 1.3 m; just below the state standard of 1.4 meters. This is the same result as station 203.

The state standard was nearly met in 2019 for total phosphorous. The Sherburne SWCD sampled station 204 six (6) times in 2019 (May-September), while the BELIA sampled near station 204 once in October. The average value for all samples was 0.05 mg/l. When adjusted for the growing season, that average value is 0.046 mg/l. This is relatively consistent with data presented earlier that shows TP values at station 204 at or near the state standard starting in 2003 through 2009, the last year of record.

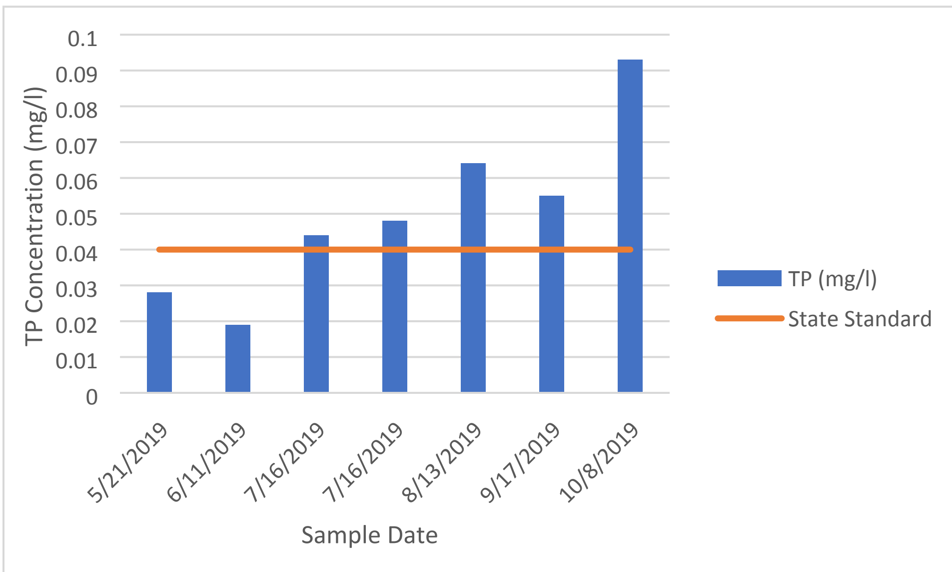

Figure 25. 2019 TP results for station 204

Lab samples were collected and processed for chlorophyll-a on six (6) separate dates; May through October. While the growing season averages for secchi depth and TP were slightly exceeding state standards (when May and October results were excluded), chlorophyll-a concentrations were much more elevated. The average chlorophyll-a concentration when using all samples, May through September was 34.42 ug/l. When adjusted for June through September, the average increases to 39.52 ug/l, while the state standard is 14 ug/l. Chlorophyll-a concentrations are below the state standard in May and June, and exceed the state for the remainder of the growing season with the maximum value (83.7 ug/l) observed in August. Figure 26 below shows all results for 2019 chlorophyll-a sampling.

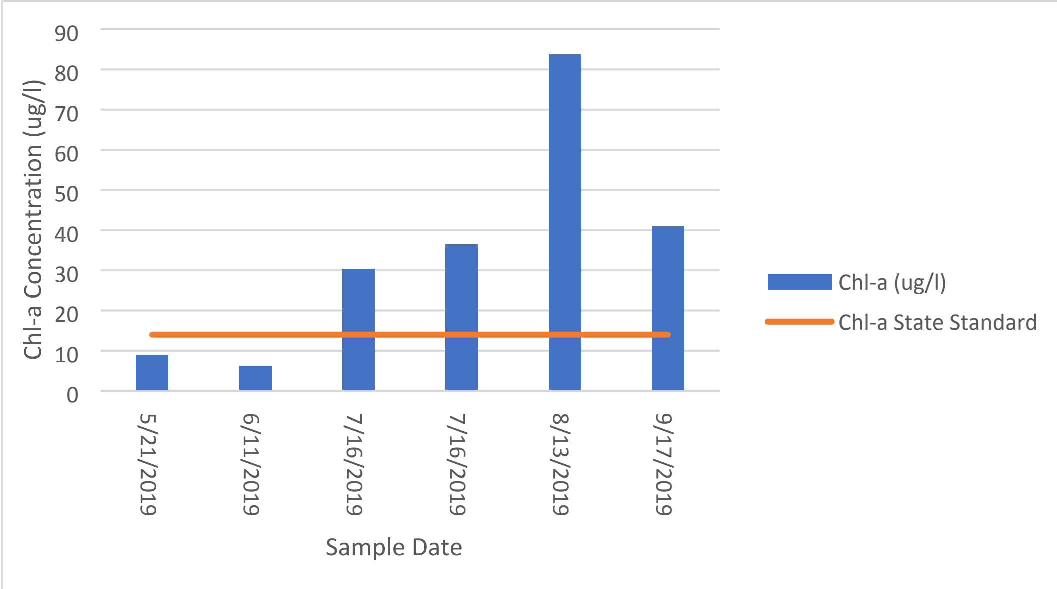

Figure 26. Chlorophyll-a Results for Big Eagle Lake Station 204 (2019 data)

When compared to state standards, both TP and secchi depth average growing season results (June-September) were very close to meeting those standards in 2019, while chlorophyll-a was very elevated. Table 6 below summarizes the calculated growing season averages and state standards for Big Eagle Lake.

	2019 Average Result	State Standard
Total Phosphorous (mg/l)	0.046	0.04
Secchi Depth (m)	1.3	1.4
Chlorophyll-a (ug/l)	39.52	14

Table 5. Big Eagle 2019 Average Water Quality Results and Comparative State Standards

4.7 Aquatic Vegetation

Aquatic vegetation data was not collected in 2019 as part of this project; however, two (2) documents provided by the BELIA offer some information on the historical vegetative community of the lake and associated issues.

A document titled “Big Eagle Lake Improvement Association Lake Management Plan-2008” (no author), indicates that Eurasian water milfoil (EWM) a common aquatic invasive species was present at the time of the report in 2008 and was first detected in 2005. One of the strategies identified in this plan was to conduct a whole lake vegetation survey; which it appears would be the first one completed for Big Eagle Lake. No additional information on vegetation is provided in this document.

The other document is a report drafted by Eric Fieldseth, AIS Consulting, who completed a vegetation survey of Big Eagle Lake in 2015 and 2018. Early season sampling (May) data from the 2018 survey notes indicate that aquatic vegetation was found at only 23.7% of the survey points (108 acres) with curly leaf pondweed (CLP) present at 21.6% of all points or 91% of the vegetated sample points which indicates that CLP is very dominant in the spring. This is compared to the 2015 survey in which CLP was found at only 10.35% of the sampling points in May.

Species diversity was similar between the 2015 survey and the 2018 survey when both the early and late season results for the 2018 survey are combined. Between the 2015 and 2018 surveys coontail, muskgrass, Eurasian water milfoil, decreased in frequency of occurrence, while northern watermilfoil, white stem pondweed, and elodea, were not found. Conversely, Curlyleaf pondweed, water stargrass, narrow-leaf pondweed, southern naiad, and sago pondweed increased in frequency of occurrence and wild celery and yellow water lily were documented.

The floristic quality index (FQI) for the aquatic community in 2018, was calculated at 16.7 which is degraded, based on the North Central Hardwood Forest FQI threshold value of 18.6. Lastly, the maximum depth of plant submerged plant growth incrased from 7 ft in 2015 to 9 ft in 2018, but the late season survey showed growth out to only 4.5 feet, which is another indication of reduced water clarity.

A 2002 MN DNR Fisheries survey report indicates that an aquatic plant survey was completed but was not available for this report.

4.8 Fisheries

Big Eagle Lake is one of the most popular angling lakes in Sherburne County (Cibulka, Personal Communication). The MN DNR has surveyed the Big Eagle Lake fishery five (5) times beginning in 1982 and again in 1988, 1993, 2002, and lastly in 2012. These surveys have typically been conducted in July or August and utilized multiple gear types including, electrofishing, standard trap nets, specialized trap nets, gill nets, and seine nets. While survey data does not provide an estimate of the population size, the surveys do provide data on relative abundance, size distribution, and growth rates. For this report we have focused on catch per unit of effort (CPUE), or how many fish per unit of time or net set, to provide an idea of relative abundance for each survey year and also identify trends across years. We also are using just standard trap net and gill net data to report on CPUE as data was available for almost all survey years for these gear types.

4.8.1 Big Eagle Trap Net Data

Trap net data was available for four (4) of the five (5) survey years (1982, 1993, 2002, and 2012). Based on this data, Big Eagle supports a relatively diverse assemblage of fish species. Represented species include black bullhead, black crappie, bluegill, brown bullhead, common carp, common shiner, green sunfish, hybrid sunfish, largemouth bass, northern pike, pumpkinseed, walleye, white crappie, white sucker, yellow bullhead, and yellow perch. Species diversity reflected as trap net catch peaked during the first year with 13 species captured, and decreased to 12 in 1993, 8 in 2002, and 7 in 2012. A total of 16 species are represented in the entire dataset.

Three (3) of the species not captured in the 2002 and 2012 surveys were bullhead species (black, brown, and yellow). Yellow perch, white crappie, pumpkinseed, green sunfish, and common shiner trap net catch rates declined during this same time period. Northern pike were not captured in the 2012 trap net survey after showing consistent catch rates during the previous three (3) surveys (average value was 0.55 CPUE or 3.6 individual fish/survey year). Walleye were captured for the first time during the 2012 survey.

Bluegill had the highest relative abundance in 3 out of the 4 survey years (1993, 2002, and 2012), and were the second most abundant portion of the catch in the 1982 survey. When looking at all survey data, white crappie and black crappie were also abundant, but catch rates have declined with white crappie not found in the 2002 and 2012 surveys. Black crappie is typically the second most abundant fish species found in the trap nets surveys.

It is important to note that gear can be biased (better at catching certain species than others), but it can still be informative to see assemblage data and look at trends in catch rates across multiple years.

4.8.2 Big Eagle Gill Net Data

Gill net data was available for all five (5) years; 1982, 1988, 1993, 2002, and 2012. Similar to gill net data, the Big Eagle fish assemblage is relatively diverse with 15 different species represented in the catch data. Diversity of species captured remained consistent unlike trap net data. The number of different species captured ranged from 11 (2012) to 13 (1988). Hybrid sunfish and green sunfish were not captured in gill nets, but bowfin (dogfish) were; all other species captured in trap nets were captured in gill nets.

Three (3) gamefish species are present in Big Eagle Lake; Northern Pike, Walleye, and Largemouth Bass. Northern Pike have a higher relative abundance than walleye or largemouth from the perspective of the CPUE data (electrofishing data may represent largemouth bass more accurately). Figure 27 below shows the gill net CPUE values for these three (3) species.

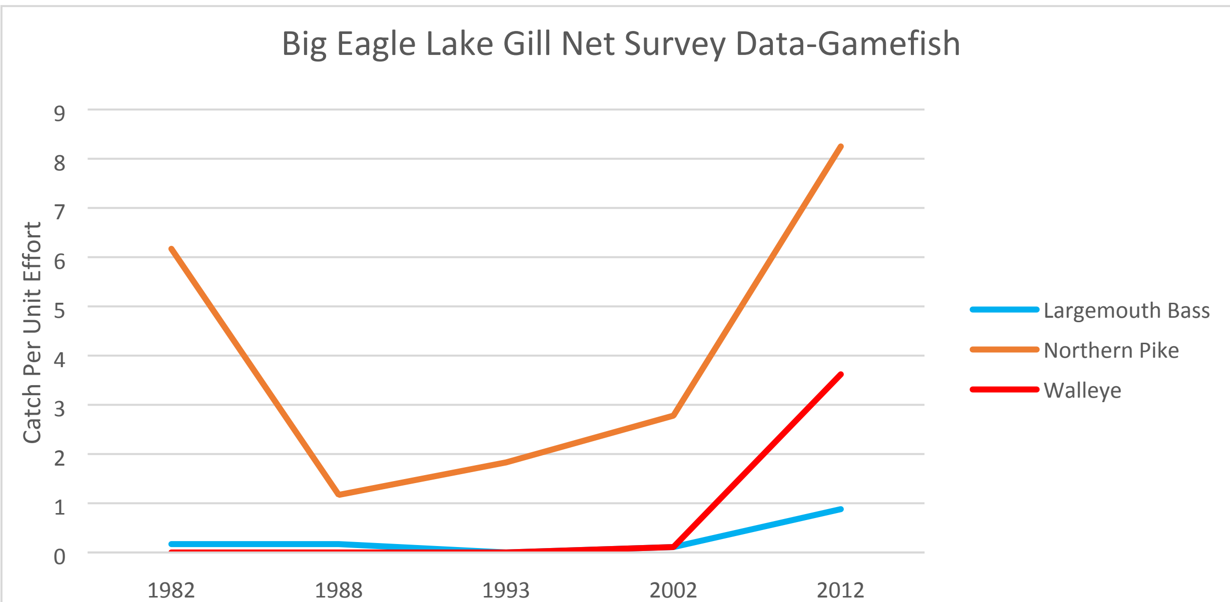

Figure 27. Big Eagle Gill Net Data (Gamefish)

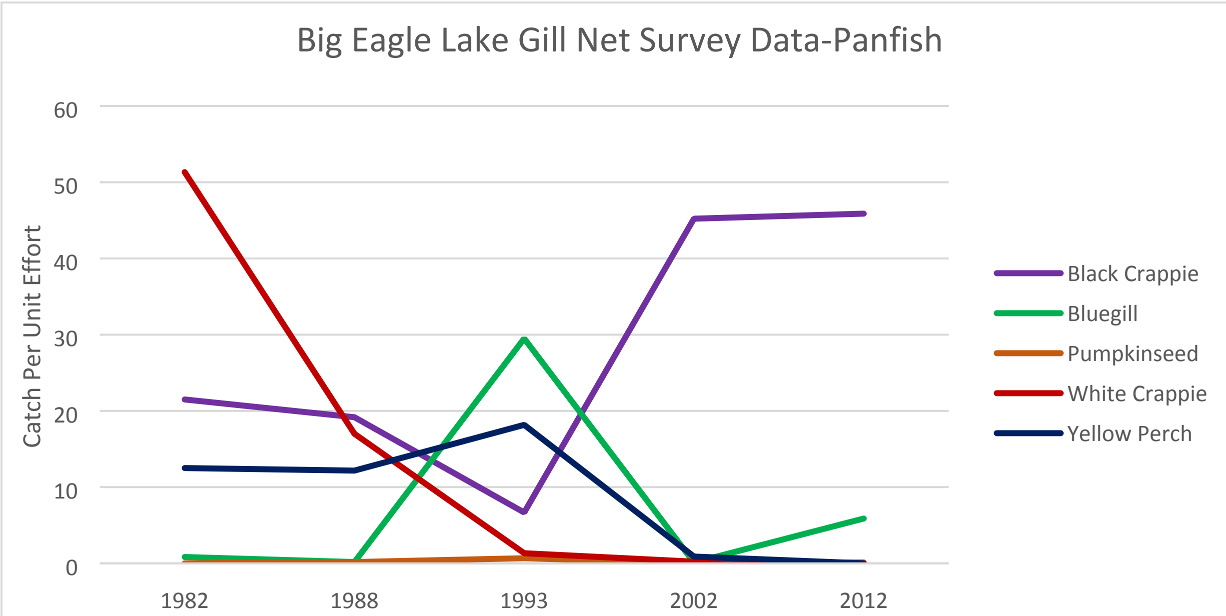

Figure 28. Big Eagle Gill Net Data (Panfish)

Panfish data shows varying trends regarding CPUE data. Black crappie CPUE has more than doubled in the two (2) most recent surveys while perch and white crappie have decreased to 0. Pumpkinseed relative abundance remains consistently low, and bluegill appear to remain low for gill net relative abundance (inverse of trap net data) with the exception of a dramatic spike in 1993.

4.8.3 2019 Common Carp Assessment

The Big Eagle Lake Improvement Association (BELIA) commissioned WSB to complete an assessment of the common carp population in 2019 with the objective to assess the potential impact common carp may be having on the water quality and ecological integrity of Big Eagle Lake.

Although carp management is not the only action to improve water quality, it may be a necessary component of an overall lake management plan. Carp can cause loading of nutrients internally within a basin due to their feeding habits and excretion rates when biomass becomes elevated. An elevated carp biomass threshold value currently used and established by the scientific community is ~90 lbs/acre (Bajer, 2012).

We utilized an electrofishing catch per unit effort (CPUE) methodology. To do this, a boat electrofisher is used to stun and capture carp and other fish species as it traverses representative habitat types in the lake littoral zones. Time spent electrofishing is recorded, and all carp are captured, measured for length and weight, given a unique fin clip, and released. The number of carp captured is used as an input into an existing model that provides an estimate on the number of individual carp per acre. Average weights and lake acreage can be used to estimate carp density and overall abundance.

Multiple electrofishing CPUE events per waterbody are pursued during each season (late summer/early fall) to gain confidence in estimates developed through this method of estimation. On Big Eagle Lake, we sampled via boat electrofishing on two separate occasions, one on

August 22 and the other on September 24, 2019. On both survey dates, at least three transects were traversed to capture the variability of carp abundance throughout the lake basin.

Using a boat electrofisher, nine (9) transects were traversed on Big Eagle Lake on two visits to the lake. Time spent electrofishing, number of carp captured, and length and weight data was collected to be used in a common carp catch per unit effort model. Each transect was averaged to report a daily CPUE and each date was averaged to report a yearly CPUE for the lake and variation between dates is used to calculate a standard deviation (Table 1). The results of the 2019 electrofishing CPUE survey indicate that biomass in Big Eagle Lake (171 ± 167.8 lbs/acre) is above the management threshold of 90 lbs/acre.

Lake	**Date -2019**	**Event Type**	**# of Transects/ Total Time (hrs)**	**Total # Carp Captured**	**2019 Fin Clip**	**CPUE estimate (lbs/ac) By Date**	**2019 CPUE estimate (lbs/ac)**
Big Eagle	22-Aug	CPUE/Fin Clip	5 / 1.88	11	Left Pelvic	99.6	**171.7**
Big Eagle	24-Sep	CPUE/Fin Clip	4 / 1.35	10		243.8	**± 167.8**

Table 6. 2019 Big Eagle Lake Carp Biomass Estimates

Results using the carp electrofishing CPUE model show that common carp biomass density is elevated in Big Eagle Lake however, the variability is between survey dates is high. Although a review of the CPUE estimate suggests that carp may be contributing to poor water quality in Big Eagle Lake, a closer look at the size distribution in Big Eagle Lake explains the variability in data and carp dynamics in the lake basin.

Plotting the size distribution over the two survey dates, data suggest that carp are not actively recruiting to the lake (Figure 29). Zero (0) carp were sampled that were smaller than 24 inches, indicating that these fish are likely older than 5 years. Additionally, the size distribution in the sampling events can also help to describe the variability in the CPUE estimates reported on each survey date. Few fish were captured in each transect; however the weight of each fish was between 5 and 28 pounds, with larger and heavier fish on average in the September survey date.

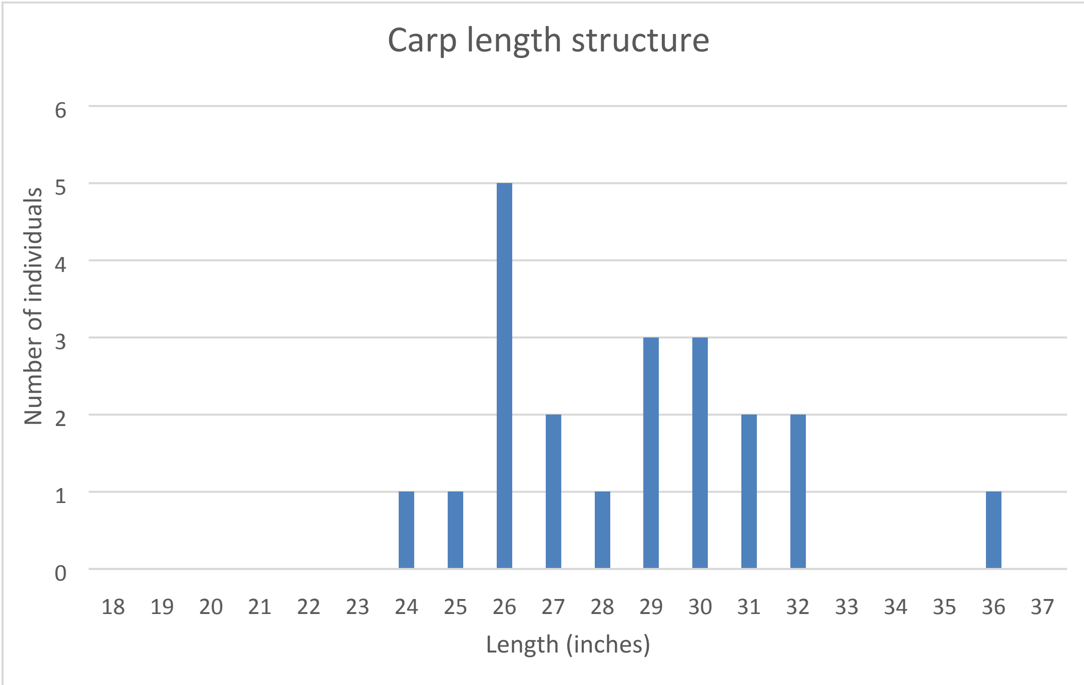

Figure 29. Length histogram of carp captured in Big Eagle Lake via boat electrofishing in 2019.

In 2019, data suggests that carp may be contributing to poor water quality in Big Eagle Lake. Additional loading analysis is presented later in this report. With the large range of variability, it would be suggested that additional surveys in subsequent years be pursued before moving towards a carp management program. The carp barrier at outlet of Big Eagle Lake seems to be preventing the regular recruitment of carp into the lake basin and survey data collected in multiple years could help to support this hypothesis. If this is the case, the carp population will continue to decline naturally, although the size of carp may increase.

5. LOADING ANALYSIS

Developing a holistic understanding of both the internal and external phosphorous loading mechanisms that drive the water quality of Big Eagle Lake is perhaps the most important aspect of this overall project and corresponding report. Modeling and direct measurement were both used to develop a load estimate for Big Eagle Lake. The total load estimate was developed by first creating a P8 model to estimate loads from each of the subwatersheds within the entire Big Eagle Lakeshed (external). This, along with septic system data was used to identify the initial external load. This external load was further refined by using data collected at station 100 (flow and TP concentration) to calculate a monitored load using FLUX.

Sediment cores were collected and analyzed to identify a anoxic sediment release rate for TP and combined with dissolved oxygen profiles collected between May and October to calculate an internal load from sediment P release. Finally, data from the carp population estimate was used along with P loading rates based on carp biomass density to calculate an internal load from carp bioturbation.

All loads were summed to determine the total load to Big Eagle Lake. Each of these steps is discussed in detail in the following sections.

5.1 Big Eagle Lake Watershed P8 Model Development and Modeled External Load Calculation

WSB first verified the current area that drains to, or the watershed boundaries, for Big Eagle Lake through use of satellite topographic imagery, LIDAR contours, the National Wetland Inventory, and the Minnesota DNR Public Waters Inventory. The total watershed size analyzed is 4,330 acres which excludes the actual surface area of Big Eagle Lake as shown in Figure 7.

For this study, the watershed was split into five (5) subwatersheds. Four (4) of these subwatersheds contain ponds and wetlands that filter the water prior to discharging to the lake. These four subwatersheds are considered to have a “long hydraulic time” because of the indirect pathway water flows. The south watershed is considered to have a “short hydraulic time” as it includes the area immediately around the lake that flows directly into the lake.

WSB created a model using P8, a modeling software that predicts the generation and transport of stormwater runoff pollutants in urban watersheds. The model created for this study reflects the subwatersheds that discharge into Big Eagle Lake. The model incorporates the soil type of the subwatersheds and rainfall data sourced from NOAA Atlas-14.

The P8 model contains five major subwatersheds and four major inlets that discharge in to Big Eagle Lake. The Northwest Subwatershed, the Central Subwatershed, the Northeast Subwatershed, the West Subwatershed and the South Subwatershed (direct), which are described in section 3.4. Table 8 summarizes the soils types for each of the subwatershed areas:

Subwatershed Area	Soil Type A (acres)	Soil Type B (acres)	Soil Type A/D (acres)	Soil Type B/D (acres)	Soil Type C/D (acres)	Overall Area (acres)	Land Use
Northwest	168	125	53	7	11	364	Open Space, grass cover > 75%
Central	783	81	3	-	-	867	Open space, grass cover > 75%
Northeast	1,146	580	88	-	-	1814	Woods/grass combination, good
West	442	385	51	36	37.5	952	Open Space, grass cover > 75%
South (Direct)	278	49	6	-	-	333	Residential
Total	2,817 (65.06%)	1,220 (28.18%)	201 (4.64%)	43 (.99%)	49 (1.13%)	4330	-

Table 7. Big Eagle Watershed Soil Types and Land Use

5.1.1 Septic System Influence

Contributions of the loading rate of TP and TSS to Big Eagle Lake from septic systems adjacent to the lake were also calculated. Information from Sherburne County Planning and Zoning Department records was used to identify how many septic systems were located on the lake. A total of 136 septic systems were included in the model, with 35 of those systems on seasonal properties. 101 systems were assumed to contribute to the loading rate 365 days of the year and 35 systems were assumed to contribute only during May through August (123 days). For this analysis, it was assumed at the average number of bedrooms associated with each septic system was 2 (this equals an estimated 4 people per residence), which was used to estimate the amount of septic effluent produced by the system (75 gal/day/person). Table 9 summarizes information on septic system use.

Type of System	Number of Systems Adjacent to Big Eagle Lake	Number of Active System Days	Users
Seasonal Septic System	35	123*	2 bedrooms 4 people per system
Year-Round Septic System	101	365	2 bedrooms or 4 people per system

Seasonal systems are assumed to be active May (31 days), June (30 days), July (31 days), and August (31 days).

Table 8. Big Eagle Lake Septic System Analysis

Each system was assumed to produce TSS (0.00025 lbs/gal per day[1]) and TP (1.518E-6 lbs/gal per day[2]) in the septic effluent. Table 3 summarizes the estimated amount of TP and TSS associated with the septic system effluent around Big Eagle Lake.

Pollutant	Daily Rate (lbs/gal per day)	Septic Effluent Produced (gal/day)	Seasonal Systems Contribution (lbs/season)	Year-Round Systems Contribution (lbs/yr)	Annual Contribution (lbs/yr)
TP	1.518 E-6	300	1.96	16.78	18.8
TSS	0.0025	300	323	2,765	3,087

Table 9. Big Eagle Lake Septic System TP and TSS Loading

5.1.2 P8 Model and Septic Loading Summary

Total TSS and TP results for the Big Eagle Lake watershed were produced using P8. The indirect subwatersheds flow through wetlands/low areas prior to discharging into Big Eagle Lake. This indirect discharge is treated to a certain extent by being routed through the wetlands/low areas. The model results of the inflow to Big Eagle Lake are summarized in Table 10.

Load (lbs/yr)							
	Indirect				Direct	Septic Systems	Overall
Variable	Northwest Subwatershed	Central Subwatershed	Northeast Subwatershed	West Subwatershed	South Subwatershed		
Area (ac)	364	867	1814	952	333	-	4,330
TSS	2,586 (2.11%)	33,290 (27.21%)	41,020 (33.53%)	12,400 (10.14%)	29,962 (24.49%)	3,087 (2.52%)	122,345
TP	24 (4.07%)	140 (23.73%)	248 (42.03%)	65 (11.02%)	95 (16.10%)	18 (3.05%)	590

Table 10. TSS and TP Inflow to Big Eagle Lake Summary

5.2 Station 100 (Northeast Subwatershed Outlet) Monitored Load and Refined External Load

Outlets for the northwest (station 500), west (station 400), and central (station 300) are minor and flow intermittently making it difficult to establish a flow and calculate a load for each of them. However, the outlet for the northeast subwatershed is located at station 100, which flows regularly, making it possible to document flows and associated TP concentrations.

The station 100 site was surveyed in May 2019 to determine the elevation of the culvert pipe outlet invert, water level (time of survey), and top of the culvert pipe at the outlet. A Troll 100 datalogger was placed near the culvert outlet to document water level (and corresponding elevation) over the course of the monitoring period. A total of 11 samples were collected for analysis to determine TP concentration. Velocity measurements were also taken on 10 different sampling dates.

5.2.1 Water Level Logger Data Preparation

Data was downloaded from the logger on a monthly basis by BELIA volunteers to ensure the logger was functioning properly and to secure data in the event there was an issue with the logger. The last download was completed on October 17, 2019.

The raw data was taken from two separate loggers, one at an inlet (100) and one at an outlet weir (700). This raw data was used with surveyed elevations to get a water surface elevation. The data was compared to the observed staff gauge readings and some clear errors were noticed. We took the average difference between the staff gauge readings and the logger readings at the weir (700) to adjust the data over these intervals and used Flowlink to manually adjust the graph to match the readings of the staff gauge over those two time periods.

The loggers seem to be consistent until mid-September, after which the water elevation at the inlet (100) dips down below the outlet level (700). This may not be accurate data and was be omitted in curve number calculations, but is shown in the figure below.

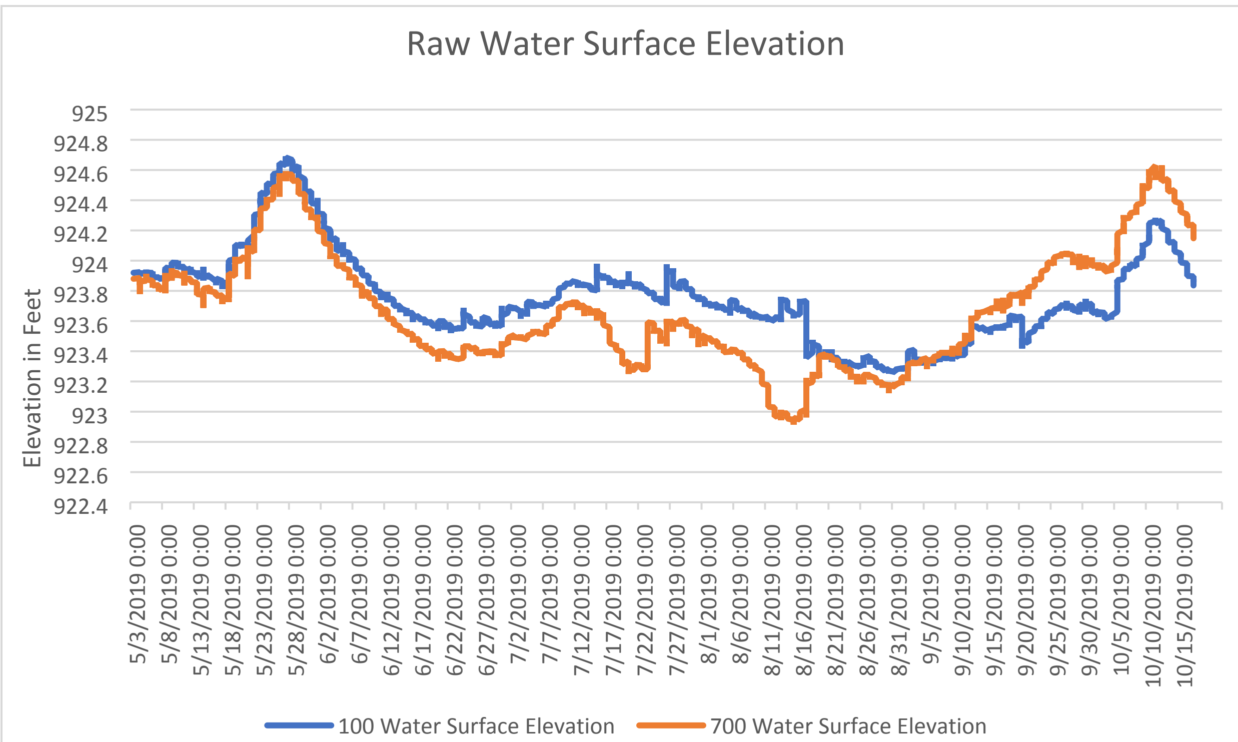

Figure 30. Surface Water Elevations at Station 100 and 700

This adjusted data was then provided to the Sherburne SWCD for development of the rating curve.

5.2.2 Rating Curve Calculation

Sherburne SWCD staff collected data at the Station 100 culvert on 10 occasions in 2019 under a variety of flow conditions (high, medium, low flow, etc.). During these visits, staff collected information pertaining to the date/time, weather, description of flow conditions, water depth, and flow velocity. Flow velocity was determined with use of a flow meter (model Aqua Calc Pro+, manufactured by AquaCalc LLC).

At the end of the monitoring season, Station 100 data was downloaded from the field datalogger and a database was developed. Water discharge for the 10 site visits were calculated through standard equations using the flow rate and cross-sectional area of the water column. A plot was developed using the discharge data compared with the water elevation (stage) which resulted in a rating curve for the site. This rating curve was utilized in further load calculations for Station 100.

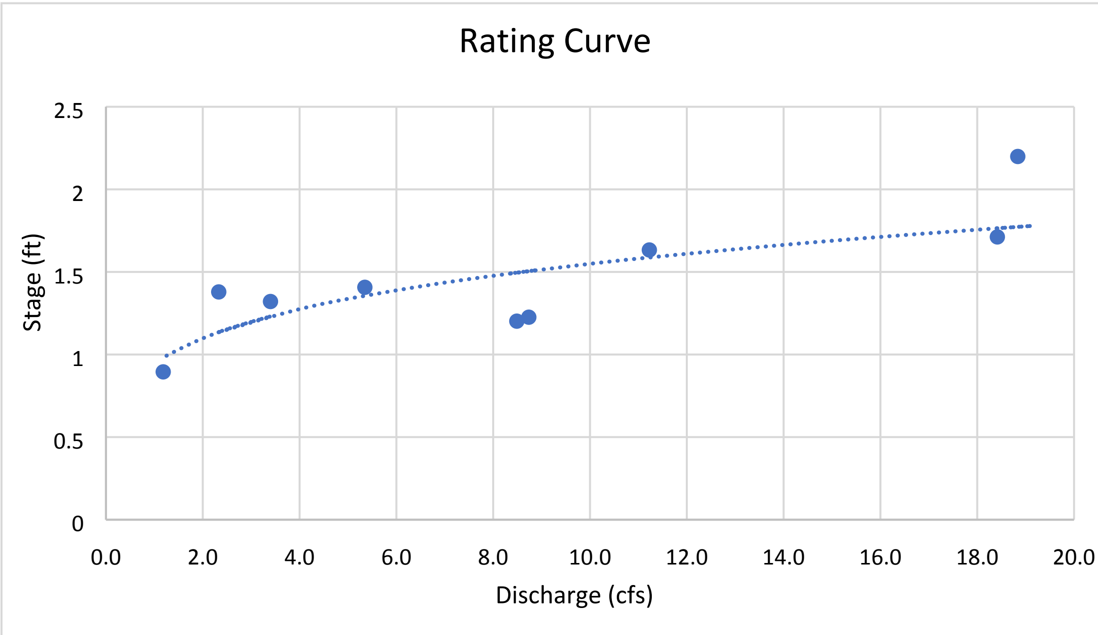

Figure 31. Station 100 Rating Curve

<u>5.2.3 Calculating daily discharge and Flux input files</u>

Depth obtained from the level logger was converted using the rating curve formula; which converts the depth in the stormwater pipe into a flow discharge. Each day's flow was averaged to give a single flow rate per day. This was necessary for the nutrient loading software, FLUX32. This software uses daily flow data with instream water quality sampling data to provide valuable flow and nutrient loading information.

The computed daily discharge along with the water quality sampling data were set up in two separate spreadsheets. With this information, FLUX32 provided a total phosphorous concentration and yearly load for station 100.

Measured velocity readings from SWCD are variable and do not directly correspond to level logger readings. The highest velocity recorded on 5/21/19 is 2 ft/s, with a water depth of 1.712' in the pipe. The level was recorded as 2.199' on 5/29/19 and velocity slowed to 1.24 ft/s, potentially indicating backflow. This is apparent in the 6/6/19 velocity measurement when level was 1.633, but velocity was 1.35 ft/s when compared to data from 6/18 and 6/25 with levels around 1.2' and velocity measured at 1.85 ft/s.

Velocity measurements were predicted for various water depths where velocity was not measured by fitting the velocity measurement data to a polynomial curve and using the y-intercept formula to predict velocities and associated discharges for all water depths.

5.2.4 Flux Process and Results

Using the two input files; daily average discharge and water quality (TP), FLUX provided a nutrient concentration. FLUX requires the two input files discussed earlier: daily average flow or discharge and a water quality (TP) file. Once the files are selected the regression method was used to calculate the total phosphorous flow-weighted concentration average of 0.0667 mg/L. This value is then used in the Bathtub water quality modeling program. Flux Outputs can be found in **Appendix A.**

5.3 Internal Loading Estimate

In addition to external loads (modeled or measured), internal loading sources were identified, and corresponding TP loads were calculated to identify the all TP load amounts affecting Big Eagle Lake water quality. While there is some suggestion that submergent aquatic vegetation (SAV) senescence can lead to internal loading, we only included loading calculations from anoxic sediment release and carp bioturbation based on uncertainty of SAV internal loading calculations in published literature.

5.3.1 Anoxic Sediment Release

Lake sediments naturally contain some concentration of phosphorous, which has most likely increased in many lakes from external sources driven by anthropogenic land uses and other natural factors as lakes age. Anoxic (little to no oxygen) conditions can increase the rate at which phosphorus is released (mobilized) from the sediment which, in turn, increases the internal and overall phosphorous loads. An internal loading rate and total load were calculated for Big Eagle Lake as part of this project.

To develop the P loading rate, the Saint Anthony Falls Laboratory (SAFL), University of Minnesota, was contracted to collect and analyze samples. SAFL collected three (3) sediment cores in October 2019 at locations that corresponded with water quality sampling station 203 and 204.

These samples were brought back to the lab and, after filtering the sample water from Big Eagle Lake, underwent analysis under three (3) separate sets of conditions: **(1)** oxic (oxygenated at ~11 mg/l DO) and mixed water column, **(2)** non-aerated and unmixed water column, and **(3)** anoxic (~0.56 mg/l DO and mixed water column.

Results under phase 1 (oxic conditions) showed a small increase in water column TP, which may have been due to factors other than anoxic P release.

Phase 2 (non-aerated, unmixed) results showed that DO concentrations only decreased to ~3.6 mg/l and there was minimal change in water column TP.

Conditions under phase 3 (anoxic, mixed water column) changed dramatically, showing a DO concentration of 0.56 mg/l and an increase in water column TP concentration from ~0.15 mg/l TP during phases 1 and 2 to a maximum of ~0.75 mg/l TP during phase 3 for sample 1. Additional methodology and details can be found in Appendix X.

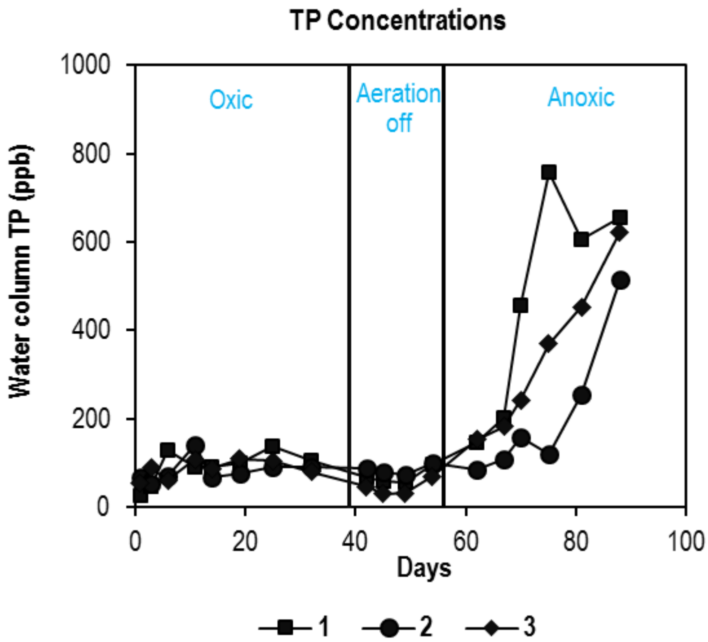

Figure 32. TP Concentrations in during phases 1, 2, and 3 for all samples.

Based on this, the average anoxic sediment release rate for Big Eagle Lake was calculated at 6.56 mg P/m²/day (±1.20).

Dissolved oxygen profile data was the used to determine at what depth anoxia was occurring over the course of the growing season and for how long. For purpose of this project anoxic conditions criteria equals a DO concentration ≤ 1 mg/l (using Nurnberg, 1988). Since both stations 203 and 204 resulted in very similar dissolved oxygen profiles and stratified layer depths, only data from 203 was used to calculate internal load from anoxic sediment release.

Anoxic conditions were first observed at station 203 on June 12, 2019 at the 18' contour. Anoxic conditions persisted between the June 12 sample and the August 21 sample. On August 21, the anoxic layer was evident at 16', but by August 30, the entire water column had become mixed before stratifying again by September 5, and finally turning over and becoming mixed on September 26, 2019.

Concurrently, Big Eagle Lake bathymetry data was updated to reflect 1-foot contour intervals by interpolating the 5' contour MN DNR bathymetry layer. Acreages were calculated for each 1' contour depth and converted to square meters.

Sampling dates were used to determine the period of time that anoxic conditions persisted, and along with the anoxic P release rate identified by SAFL, a total load for the summer growing season was calculated at 263 kg P. Table 11 shows the results for anoxic depth layer, associated acreages and calculated loads in mg and kg, along with the total growing season load.

Date	Anoxic Depth (ft.)	Corresponding Lake Area (ac)	Corresponding Lake Area (m²)	# of Days Anoxic	TP Loading Rate (mg P/m²/day)	Load (mg)	Load (kg)
6/12/2020	18	63	254,898	7	6.56	11,704,916.16	11.70
6/19/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
6/26/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
7/3/2020	14	148	598,808	7	6.56	27,497,263.36	27.50
7/11/2020	13	170	687,820	8	6.56	36,096,793.60	36.10
7/17/2020	12	182.6	738,800	6	6.56	29,079,152.26	29.08
7/27/2020	17	70.2	284,029	10	6.56	18,632,315.52	18.63
8/1/2020	15	105.2	425,639	4	6.56	11,168,772.61	11.17
8/7/2020	13	170	687,820	6	6.56	27,072,595.20	27.07
8/14/2020	15	105.2	425,639	7	6.56	19,545,352.06	19.55
8/21/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
	stop-mixed water column						
9/5/2020	19	38.3	154,962	10	6.56	10,165,494.08	10.17
9/15/2020	19	38.3	154,962	3	6.56	3,049,648.22	3.05
9/18/2020	15	105.2	425,639	8	6.56	22,337,545.22	22.34
	stop-mixed water column						
						Total Growing Season Load	263.39

Table 11. Anoxic Sediment Load Using Station 203 Data

5.3.2 Bioturbation from Common Carp

Invasive common carp can lead to direct loading of phosphorus through excretion and bioturbation and secondarily through bioengineering waterbodies they live in (i.e., reduction in SAV, reduced photosynthetically available radiation for SAV growth, negative changes in fish diversity and abundance, etc.). Multiple sources document the negative effects of carp on water quality, vegetation, fisheries, and waterfowl.

This report provides an internal load calculation using the carp population estimate described in section 3.8.3 and a methodology described in LaMarra (1975) from experiments completed in Minnesota. LaMarra calculated TP loading rates (1.07-2.18 mg P/m²/day) from carp using carp biomass density (200 kg/ha). For these calculations we used the more conservative factor of 1.07 mg P/m²/day.

In 2019, we estimated the carp biomass in Big Eagle Lake to be 192 kg Carp/ha (171 lbs carp/ac). Using this biomass density, the loading factor would be slightly less (1.02 mg P/m²/day). We also only used the littoral acreage of Big Eagle Lake (330 acres) since carp would be using these shallower water areas during the growing season (121 days) before moving to deep water areas during the fall, winter, and spring, when algal production is relatively non-existent.

Based on this, the total load contribution from carp is calculated to be 164.56 kg or 362.85 pounds P/year.

5.4 Loading Summary

Using a combination of modeled and monitored loads, Tables 12 and 13 provide a summary of the existing TP loads from Big Eagle Lake using data from 2019 described in earlier sections of the report. Table 13 uses data gathered from station 100 and analyzed using Flux for a total load from the Northeast Subwatershed. The difference between the P8 modeled loads and the FLUX results may be attributable to two factors 1.) the P8 results are modeled, while station 100 FLUX results are measured 2.) 2019 was a very wet year which is reflected in the FLUX results, while P8 uses a historical precipitation dataset, so we may be seeing an extreme for the load in the 2019 FLUX results. Also, only 1 land cover type was able to be applied to the entire subwatershed in the P8 model, not reflective of the various land cover types present within the subwatershed. This may further increase variability between the P8 modeled loads and the FLUX results.

Source		**TP Load (lb/yr)**	**Method**
External	Northwest Subwatershed	24	Modeled from P8
	Central Subwatershed	140	Modeled from P8
	Northeast Subwatershed	248	Modeled from P8
	West Subwatershed	65	Modeled from P8
	South Subwatershed	95	Modeled from P8
	Septic Systems	18.8	Data From Sherburn County, using Effects of Septic Systems on Ground Water Quality – Baxter, Minnesota. May, 1999. Minnesota Pollution Control Agenecy
	Atmospheric	54	Based on 30 kg/km² from BathTUB
	Total External Load	**644.8**	
Internal	Anoxic Sediment Release	580.7	Calculated from SAFL and DO Profiles
	Carp	362.85	Calculated using LaMarra 1975 and 2019 CPUE data.
	Curly Leaf Pondweed	Not Included.	
	Total Internal Load	**943.55**	
	Total Existing Big Eagle Lake Load	**1588.35**	

Table 12. Big Eagle Lake Existing Loads Using P8 model for Tributaries.

Source		TP Load (lb/yr)	Method
External	Northwest Subwatershed	24	Modeled from P8
	Central Subwatershed	140	Modeled from P8
	Northeast Subwatershed	1171	Monitored-from Station 100 and Flux
	West Subwatershed	65	Modeled from P8
	South Subwatershed	95	Modeled from P8
	Septic Systems	18.8	Data From Sherburn County, using Effects of Septic Systems on Ground Water Quality – Baxter, Minnesota. May, 1999. Minnesota Pollution Control Agenecy
	Atmospheric	54	Based on 30 kg/km² from BathTUB
	Total External Load	**1567.8**	
Internal	Anoxic Sediment Release	580.7	Calculated from SAFL and DO Profiles
	Carp	362.85	Calculated using LaMarra 1975 and 2019 CPUE data.
	Curly Leaf Pondweed	Not Included.	
	Total Internal Load	**943.55**	
	Total Existing Big Eagle Lake Load	**2511.35**	

Table 13. Big Eagle Lake Existing Loads Using P8 model for Tributaries, and FLUX output for Northeast (station 100).

6. BATHTUB MODEL AND LOAD REFINEMENT

To further refine and validate load calculations, BATHTUB (Version 6.1) was used to develop a model that used inputs from P8 and FLUX results, as well as internal loading calculations and observed water quality measurements.

We ran three (3) model scenarios to assess the addition of monitored inflow and internal loading on observed and predicted in lake TP, chl-a, and secchi depths.

In all three (3) scenarios the model was set up as a single reservoir, spatially averaged (Scheme 1), with the Big Eagle Lake Basin identified as the one and only segment. Global variables, such as precipitation and evaporation remained the same for all three (3) scenarios. Segment morphometry, observed water quality (TP, chl-a, and secchi depth), and calibration factors also remained the same, while the internal load was added for scenario 3, and remained at 0 for both scenario 1 and 2.

Five (5) tributaries were added which represented each of the subwatersheds discussed previously. For model scenario 1, all tributaries were identified as non-point inflows, while for model scenarios 2 and 3 the northeast subwatershed was identified as a monitored inflow using results from FLUX for station 100. Export coefficients for each landuse type within the subwatersheds were edited using data from P8 and applied to all three (3) models.

To summarize, Model scenario 1 utilized the data from P8 for all five (5) tributaries to calculate loading and did not include the addition of internal loading. Model scenario 2, used P8 data for 4 of the 5 tributaries, while using FLUX output data for the northeast subwatershed and no internal loading factor. Model scenario 3 utilized the same tributary data as model scenario 2 but added an internal release component.

The internal loading factor used for Model Scenario 3 was 2.49 mg P/m²/day. This was calculated using both the anoxic sediment release factor (6.56 mg P/m²/day) and the carp loading factor (1.02 mg P/m²/day). Added together the unadjusted factor would be 7.58 mg P/m²/day. However, BATHTUB is using an averaging period of 1 year, while we used a 4-month period to calculate the loading for both anoxic sediment release and carp bioturbation. Therefore, we adjusted this factor by multiplying by 0.32 to get an adjusted internal loading factor of 2.49 mg P/m²/day.

6.1 BATHTUB Results

Results of the BATHTUB model scenarios are shown in Table 14. Note that observed TP, Chl-a, and secchi depth remain the same for all models since those are the average growing season values derived from BELIA and Sherburne SWCD sampling in 2019 and are used to validate and calibrate the models. Also the load from atmospheric deposition (precipitation) remains the same for all three (3) model scenarios.

Load Source	Model 1 load kg/year (lbs/y)	Model 2 load kg/year (lbs/y)	Model 3 load kg/year (lbs/y)	Refined Model 3 load (kg/year (lbs/y)
Trib 1-NortheastDrainage (Station 100)	114.2 (251)	531.3 (1,168)	531.3 (1,168)	531.3 (1,168)
Trib 2- Northwest Drainage	11.6 (25)	11.6 (25)	11.6 (25)	11.6 (25)
Trib 3- Central Drainage	65.6 (144)	65.6 (144)	65.6 (144)	65.6 (144)
Trib 4- West Drainage	31 (68.2)	31 (68.2)	31 (68.2)	31 (68.2)
Trib 5- South (Direct)	11.3 (24.9)	11.3 (24.9)	11.3 (24.9)	11.3 (24.9)
Precipitation	56.1 (123.4)	56.1 (123.4)	56.1 (123.4)	56.1 (123.4)
Internal Load	0	0	1,700 (3,400)	683 (1,502)
Total Load	289 (635.8)	706 (1,553.2)	2,407 (5,295.4)	1,390 (3,058)
Observed TP Concentration (ppb)	50	50	50	50
Predicted TP Concentration (ppb)	52.1	36.4	77.6	55.8
Observed Chl-a Concentrations (ppb)	34.4	34.4	34.4	34.4
Predicted Chl-a Concentrations (ppb)	25.5	18.5	33.3	26.6
Observed Secchi Depth (m)	1.4	1.4	1.4	1.4
Predicted Secchi Depth (m)	1.4	1.8	1.1	1.3

Table 14. Big Eagle Lake BATHTUB Model Results

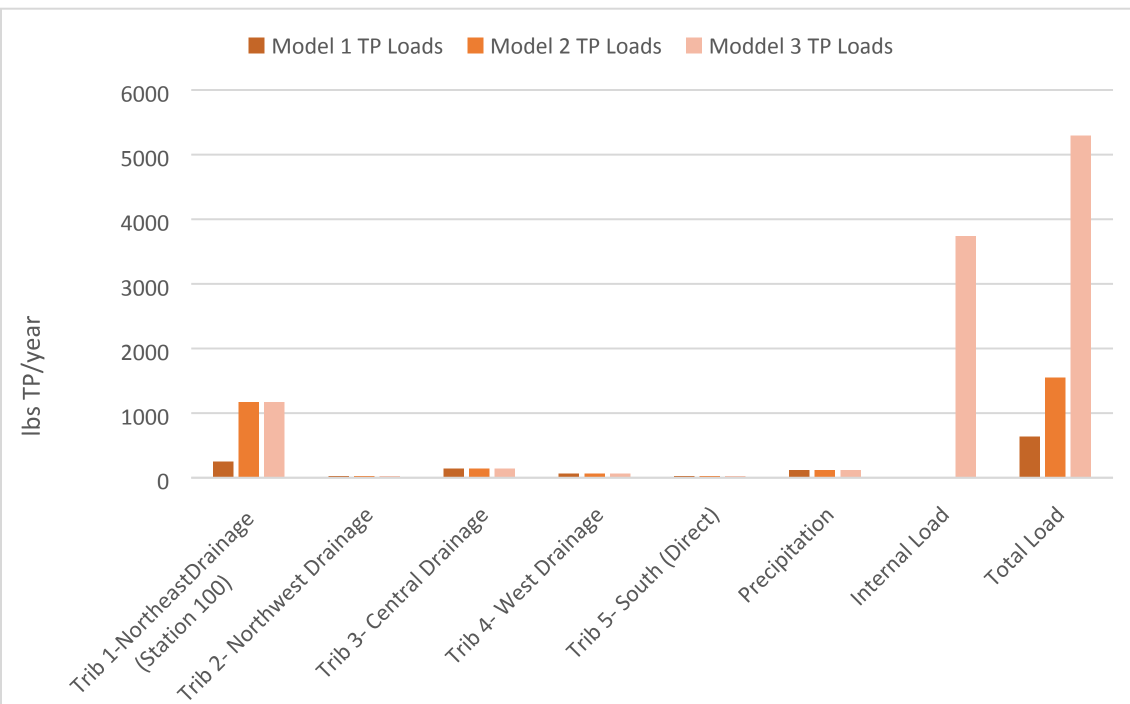

Figure 33. BATHTUB Modeled Loads

Models were compared by using the observed in-lake water quality values from 2019 sampling against the predicted values for each model scenario. Interestingly Model 1 predicted and observed values for both TP and secchi depth are very close, while the model underpredicts chlorophyll-a concentration. We attribute this to an unidentified error in the model, potentially attributable to an incorrect input variable or model coefficient, since this model lacks the increased load from station 100 and the internal loading component.

Model 2 underpredicts both TP and chlorophyll-a concentrations, while overpredicting secchi depth, which should be the case, since internal loading is not factored in.

Lastly, Model 3 overpredicts TP, slightly underpredicts Chlorophyll-a, and predicts a shallower secchi depth than what was observed in 2019. We assume that this may be due to an overestimated internal TP loading rate; not all available phosphorous may be transported into the mixed layer and result in increased TP and chlorophyll-a concentrations as discussed in Walker, 2004. Based on this, we adjusted the internal loading rate from 2.49 mg P/m²/day to 1 mg P/m²/day.

This resulted in a predicted TP value of 55.8 µg/l; very close to the observed value of 50 ppb. Chlorophyll-a was underpredicted in this refined model (26.6 ppb) compared to an observed value of 34.4 ppb, while secchi depth was very close; 1.3 m predicted versus 1.4 m observed.

The refined Model 3 estimates a total load of 3,058 pounds TP/year, with 1,555 pounds TP/year from external sources and 1,502 pounds TP/year from internal loading. These are very close to the estimates calculated or modeled in tables 12 and 13, with a slightly higher internal loading total from the BATHTUB model even though the rate is lower in BATHTUB than what was measured. This may be due to the model applying the rate to the entire Big Eagle Basin.

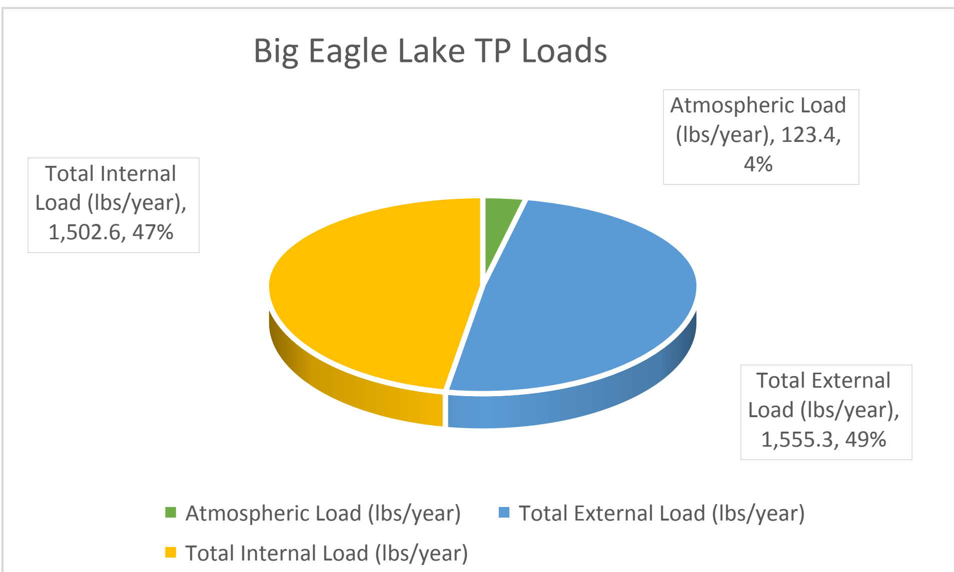

Figure 34. Big Eagle Load Allocation

Using the refined model and the associated loads, BATHTUB calculated the TP load response shown in Figure 35.

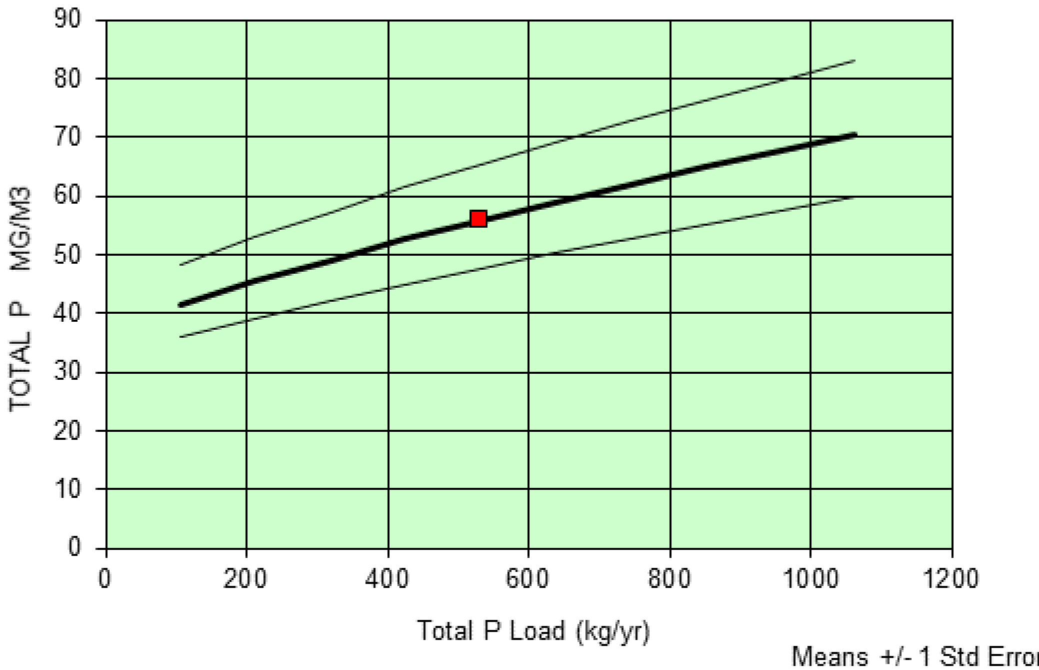

Figure 35. Big Eagle Lake BATHTUB TP Load response Under Existing Conditions

To identify the total maximum daily load (TMDL) for phosphorous, we iteratively ran the BATHTUB model until the predicted in-lake water quality standard was met for TP, chl-a, and secchi. The first iteration reduced the northeast load by adjusting total P concentration from 66.7 µg/l TP to 35 µg/l TP and internal loading factor from 1 to 0.5 mg P/m²/day. This resulted in an in-lake TP concentration of 39 µg/l , just under the 40 µg/l state water quality standard, but still exceeded the chlorophyll-a standard of 14 µg/l with a result of 20 µg/l, and increased secchi depth to 1.7 m; easily meeting the 1.4 m standard.

Additional model runs that included reducing either TP concentrations or flow rates from the other four (4) subwatersheds were completed, but these runs showed little change in in lake TP concentrations or chl-a concentrations. Chlorophyll-a concentrations lagged or showed little response comparable to TP concentrations as in the above example.

The chlorophyll-a in lake concentration met the standard of 14 ppb when the internal loading factor was reduced to 0.22 mg p/m²/day and the TP concentration from the Northeast subwatershed was changed to 20 ppb. Under this predictive model in lake TP concentration is 28.3 ppb, chlorophyll-a is 14.4 µg/l , and secchi depth increases to 2.3 m. While under this scenario predicted chlorophyll-a concentration is 14.4, the margin of error shows that the concentration could be slightly above 10 ppb. Based on these predicted in-lake concentrations, the loading capacity of Big Eagle Lake is 485.20 kg TP/year or 1,067 lbs TP/year to meet established water quality standards. This would require a 66% reduction in TP from the existing loads identified in the refined model 3. The table below shows the existing loads for Big Eagle Lake and the required TP reductions needed to meet water quality standards.

Loading Source	Existing TP Load (lbs/year)	Load Required to Meet TMDL (lbs/yr)	Load Reduction Required (pounds)	% Reduction Required
Trib 1-NortheastDrainage (Station 100)	1,168.9	350.5	818.4	70.0%
Trib 2- Northwest Drainage	25.6	25.6	0.0	0.0%
Trib 3- Central Drainage	144.4	144.4	0.0	0.0%
Trib 4- West Drainage	68.2	68.2	0.0	0.0%
Trib 5- South (Direct)	24.8	24.8	0.0	0.0%
Atmospheric	123.4	123.4	0.0	0.0%
Total External	1,555.3	736.9	818.4	52.6%
Internal Load	1,502.6	330.6	1,172.1	78.0%
Total Load[1]	**3,058**	**1,067.3**	**1,990.6**	**65.1%**

Table 15. Big Eagle TP Load Requirements

[1]This table is similar to tables 12 and 13 in that it displays TP loads from various sources. However, the loads displayed in table 12 and 13, are derived from a combination of P8, Flux, and direct measurements/calculations, while the loads in Table 15 are estimated from BATHTUB. BATHTUB did not generate a separate load from septic systems and is therefore not reflected in Table 15. BATHTUB also does not partition the internal load (carp or anoxic sediment release) which is shown as an aggregate internal load.

Significant reductions in both internal and external loads will be required to meet water quality standards in Big Eagle Lake. The model focuses on load reductions from the Northeast Subwatershed of 818 pounds or 70% of the load from that subwatershed or 52% of the entire external load, and internal loading which requires a reduction of 1,172 pounds TP or 78% of the internal load. Combined these reductions result in 1,990 pounds of phosphorous or 65.1% of the entire existing Big Eagle Lake phosphorous load.

7. LOAD REDUCTION IMPLEMENTATION STRATEGIES

This section identifies specific strategies or best management practices (BMPs) that can be implemented by the BELIA and/or its partners to reduce the existing phosphorous load and allow Big Eagle Lake to meet water quality standards.

7.1 External Load Reductions

To reduce the external pollutant loading to Big Eagle Lake, a best management practice (BMP) can be implemented within the lake watershed. Ten (10) potential BMP types and locations were identified within the various subwatersheds. The location of the proposed BMPs in relation to Big Eagle Lake's subwatersheds are shown on Figure 35. To determine the pollutant load reductions the BMPs have the potential to provide, P8 water quality modeling was performed. Cost estimates for the BMP projects were also determined. Tabulations of the load reductions and project costs are shown in Table 16. The proposed BMP locations avoid wetland areas present in the NWI, but a detailed wetland delineation should be performed if construction of these projects is to occur.

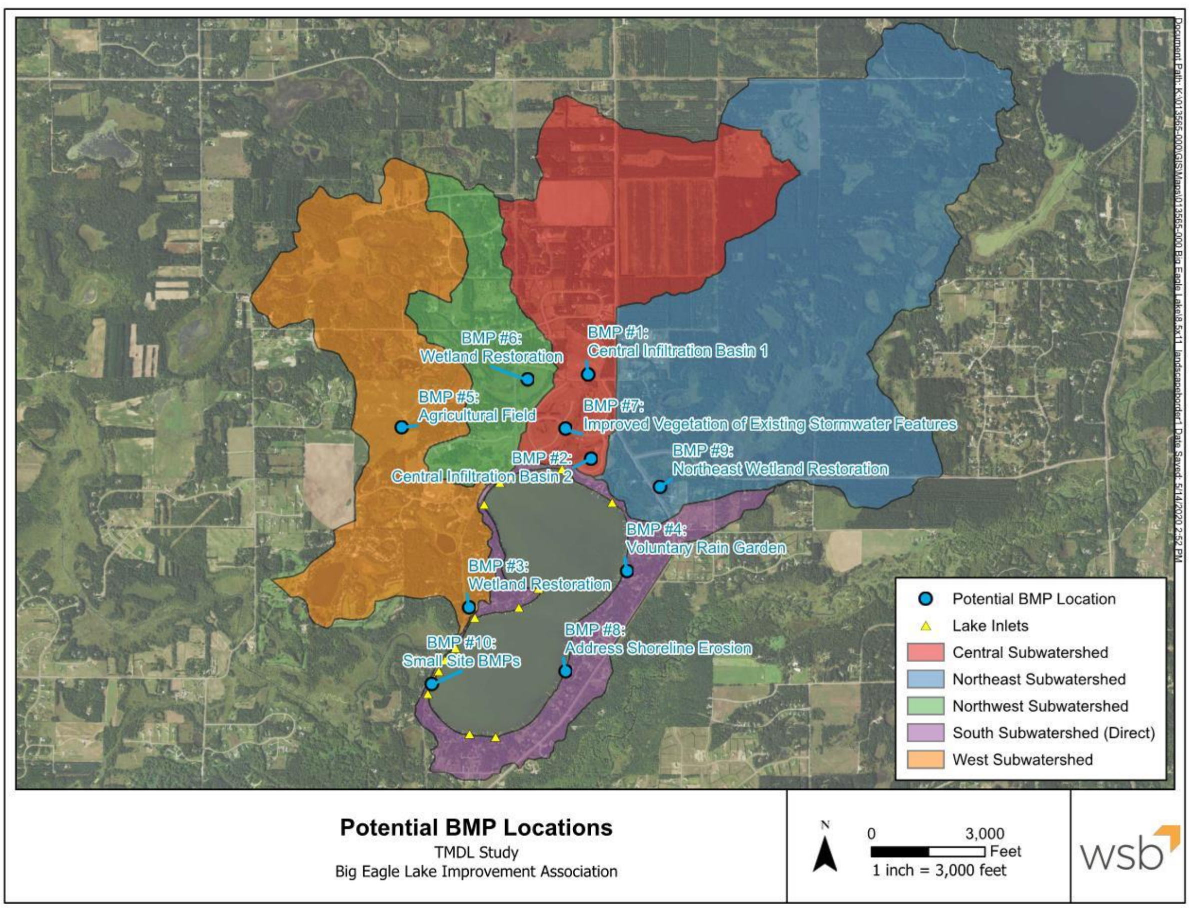

Figure 35. Big Eagle Lake Potential BMP Locations

BMP #1: Central Infiltration Basin 1

BMP #1 is located in the central subwatershed of Big Eagle Lake. The BMP is located strategically, capturing the northern portion of the central drainage area before water reaches the wetlands and subsequently Big Eagle Lake. The area is an existing low point and a natural collection point for water.

An infiltration basin is proposed in this location. According to the Web Soil Survey, soils are predominantly of hydrologic group A, and will facilitate infiltration. The bottom of the infiltration basin is assumed to be at an elevation of 950 with a bottom surface area of 1.725 acres. A 12-inch orifice will control the outflow and is set 1.5 feet above the bottom of the basin, providing 2.778 acre-feet of treatment volume. A 1.5-foot treatment depth was utilized to facilitate a 48-hour drawdown time for the average infiltration rates that could be found on-site. An infiltration rate of 1 inch per hour was utilized in the water quality modeling to represent a conservative average rate that may be found in the area based on present soils. Additional soil boring information will be needed to determine the allowable infiltration rate and treatment depth at the time of implementation. The basin has side slopes at a horizontal, vertical ratio of 3 to 1.

The design parameters were inserted into P8. Notably, a drainage area for BMP #1 was delineated and routed to the proposed BMP in the water quality model. The model is set up such that all infiltrated water is discarded from the analysis and water that is unable to infiltrate is passed to the central wetland area.

To construct this infiltration basin, property and easements must be purchased as this land is privately owned and zoned as residential area.

BMP #2: Central Infiltration Basin 2

BMP #2 is a proposed infiltration basin and is located in the southeast corner of the central subwatershed of Big Eagle Lake. The BMP is located in an existing low area and captures runoff from the developed impervious area before discharging to the central wetland and Big Eagle Lake. The site is located directly to the northwest of residential parcels and the BMP will sit at the rear of the proposed homes.

The bottom of the proposed infiltration basin is assumed to be at an elevation of 940 with a bottom surface area of 0.384 acres. A 12-inch orifice will control the outflow and is set 1.5 feet above the basin bottom, providing 0.665 acre-feet of treatment volume. The design assumptions for BMP #2 directly mirror the assumptions presented for BMP #1.

By modeling the proposed BMP in P8, load reductions were determined. A drainage area for BMP #2 was delineated and routed to the proposed BMP. Infiltrated water is discarded from the model and water that passes the infiltration basin through the outlet pipe is routed to the central wetland.

To construct this infiltration basin, property and easements must be purchased as this land is privately owned and zoned as residential area.

BMP #3: Wetland Restoration

Proposed BMP #3 is located at the base of the west subwatershed. Water is conveyed through the existing wetland before entering Big Eagle Lake. To repair hydrology, plant communities, and soils of the wetland, a restoration can be undertaken. Wetland restoration projects are shown to increase water quality by collecting and filtering out pollutants such as sediment, nutrients, and pesticides[1]. The effectiveness of phosphorus removal in restored wetlands is variable[1].

BMP #4: Voluntary Rain Garden

BMP #4 is located in the south (direct) subwatershed. The BMP is a voluntary rain garden program for residents and property owners within the subwatershed. The south subwatershed is an ideal location for a BMP because of the direct impervious runoff to Big Eagle Lake. To quantify the total pollutant load reductions for a rain garden program, an assumed 15% of the parcels within the subwatershed install a rain garden.

Design assumptions include assuming a base elevation of 940, an individual rain garden base footprint of 315 square feet, 1.5 feet of treatment volume for infiltration to occur, 3 to 1 side slopes, and an infiltration rate of 1 inch per hour as an average of the hydrologic group A and B soils present in the subwatershed. Rain garden specifics must be investigated in more detail before program implementation.

The rain garden program BMP was inserted into P8 as one BMP device, combining the storage of all the basins on 15% of the parcels. The bottom area was found to be 0.622 acres and the treatment volume 2.103 acre-feet. The direct subwatershed was routed to the BMP. Infiltrated water exits the model. Water unable to infiltrate through the BMP area enters Big Eagle Lake.

Implementing a voluntary raingarden program presents various challenges. Residents must be willing to install and maintain a garden.

BMP #5: Agricultural Field

Agriculture fields in the Big Eagle Lake watershed are primarily planted with corn and soybeans. To enhance soil health and retain rainfall on site, encourage field owners to interseed field crops with cover crops.

The agricultural field identified as BMP #5 on the Figure has been identified by Sherburne Soil and Water Conservation District (SWCD). Because the field is gently sloped, there is likely overland flow occurring. By adding vegetated field borders along the south and east edges of the site, runoff can be reduced.

To quantify TSS and TP removal rates via this BMP option, the 60-acre agricultural field was routed to a 1000-foot-long and 15-foot-wide swale with a slope of 0.5% and side slopes at a horizontal to vertical ratio of 3 to 1.

BMP #6: Wetland Restoration

To improve wetland functionality, wetland restoration projects can be undertaken, as explained for proposed BMP #3. SWCD identified a potential restoration project on the southeast corner of 188th Street NW and 241st Avenue, shown on the Figure as BMP #6.

BMP #7: Improved Vegetation of Existing Stormwater Features

The infiltration potential of existing stormwater features near a development on the north side of Big Eagle Lake can be improved through the addition of quality vegetation. According to SWCD, the soils in the area are suitable for prairie and oak savannah plantings. SWCD potentially has funds available through the prairie program or a Minnesota Board of Water, Soil Resources (BWSR) Lawns to Legumes grant to aid in the planting of prairie species.

BMP #8: Address Shoreline Erosion

According to a shoreland development study performed by SWCD, about 66% of Big Eagle Lake shoreline is developed. Sites of varying erosion severities were identified around the lake. There are 35 sites identified as minor erosion, 7 as moderate erosion, and 3 as severe erosion. BMP #8 is a voluntary shoreline restoration project, open to all landowners with erosion present on their properties. Landowners can develop an erosion mitigation plan with SWCD to address erosive areas and improve the water quality of Big Eagle Lake. Site visits and technical designs are available to residents free of charge. Some projects may qualify for financial assistance.

BMP #9: Northeast Wetland Restoration

The northeast subwatershed contributes the highest TSS and TP loading to Big Eagle Lake on an annual basis, according to past P8 modeling results, mostly due to its size. The subwatershed consists primarily of public land and is comprised of forests and wetlands. Siting a BMP in the northeast subwatershed offers challenges because of the number of wetlands and other protected areas. A wetland restoration project could potentially be sited at BMP #9, shown on the Figure, to improve wetland functionality and water quality.

BMP #10: Small Site BMPs

For use anywhere that storm sewer empties into a waterbody within the Big Eagle Lake watershed, a pretreatment BMP can be utilized. Install SAFL Baffles, Hydroguards, Rain Guardian Turrets, or hydrodynamic separators to reduce sediment loading to the lake. Specific siting locations may be identified and incorporated into design as projects arise within the watershed.

Potential BMP Summary

Below is a summary table of the potential load reductions for each BMP as well at the estimated costs to construct the BMPs.

BMP		**Subwatershed**	**Potential Load Reduction**		**Estimated Cost**
			TSS	**Phosphorus**	
#1 Infiltration Basin		Central	8460 lbs/yr	20.6 lbs/yr	$175,000 - 275,000
#2 Infiltration Basin		Central	1508 lbs/yr	4.6 lbs/yr	$50,000 - 75,000
#3 Wetland Restoration		West	75%[1]	16-32.5[1]	$120,000 - 200,000
#4 Rain Gardens		South (Direct)	103 lbs/yr	0.25 lbs/yr	$1,700 - 2,800[2]
			8833 lb/yr	21.6 lb/yr	$150,000 – 250,000[3]
#5 Ag Filter Strips		West	432.8 lbs/yr	1.2 lbs/yr	$7,500 - 12,500
#6 Wetland Restoration		Northwest	75%[1]	12.5-25[1]	$340,000 - 560,000
#7 Improved Vegetation		Central	24.4 lbs/yr	0.1 lbs/yr	$15,000 - 25,000
#8 Shoreline Erosion Repairs	Minor[4]	South (Direct)	0.163 lbs/yr	0.001 lbs/yr	$900 - 1,500
	Moderate[5]		0.654 lbs/yr	0.002 lbs/yr	$3,600 - 6,000
	Major[6]		1.495 lbs/yr	0.004 lbs/yr	$8,000 - 14,000
#9 Wetland Restoration		Northeast	75%[1]	62-124[1]	$275,000 - 450,000
#10 Small Site BMPs		South (Direct)	85%	0%	$17,000 - 30,000

Table 16. Potential BMP Annual External Load Reduction and Estimated Cost

[1] Lenhart, C., Gordon, B., Peterson, J., Eshenaur, W., Giford, L., Wilson, B., Stamper, J., Krider, L,. and Utt, N. 2017. Agricultural BMP Handbook for Minnesota, 2nd Edition. St. Paul, MN: Minnesota Department of Agriculture (Pg. 215-218).

[2] Totals for each rain garden.

[3]Total if 15% of properties (86) volunteered to install a rain garden

[4] Load reduction per year for the improvement of one minor erosion site, estimated as 100 square feet

[5] Load reduction per year for the improvement of one moderate erosion site, estimated as 400 square feet

[6] Load reduction per year for the improvement of one severe erosion site, estimated as 900 square feet

In addition to the BMPs identified in Table 16, inter-seeded cover crops may provide additional TSS and TP removals over large portions of the subwatersheds that contain row crop land uses to reduce soil erosion and sequester nutrients. This practice should be considered when practical.

7.2 Internal Load Reductions

Options to reduce internal loading are limited to alum application and integrated pest management of common carp.

7.2.1. Alum Application

Alum or aluminum sulfate can be an effective management tool to improve water quality. Alum inactivates phosphorous by first forming a flocculent or "floc" that settles to the bottom. This floc forms a barrier to the sediment phosphorous release and binds phosphorous in the sediment.

These treatments generally last for many years and improvements in water clarity can occur within a growing season. According to Huser (2016) the average treatment longevity for alum treatments was 11 years (ranging from 0-45 years).

Based on the dissolved oxygen profiles documented in 2019, the potential treatment area would be roughly 183 acres, or the portion of the lake greater than 12 feet where the lake becomes anoxic.

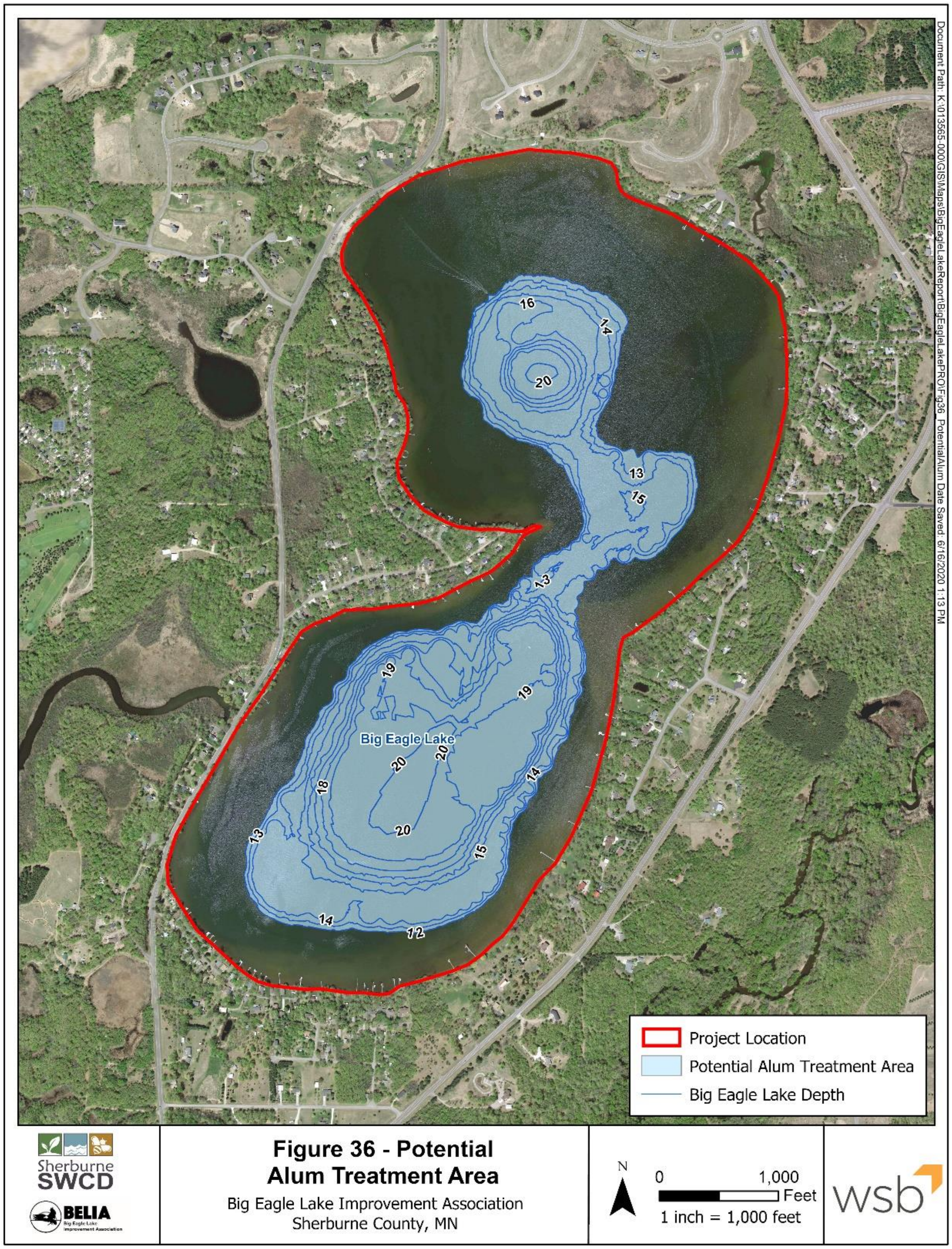

Figure 36. Alum Application Area

Personal communication with John Holz (HAB Aquatic Solutions) suggest that there may be an 80-85% reduction in phosphorous release rates from an alum application. Based on that assumption, an alum application may be one the most effective ways to meet phosphorous load reduction goals. Costs for alum applications vary, but HAB Aquatic Solutions estimates an alum application cost of $800,000.

7.2.2 Carp Management

Common carp (Cyprinus carpio), a non-native fish originating in the Caspian region of Eurasia, are the most widely distributed nuisance fish in the United States (Nico et al., 2012). Carp can have direct and indirect negative effects on water quality by uprooting submergent and emergent aquatic vegetation and by releasing phosphorous sequestered in lake sediments (Chumchal, 2005, Zambrano, 2001). The phosphorus is then available to free floating algae and can lead to an increase in total phosphorous and Chlorophyll-a concentrations in the lake and to a decrease in water clarity. The decrease in water clarity can further exacerbate the effects of carp by shading out submergent aquatic vegetation. This is described in more detail in section 3.8.

Development and implementation of a carp integrated pest management plan (IPM) may provide additional phosphorus load reduction benefits as well as other ecological improvements. Holistic carp IPM includes a variety of components illustrated in Figure 36. Integrated pest management provides a more sustainable approach to managing invasive populations, specifically carp, by providing additional control tools rather than just adult removal and ensuring that biomass that is removed will not simply be replaced through recruitment.

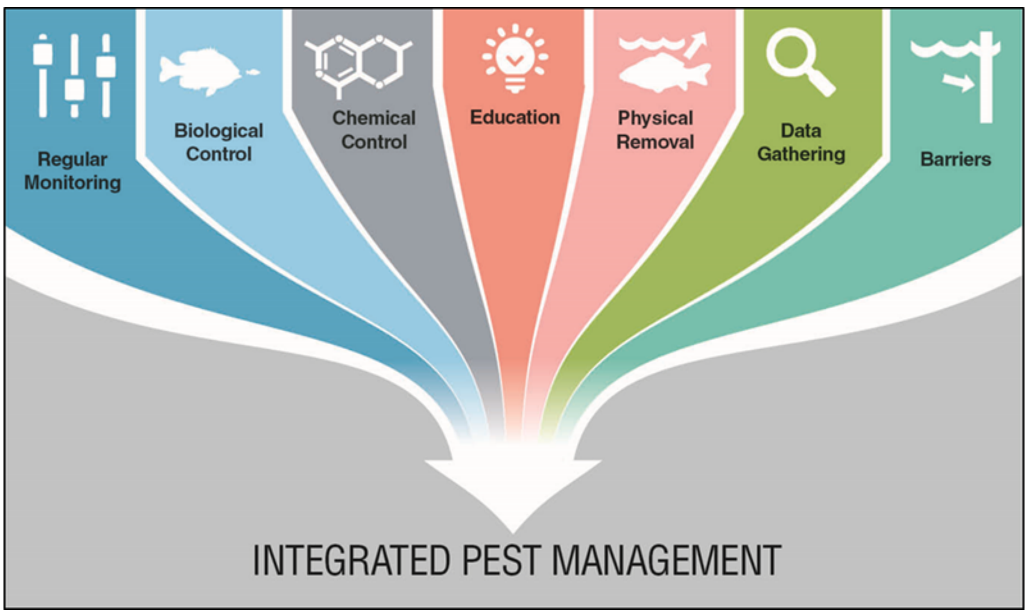

Figure 37. Common Carp Integrated Pest Management Diagram

Existing qualitative and quantitative data show that applying data collection, physical removal, biological control, barrier technology, followed by regular monitoring and education will likely result in achieving successful management of carp to mitigate their deleterious effects on water quality and aquatic habitat in a system of lakes and wetlands.

Anecdotal information on Big Eagle Lake carp suggests that the carp population consists of large individuals (potentially older) which may indicate a population that is declining. Electrofishing survey data from 2019 may support this as the smallest carp captured was in the 24” range. While not incredibly accurate, we might assume that a 24” carp may be at least 4-5 years old, and we also know that no juvenile or young of year carp were captured in these surveys. However, carp biomass density is still elevated above 100 kg/ha (89 lbs/acre), which is contributing to the overall TP load.

Implementation of a Big Eagle Lake carp IPM would include young of year sampling to determine recruitment (f any), radio tag/telemetry surveys combined with passive integrated transponder (PIT) technology to identify potential migration routes, nurseries, and winter aggregations for removal, and some ageing to develop an age structure Big Eagle Lake. If carp are not found to be reproducing or recruiting, adult biomass removal may be the singular tool needed to address the current elevated biomass.

By reducing the carp biomass density from 171 lbs/acre to 50 lbs/acre, loading from carp can be reduced from ~363 pounds to 104 pounds. Estimated costs for implementation of carp IPM are $60,000 over a period of 2-3 years. Subsequent surveys would be needed to ensure the population has not rebounded. In the event carp biomass has increased after a removal effort, additional removals may be necessary in the future and would add additional cost.

Bowfishing may be encouraged to further reduce carp populations within Big Eagle Lake. However, proper disposal of carp carcasses and the potential targeting of native gamefish need to be considered for this technique. The BELIA may want to consider an organized bowfishing event. Disposal could be offered as part of the event and data on total number and weight of fish removed could be collected to update the existing population estimate.

7.2.3 BMP Cost Summary

Both total costs and cost per pound of TP removal vary dramatically between identified BMPs. Table 17 below provides cost per pound of TP removal comparison for each of the BMPs.

BMP	TP Load Reduction (pounds)	Mid Range cost	Cost Per Pound
#1 Infiltration Basin	20.6	$225,000	$10,922
#2 Infiltration Basin	4.6	$62,500	$13,587
#3 Wetland Restoration	32.5	$160,000	$4,923
#4 Rain Gardens	0.25	$2,250	$9,000
	21.6	$200,000	$9,259
#5 Ag Filter Strips	1.2	$10,000	$8,333
#6 Wetland Restoration	25	$450,000	$18,000
#7 Improved Vegetation	0.1	$20,000	$200,000
#8 Shoreline Erosion Repairs	0.001	$1,200	$1,200,000
	0.002	$4,800	$2,400,000
	0.004	$11,000	$2,750,000
#9 Wetland Restoration	124	$362,500	$2,923
#10 Small Site BMPs	0	$23,500	No TP Removal
Alum Treatment	969	$800,000	$826
Carp Management	259	$60,000	$232

Table 17. BMP Cost per Pound for TP Removal

To calculate the cost per pound of TP removal, the mid-range cost from Table 16 was used along with the higher 50% removal rate for external BMPs and the 85% removal efficiency for the alum application. None of the costs are adjusted for expected life span, rather the costs provided are calculated by simply dividing initial installation or implementation costs by the load reduction expected. These are annual reductions so amortizing the cost over a 10-year period or longer for most of the BMPs would result in a much lower cost per pound. Carp management is the most variable BMP and may require more frequent maintenance (biomass removal and population estimate updates). However, without additional ageing and spatial data it is difficult to determine how often carp may recruit, if at all.

8. SUMMARY

In summary, historical data and data collected in 2019 indicate that Big Eagle Lake is impaired as it is not meeting numerical water quality standards for total phosphorous, chlorophyll-a, or secchi depth, and is not providing designated or beneficial uses as identified in section 2.2 (supporting healthy cool or warm water biota and suitable for aquatic recreation).

The impairment for Big Eagle Lake is due to excess nutrients (Total Phosphorous), which in turn has elevated the chlorophyll-a (algae) concentration in Big Eagle Lake and reduced water clarity (secchi depth).

The primary sources of this impairment are the northeast subwatershed and internal loading from carp and anoxic sediment release. Combined these three (3) sources contribute 87% of the TP load to Big Eagle Lake.

To meet water quality standards for Big Eagle Lake, nearly 65% of the existing TP load needs to be eliminated. Specific BMPs and strategies are identified in section 6 above and detailed in Table 18 below.

Load Source	Existing Load (Pounds/Year)	Sum of Load Reduction From BMPs (Pounds)[1]	Sum of Load Reduction From BMPs (Pounds)[2]
Central Subwatershed	144.4	25.3	25.3
West Subwatershed	68.2	17.2	17.2
South (Direct) Subwatershed	24.8	21.9	21.9
Northwest Subwatershed	25.6	12.5	25
Northeast Subwatershed	1,168.9	62	124
Atmospheric	123.4	0	0
Septic Systems	18.8	0	0
Total External Load Reduction		138.9	229.9
Internal-Anoxic Sediment Release	1,140	912[3]	969[4]
Internal- Carp	362	259	259
Sum of Internal BMPs		1,171	1,228
Total Load Reduction		1,309	1,457

Table 18. Load Reduction Summary

1- calculated using a 25% TP removal efficiency
2- calculated using a 50% removal efficiency
3- calculated by subtracting the internal carp load of 362 pounds TP, from the total internal load identified in Table 15 of 1,502 pounds TP and using an 80% removal efficiency.
4- calculated by subtracting the internal carp load of 362 pounds TP, from the total internal load identified in Table 15 of 1,502 pounds TP and using an 85% removal efficiency.

Limited opportunities exist to implement external BMPs within the Big Eagle Lakeshed to reduce the phosphorous load to the lake due to the small size and relatively undeveloped nature of the watersheds (except for the south (direct subwatershed). The Northeast subwatershed also includes the Uncas Dunes Scientific and Natural Area, which is kept in a mostly undegraded state and should not contribute to TP loading of Big Eagle Lake.

In summary, Big Eagle Lake can meet water quality standards through implementation of identified BMPs. Continued monitoring of in-lake and in-stream water quality (secchi depth, TP, Chl-a) can provide critical data to evaluate the effectiveness of implemented BMPs and used to further refine the Big Eagle Lake models.

APPENDIX A

FLUX Output Files

FLOW AND LOAD SUMMARIES FOR TP

Method: C/Q Reg3(daily) (6)

DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flow Obs	Chm Obs	Events	Vol %	Mean Daily	Sample Flo	TP (mg/L)"	Flux (lbs/y)	Slope LogC	R^2	p > LogC/LogQ
Overall	168	11	11	100	8.913091	8.515368	0.071	1171.1	-0.0746	0	0.4522

DAILY FLOW STATISTICS

Daily Flow Duration 168 Days = 0.460 Years

Daily Mean Flow Rate 8.91 (CFS)

Daily Total Flow Volume 1.29378E08 (ft^3)

Daily Flow Date Range 05/03/2019 to 10/17/2019

Samples Date Range 05/09/2019 to 09/20/2019

LOAD ESTIMATES FOR TP

Method	Mass(lbs)	Flux(lbs/y)	Flux Varian	Flw-Weigh	C.V.
1 Average Load	480.47	1044.6	35143	0.0595	0.27
2 Flw Wghted Conc.	502.91	1093.4	8767	0.0622	0.13
3 Flw Wghted IJC.	490.8	1067.1	9611	0.0607	0.14
4 C/Q Reg1	501.2	1089.7	8084	0.062	0.12
5 C/Q Reg2(VarAdj)	495.92	1078.2	8400	0.0614	0.13
6 C/Q Reg3(daily)	538.65	1171.1	8402	0.0667	0.12
8 Time Series*	514.98	1119.6	N/A	0.0637	N/A

APPENDIX B

Eagle Lake Phosphorous Release Study-Technical Memo

ST. ANTHONY
FALLS LABORATORY

Eagle Lake Phosphorus Release Study

Technical Memorandum

Prepared by:
Poornima Natarajan
John S. Gulliver
St. Anthony Falls Laboratory
University of Minnesota
2 Third Avenue SE Minneapolis, MN 55455

Prepared for:
WSB & Associates, Inc.
701 Xenia Avenue South, Minneapolis, MN 55416

February 2020
Minneapolis, Minnesota

College of Science & Engineering
University of Minnesota

Eagle Lake Phosphorus Release Study

Objective

The objective of this study was to determine the sediment phosphorus release from Eagle Lake, located in Sherburne County, MN. Sediment cores from Eagle Lake were incubated in the laboratory under controlled oxic and anoxic conditions to determine the total phosphorus and ortho-phosphate release rates from the sediments.

Method

Sediment core collection

Intact sediment cores with overlying water were collected from three stations in the deepest part of Eagle Lake (6.1-m or 20-ft contour) in October 2019 (Figure 1). The coring stations were selected based on the locations of existing sampling stations (#203 and #204) in the lake. Using a piston corer attached to drive rods, the sediment cores (~30-50 cm sediments with ~40-60 cm water column) were extracted into polycarbonate tubes (70 mm O.D). *In situ* dissolved oxygen (DO) and temperature measurements taken at the time of coring indicated that the lake was fully-mixed and unstratified (Table 1).

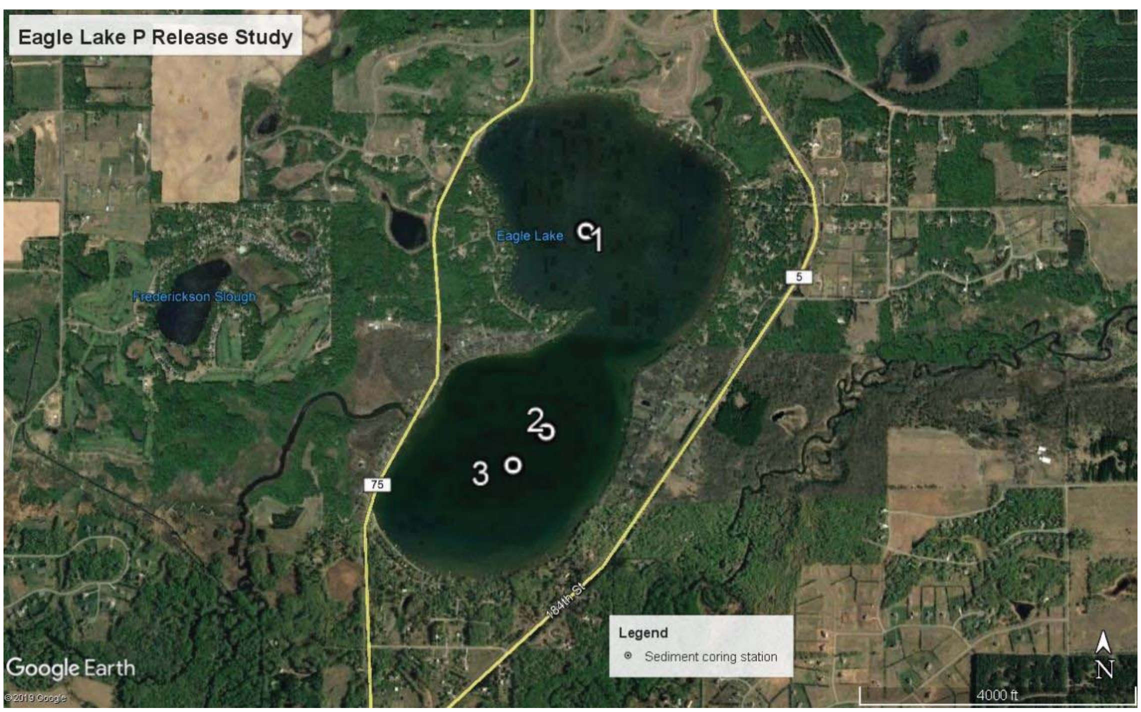

Figure 1. Map showing the sediment coring stations in Eagle Lake, MN.

Table 1. Dissolved oxygen (DO) and temperature measured at the three coring stations in Eagle Lake, MN. Measurements were taken around 13:30 on October 23, 2019.

Water depth (m)	DO (mg/L)			Temperature (°C)		
	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3
0.0	9.82	9.32	10.0	8.8	9.0	8.9
0.5	9.75	9.32	9.40	8.8	9.0	9.0
1.0	9.70	9.23	9.30	8.8	9.0	9.0
2.0	9.66	9.18	9.27	8.8	9.0	9.0
3.0	9.59	9.14	9.24	8.8	9.0	9.0
4.0	9.56	9.08	9.20	8.8	8.8	8.8
5.0	9.31	8.87	9.08	8.7	8.8	8.8

Phosphorus release experiments

In the laboratory, the water overlying the sediments in each core was drained, filtered (using 1.2-µm glass microfiber filter), and then carefully refilled into the cores without disturbing the sediments. Porous air stones attached to vinyl tubing were placed ~5 cm (~2 inches) above the sediment surface to serve as bubblers for air (to simulate oxic conditions) or ultrapure nitrogen gas (to simulate anoxic conditions) (Figure 2). The phosphorus release study was divided into three phases: (1) oxic (~11 mg/L DO) and mixed water column, (2) non-aerated and unmixed water column, and (3) anoxic (~0.56 mg/L DO) and mixed water column. The columns were kept at room temperature (15 ± 2.3 °C).

Figure 2. Eagle Lake sediment cores set up in the laboratory for the phosphorus release study.

Water samples for total phosphorus (TP) and ortho-phosphate (ortho-P) analyses were drawn from approximately the center of the mixed water columns under phases 1 and 3. During phase 2 (aeration off), an additional water sample was drawn ~8 cm (3.1 inches) above the sediment surface to obtain the average phosphorus concentration in the water column; this was done to account for the concentration gradient that can develop under unmixed conditions. TP analysis was performed on persulfate-digested samples using the ascorbic acid colorimetric method (detection limit = 0.025 mg P/L), and ortho-P analysis was performed in a Lachat QuikChem 8000 series FIA autoanalyzer using ascorbic acid (detection limit = 0.010 mg P/L) (Standard Methods 4500 P, APHA/AWWA/WPCF 1995).

The mass of phosphorus in the water column (mg) was calculated by multiplying the phosphorus concentration (mg/L) and the water column volume (L). The water volume was adjusted for the sample volume withdrawn during each sampling exercise. The change in initial phosphorus mass divided by the experimental duration (days) and the sediment surface area (same as the core liner area, m^2) yielded the phosphorus release rate ($mg/m^2/day$) for each sediment core.

Water column DO levels were also monitored throughout the study. The DO concentrations in the unmixed water columns during the second phase (aeration off) were used to obtain a measure of the sediment oxygen demand using the Michaelis-Menten kinetic model (Olsen 2017):

$$S = \frac{S_{max}[C_{O2}]}{K_M + [C_{O2}]}$$

where S is the substrate consumption rate, S_{max} is the maximum dissolved oxygen consumption rate, C_{O2} is the substrate (oxygen) concentration, and K_M is the half-consumption concentration. A constant K_M of 1.4 mg/L was used for all cores. It is assumed that all DO reduction is due to the microbial oxygen demand of the sediments, so K_M represents the surface of the sediments.

Results

The results of the phosphorus release study are shown in Figure 3. Under oxic conditions, a small increase in water column TP was observed for the three sediment cores over 32 days. This increase could be due to the mineralization and mobilization of labile organic phosphorus in the sediments that releases phosphate into the overlying water (Jensen and Andersen 1992).

Once aeration was switched off, the DO concentrations slowly decreased in the water columns due to the sediment oxygen demand (Figure 4). However, the DO measurements at the end of the 15-day period was still around 3.6 mg/L, much higher than the 1 mg/L DO limit considered for anoxia. The relatively low microbial oxygen demand (0.50 $g/m^2/day$ mean) and absence of fully-anoxic conditions in the three sediment cores corresponded with minimal changes in the water column phosphorus, suggesting sediment phosphorus release did not occur in all three cores during this phase (Figure 3a).

Anoxic conditions were established in the next phase due to nitrogen gas bubbling (mean DO = 0.56 ± 0.12 mg/L). The sediments released phosphorus under anoxic conditions that resulted in a significant increase in the mass of phosphorus accumulated in the water columns during the 32-day anoxic duration (Figure 3a).

The ortho-P release behavior was similar to the observations made for TP release, with small ortho-P release under oxic conditions and a significant ortho-P release during anoxic conditions (Figure 3b). On average, ortho-P constituted a major portion of the TP in the water columns (mean SRP:TP = 0.60 during oxic phase, and mean SRP:TP = 0.96 during anoxic phase).

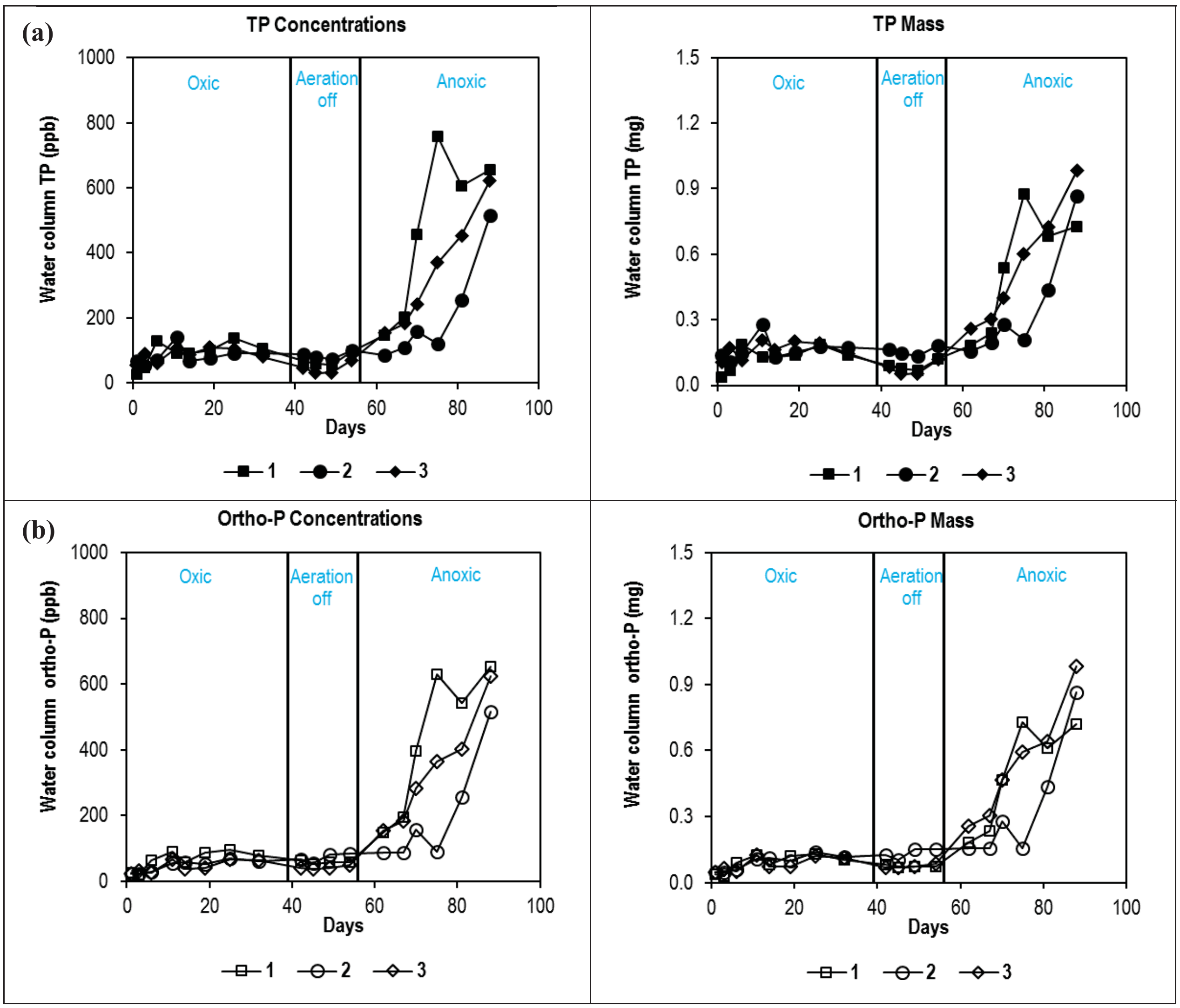

Figure 3. Water column concentrations and mass of (a) total phosphorus (TP), and (b) ortho-phosphate (ortho-P) in the Eagle Lake sediment cores during the phosphorus release study. The three phases of the study are separated by solid vertical lines (oxic = aeration on; anoxic = N_2 bubbling on).

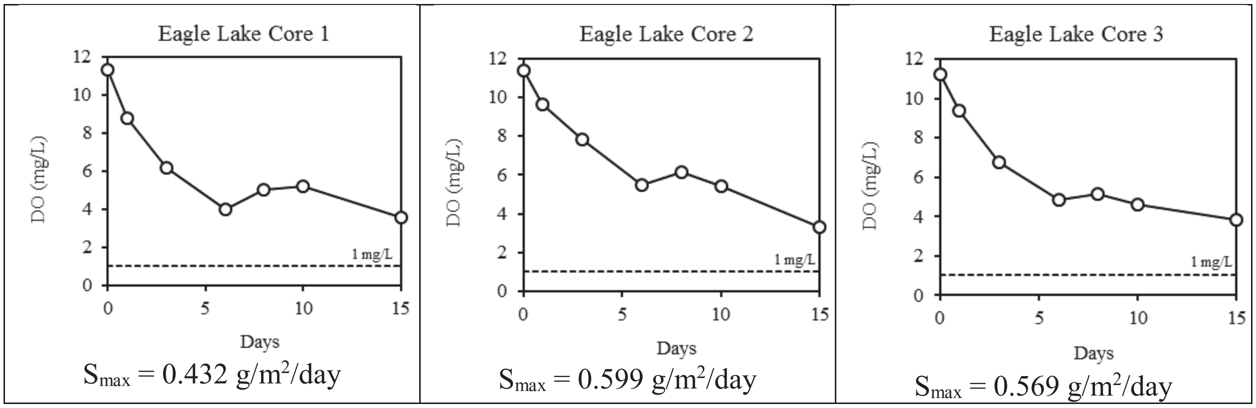

Figure 4. Dissolved oxygen (DO) concentrations in the unmixed water columns of the Eagle Lake sediment cores during the second phase (no aeration) of the phosphorus release study. The 1 mg/L reference line for anoxia is shown as dashed line in the plots. S_{max} is the calculated sediment oxygen demand.

The TP and ortho-P release rates calculated for the Eagle Lake cores are summarized in Table 2. The anoxic phosphorus release rate for the Station 3 core was higher than the remaining two cores. The mean anoxic phosphorus release rate for Eagle Lake is similar to the median for other Minnesota lakes (James and Bischoff 2016).

Table 2. Rates of total phosphorus (TP) and ortho-phosphate (ortho-P) release for the sediment cores from Eagle Lake. Phosphorus release was calculated over a duration of 32 days for each phase.

Station ID	Total phosphorus (TP)		Orthophosphate (ortho-P)	
	Oxic release rate ($mg/m^2/day$)	Anoxic release rate ($mg/m^2/day$)	Oxic release rate ($mg/m^2/day$)	Anoxic release rate ($mg/m^2/day$)
1	0.921	5.54	0.598	5.94
2	0.340	6.26	0.667	6.54
3	0.350	7.89	0.616	8.19
Mean ± Std. Dev.	0.537 ± 0.333	6.56 ± 1.20	0.627 ± 0.036	6.89 ± 1.16

Summary

The phosphorus release study on the Eagle Lake sediment cores showed that:

a) the lake sediments released a small amount of phosphorus under oxic conditions, likely due to the bacterial breakdown of the labile organic phosphorus fraction in the sediments. The mean oxic release rate was 0.537 mg TP/m^2/day for three cores.
b) the lake sediments released phosphorus under anoxic conditions, at a mean rate of 6.56 mg TP/m^2/day.
c) the oxic and anoxic release rates for ortho-P were similar to that of TP.
d) the sediment oxygen demand measured in the laboratory was relatively low (0.50 g/m^2/day mean).

Acknowledgements

This project was completed through a contract between the St. Anthony Falls Laboratory (SAFL) and WSB & Associates, Inc., under the supervision of Tony Havranek. The University of Minnesota LacCore provided the sediment coring equipment. Vini Taguchi, Katie Kemmitt, Peter Olson and Nam Nyugen at SAFL assisted with field sampling and laboratory analyses.

References

APHA, AWWA, WPCF (1995), *Standard methods for the examination of water and wastewater*, 19th Ed., American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF, former Water Pollution Control Federation or WPCF), Washington, D.C.

James, W., and Bischoff, J. (2016). *Evaluation of internal phosphorus loading and sediment characteristics in pond JP 5, Eagan, Minnesota.* University of Wisconsin-Stout, Menomonie, WI, and Wenck Associates, Maple Plain, MN, 1-28.

Jensen, H.S., and Andersen, F.O. (1992). "Importance of temperature, nitrate, and pH for phosphate release from aerobic sediments of four shallow eutrophic lakes." *Limnol. Oceanogr.*, 37(3), 577-589.

Olsen, T. (2017). *Phosphorus dynamics in stormwater ponds*. Master's Thesis, University of Minnesota, Minneapolis, MN.

APPENDIX C

Big Eagle Lake BATHTUB Output Files

Big Eagle Model 1
File: K:\013565-000\Admin\Docs\BATHTUB\BigEagleTest2.btb

Overall Water & Nutrient Balances

Overall Water Balance | **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	2	1	Trib 1-NortheastDrainage	7.3	0.6	0.00E+00	0.00	0.08
2	2	1	Trib 2- Northwest Drainage	1.5	0.1	0.00E+00	0.00	0.06
3	2	1	Trib 3- Central Drainage	3.5	0.2	0.00E+00	0.00	0.06
4	2	1	Trib 4- West Drainage	3.9	0.3	0.00E+00	0.00	0.08
5	2	1	Trib 5- South (Direct)	1.3	0.1	0.00E+00	0.00	0.09
PRECIPITATION				1.9	2.1	0.00E+00	0.00	1.10
NONPOINT INFLOW				17.5	1.3	0.00E+00	0.00	0.07
***TOTAL INFLOW				19.4	3.3	0.00E+00	0.00	0.17
ADVECTIVE OUTFLOW				19.4	1.8	0.00E+00	0.00	0.10
***TOTAL OUTFLOW				19.4	1.8	0.00E+00	0.00	0.10
***EVAPORATION					1.5	0.00E+00	0.00	

Overall Mass Balance Based Upon Component: **Predicted TOTAL P** **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	2	1	Trib 1-NortheastDrainage	114.2	39.4%	0.00E+00		0.00	200.0	15.6
2	2	1	Trib 2- Northwest Drainage	11.6	4.0%	0.00E+00		0.00	140.0	7.9
3	2	1	Trib 3- Central Drainage	65.6	22.6%	0.00E+00		0.00	340.0	18.7
4	2	1	Trib 4- West Drainage	31.0	10.7%	0.00E+00		0.00	100.0	8.0
5	2	1	Trib 5- South (Direct)	11.3	3.9%	0.00E+00		0.00	90.0	8.4
PRECIPITATION				56.1	19.4%	7.87E+02	100.0%	0.50	27.3	30.0
NONPOINT INFLOW				233.8	80.6%	0.00E+00		0.00	182.3	13.3
***TOTAL INFLOW				289.9	100.0%	7.87E+02	100.0%	0.10	86.8	14.9
ADVECTIVE OUTFLOW				96.0	33.1%	3.19E+02		0.19	52.1	4.9
***TOTAL OUTFLOW				96.0	33.1%	3.19E+02		0.19	52.1	4.9
***RETENTION				193.9	66.9%	7.94E+02		0.15		

Overflow Rate (m/yr)	1.0	Nutrient Resid. Time (yrs)	1.0951
Hydraulic Resid. Time (yrs)	3.3071	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	52	Retention Coef.	0.669

Big Eagle Model 1

File: **K:\013565-000\Admin\Docs\BATHTUB\BigEagleTest2.btb**

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:

1 = Observed Water Quality Error Only

2 = Error Typical of Model Development Dataset

3 = Observed & Predicted Error

Segment: **1** **Big Eagle Basin**

	Observed		Predicted		Obs/Pred	T-Statistics ---->		
Variable	**Mean**	**CV**	**Mean**	**CV**	**Ratio**	**T1**	**T2**	**T3**
TOTAL P MG/M3	50.0	0.00	52.1	0.19	0.96		-0.15	-0.22
CHL-A MG/M3	34.4	0.00	25.5	0.30	1.35		0.86	0.98
SECCHI M	1.4	0.00	1.4	0.28	1.01		0.02	0.02
ANTILOG PC-1	625.3	0.00	473.8	0.55	1.32		0.79	0.50
ANTILOG PC-2	19.1	0.00	15.6	0.08	1.23		0.66	2.63

Big Eagle Model 2
File: K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario2.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1-NortheastDrainage	7.3	8.0	0.00E+00	0.00	1.09
2	2	1	Trib 2- Northwest Drainage	1.5	0.1	6.88E-05	0.10	0.06
3	2	1	Trib 3- Central Drainage	3.5	0.2	3.73E-04	0.10	0.06
4	2	1	Trib 4- West Drainage	3.9	0.3	9.60E-04	0.10	0.08
5	2	1	Trib 5- South (Direct)	1.3	0.1	1.27E-04	0.09	0.09
PRECIPITATION				1.9	2.1	0.00E+00	0.00	1.10
TRIBUTARY INFLOW				7.3	8.0	0.00E+00	0.00	1.09
NONPOINT INFLOW				10.2	0.7	1.53E-03	0.05	0.07
***TOTAL INFLOW				19.4	10.7	1.53E-03	0.00	0.55
ADVECTIVE OUTFLOW				19.4	9.2	1.53E-03	0.00	0.48
***TOTAL OUTFLOW				19.4	9.2	1.53E-03	0.00	0.48
***EVAPORATION					1.5	0.00E+00	0.00	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**
Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1-NortheastDrainage	531.3	75.2%	0.00E+00		0.00	66.7	72.4
2	2	1	Trib 2- Northwest Drainage	11.6	1.6%	1.35E+00	0.2%	0.10	140.0	7.9
3	2	1	Trib 3- Central Drainage	65.6	9.3%	4.31E+01	5.1%	0.10	340.0	18.7
4	2	1	Trib 4- West Drainage	31.0	4.4%	9.60E+00	1.1%	0.10	100.0	8.0
5	2	1	Trib 5- South (Direct)	11.3	1.6%	1.03E+00	0.1%	0.09	90.0	8.4
PRECIPITATION				56.1	7.9%	7.87E+02	93.5%	0.50	27.3	30.0
TRIBUTARY INFLOW				531.3	75.2%	0.00E+00		0.00	66.7	72.4
NONPOINT INFLOW				119.5	16.9%	5.51E+01	6.5%	0.06	168.1	11.7
***TOTAL INFLOW				706.9	100.0%	8.42E+02	100.0%	0.04	65.9	36.5
ADVECTIVE OUTFLOW				335.9	47.5%	2.70E+03		0.15	36.4	17.3
***TOTAL OUTFLOW				335.9	47.5%	2.70E+03		0.15	36.4	17.3
***RETENTION				371.1	52.5%	3.01E+03		0.15		

Overflow Rate (m/yr)	4.9	Nutrient Resid. Time (yrs)	0.3135
Hydraulic Resid. Time (yrs)	0.6599	Turnover Ratio	3.2
Reservoir Conc (mg/m3)	36	Retention Coef.	0.525

Big Eagle Model 2
File: **K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario2.btb**

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:
1 = Observed Water Quality Error Only
2 = Error Typical of Model Development Dataset
3 = Observed & Predicted Error

Segment: 1 Big Eagle Basin

	Observed		Predicted		Obs/Pred	T-Statistics ---->		
Variable	**Mean**	**CV**	**Mean**	**CV**	**Ratio**	**T1**	**T2**	**T3**
TOTAL P MG/M3	50.0	0.00	36.4	0.15	1.38		1.18	2.06
CHL-A MG/M3	34.4	0.00	18.5	0.30	1.86		1.80	2.06
SECCHI M	1.4	0.00	1.8	0.27	0.76		-0.99	-1.02
ANTILOG PC-1	625.3	0.00	267.7	0.54	2.34		2.42	1.58
ANTILOG PC-2	19.1	0.00	15.6	0.08	1.23		0.66	2.62

Big Eagle Model 3
File: K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario3updated_051820.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1-NortheastDrainage	7.3	8.0	0.00E+00	0.00	1.09
2	2	1	Trib 2- Northwest Drainage	1.5	0.1	6.88E-05	0.10	0.06
3	2	1	Trib 3- Central Drainage	3.5	0.2	3.73E-04	0.10	0.06
4	2	1	Trib 4- West Drainage	3.9	0.3	9.60E-04	0.10	0.08
5	2	1	Trib 5- South (Direct)	1.3	0.1	0.00E+00	0.00	0.09
PRECIPITATION				1.9	2.1	0.00E+00	0.00	1.10
TRIBUTARY INFLOW				7.3	8.0	0.00E+00	0.00	1.09
NONPOINT INFLOW				10.2	0.7	1.40E-03	0.05	0.07
***TOTAL INFLOW				19.4	10.7	1.40E-03	0.00	0.55
ADVECTIVE OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***TOTAL OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***EVAPORATION					1.5	0.00E+00	0.00	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**
Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1-NortheastDrainage	531.3	22.1%	0.00E+00		0.00	66.7	72.4
2	2	1	Trib 2- Northwest Drainage	11.6	0.5%	1.35E+00	0.2%	0.10	140.0	7.9
3	2	1	Trib 3- Central Drainage	65.6	2.7%	4.31E+01	5.1%	0.10	340.0	18.7
4	2	1	Trib 4- West Drainage	31.0	1.3%	9.60E+00	1.1%	0.10	100.0	8.0
5	2	1	Trib 5- South (Direct)	11.3	0.5%	0.00E+00		0.00	90.0	8.4
PRECIPITATION				56.1	2.3%	7.87E+02	93.6%	0.50	27.3	30.0
INTERNAL LOAD				1700.7	70.6%	0.00E+00		0.00		
TRIBUTARY INFLOW				531.3	22.1%	0.00E+00		0.00	66.7	72.4
NONPOINT INFLOW				119.5	5.0%	5.40E+01	6.4%	0.06	168.1	11.7
***TOTAL INFLOW				2407.7	100.0%	8.41E+02	100.0%	0.01	224.3	124.2
ADVECTIVE OUTFLOW				717.0	29.8%	1.71E+04		0.18	77.6	37.0
***TOTAL OUTFLOW				717.0	29.8%	1.71E+04		0.18	77.6	37.0
***RETENTION				1690.7	70.2%	1.76E+04		0.08		

Overflow Rate (m/yr)	4.9	Nutrient Resid. Time (yrs)	0.1965
Hydraulic Resid. Time (yrs)	0.6599	Turnover Ratio	5.1
Reservoir Conc (mg/m3)	78	Retention Coef.	0.702

Big Eagle Model 3

File: **K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario3updated_051820.btb**

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:

1 = Observed Water Quality Error Only

2 = Error Typical of Model Development Dataset

3 = Observed & Predicted Error

Segment: **1** **Big Eagle Basin**

	Observed		Predicted		Obs/Pred	T-Statistics ---->		
Variable	Mean	CV	Mean	CV	Ratio	T1	T2	T3
TOTAL P MG/M3	50.0	0.00	77.6	0.18	0.64		-1.63	-2.41
CHL-A MG/M3	34.4	0.00	33.3	0.29	1.03		0.09	0.11
SECCHI M	1.4	0.00	1.1	0.28	1.28		0.87	0.88
ANTILOG PC-1	625.3	0.00	761.6	0.54	0.82		-0.56	-0.37
ANTILOG PC-2	19.1	0.00	15.5	0.08	1.24		0.69	2.71

Big Eagle Model 4
File: K:\013565-000\Admin\Docs\BATHTUB\IterativePredictions\BE_reducedNE20Reducedinternal0.25.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1-NortheastDrainage	7.3	8.0	0.00E+00	0.00	1.09
2	2	1	Trib 2- Northwest Drainage	1.5	0.1	6.88E-05	0.10	0.06
3	2	1	Trib 3- Central Drainage	3.5	0.2	3.73E-04	0.10	0.06
4	2	1	Trib 4- West Drainage	3.9	0.3	9.60E-04	0.10	0.08
5	2	1	Trib 5- South (Direct)	1.3	0.1	0.00E+00	0.00	0.09
PRECIPITATION				1.9	2.1	0.00E+00	0.00	1.10
TRIBUTARY INFLOW				7.3	8.0	0.00E+00	0.00	1.09
NONPOINT INFLOW				10.2	0.7	1.40E-03	0.05	0.07
***TOTAL INFLOW				19.4	10.7	1.40E-03	0.00	0.55
ADVECTIVE OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***TOTAL OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***EVAPORATION					1.5	0.00E+00	0.00	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**
Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1-NortheastDrainage	159.3	32.8%	0.00E+00		0.00	20.0	21.7
2	2	1	Trib 2- Northwest Drainage	11.6	2.4%	1.35E+00	0.2%	0.10	140.0	7.9
3	2	1	Trib 3- Central Drainage	65.6	13.5%	4.31E+01	5.1%	0.10	340.0	18.7
4	2	1	Trib 4- West Drainage	31.0	6.4%	9.60E+00	1.1%	0.10	100.0	8.0
5	2	1	Trib 5- South (Direct)	11.3	2.3%	0.00E+00		0.00	90.0	8.4
PRECIPITATION				56.1	11.6%	7.87E+02	93.6%	0.50	27.3	30.0
INTERNAL LOAD				150.3	31.0%	0.00E+00		0.00		
TRIBUTARY INFLOW				159.3	32.8%	0.00E+00		0.00	20.0	21.7
NONPOINT INFLOW				119.5	24.6%	5.40E+01	6.4%	0.06	168.1	11.7
***TOTAL INFLOW				485.2	100.0%	8.41E+02	100.0%	0.06	45.2	25.0
ADVECTIVE OUTFLOW				261.1	53.8%	1.45E+03		0.15	28.3	13.5
***TOTAL OUTFLOW				261.1	53.8%	1.45E+03		0.15	28.3	13.5
***RETENTION				224.1	46.2%	1.67E+03		0.18		

Overflow Rate (m/yr)	4.9	Nutrient Resid. Time (yrs)	0.3550
Hydraulic Resid. Time (yrs)	0.6599	Turnover Ratio	2.8
Reservoir Conc (mg/m3)	28	Retention Coef.	0.462

Big Eagle Refined Model 3
File: K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario3updated_052720.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Trib 1-NortheastDrainage	7.3	8.0	0.00E+00	0.00	1.09
2	2	1	Trib 2- Northwest Drainage	1.5	0.1	6.88E-05	0.10	0.06
3	2	1	Trib 3- Central Drainage	3.5	0.2	3.73E-04	0.10	0.06
4	2	1	Trib 4- West Drainage	3.9	0.3	9.60E-04	0.10	0.08
5	2	1	Trib 5- South (Direct)	1.3	0.1	0.00E+00	0.00	0.09
PRECIPITATION				1.9	2.1	0.00E+00	0.00	1.10
TRIBUTARY INFLOW				7.3	8.0	0.00E+00	0.00	1.09
NONPOINT INFLOW				10.2	0.7	1.40E-03	0.05	0.07
***TOTAL INFLOW				19.4	10.7	1.40E-03	0.00	0.55
ADVECTIVE OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***TOTAL OUTFLOW				19.4	9.2	1.40E-03	0.00	0.48
***EVAPORATION					1.5	0.00E+00	0.00	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**
Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Trib 1-NortheastDrainage	531.3	38.2%	0.00E+00		0.00	66.7	72.4
2	2	1	Trib 2- Northwest Drainage	11.6	0.8%	1.35E+00	0.2%	0.10	140.0	7.9
3	2	1	Trib 3- Central Drainage	65.6	4.7%	4.31E+01	5.1%	0.10	340.0	18.7
4	2	1	Trib 4- West Drainage	31.0	2.2%	9.60E+00	1.1%	0.10	100.0	8.0
5	2	1	Trib 5- South (Direct)	11.3	0.8%	0.00E+00		0.00	90.0	8.4
PRECIPITATION				56.1	4.0%	7.87E+02	93.6%	0.50	27.3	30.0
INTERNAL LOAD				683.0	49.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				531.3	38.2%	0.00E+00		0.00	66.7	72.4
NONPOINT INFLOW				119.5	8.6%	5.40E+01	6.4%	0.06	168.1	11.7
***TOTAL INFLOW				1390.0	100.0%	8.41E+02	100.0%	0.02	129.5	71.7
ADVECTIVE OUTFLOW				515.6	37.1%	7.78E+03		0.17	55.8	26.6
***TOTAL OUTFLOW				515.6	37.1%	7.78E+03		0.17	55.8	26.6
***RETENTION				874.4	62.9%	8.23E+03		0.10		

Overflow Rate (m/yr)	4.9	Nutrient Resid. Time (yrs)	0.2448
Hydraulic Resid. Time (yrs)	0.6599	Turnover Ratio	4.1
Reservoir Conc (mg/m3)	56	Retention Coef.	0.629

Big Eagle Refined Model 3

File: **K:\013565-000\Admin\Docs\BATHTUB\BigEagleScenario3updated_052720.btb**

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:

1 = Observed Water Quality Error Only

2 = Error Typical of Model Development Dataset

3 = Observed & Predicted Error

Segment: **1** **Big Eagle Basin**

	Observed		Predicted		Obs/Pred	T-Statistics ---->		
Variable	**Mean**	**CV**	**Mean**	**CV**	**Ratio**	**T1**	**T2**	**T3**
TOTAL P MG/M3	50.0	0.00	55.8	0.17	0.90		-0.41	-0.64
CHL-A MG/M3	34.4	0.00	26.6	0.30	1.29		0.74	0.87
SECCHI M	1.4	0.00	1.3	0.28	1.04		0.15	0.15
ANTILOG PC-1	625.3	0.00	509.9	0.54	1.23		0.58	0.38
ANTILOG PC-2	19.1	0.00	15.6	0.08	1.23		0.66	2.64

Big Eagle Model 4

File: **K:\013565-000\Admin\Docs\BATHTUB\IterativePredictions\BE_reducedNE20Reducedinternal0.25.btb**

T Statistics Compare Observed and Predicted Means Using the Following Error Terms:

1 = Observed Water Quality Error Only

2 = Error Typical of Model Development Dataset

3 = Observed & Predicted Error

Segment: **1** **Big Eagle Basin**

Variable	Observed Mean	CV	Predicted Mean	CV	Obs/Pred Ratio	T-Statistics ----> T1	T2	T3
TOTAL P MG/M3	50.0	0.00	28.3	0.15	1.77		2.12	3.92
CHL-A MG/M3	34.4	0.00	14.4	0.30	2.39		2.52	2.88
SECCHI M	1.4	0.00	2.3	0.26	0.62		-1.73	-1.84
ANTILOG PC-1	625.3	0.00	173.7	0.53	3.60		3.65	2.42
ANTILOG PC-2	19.1	0.00	15.5	0.08	1.23		0.67	2.66

APPENDIX D

Big Eagle Anoxic Factor Calculations

Station 203 Anoxic Depth and Associated TP Load							
Date	Anoxic Depth (ft.)	Corresponding Lake Area (ac)	Corresponding Lake Area (m^2)	# of Days Anoxic	TP Loading Rate (mg P/m^2/day)	Load (mg)	Load (kg)
6/12/2020	18	63	254,898	7	6.56	11,704,916.16	11.70
6/19/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
6/26/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
7/3/2020	14	148	598,808	7	6.56	27,497,263.36	27.50
7/11/2020	13	170	687,820	8	6.56	36,096,793.60	36.10
7/17/2020	12	182.6	738,800	6	6.56	29,079,152.26	29.08
7/27/2020	17	70.2	284,029	10	6.56	18,632,315.52	18.63
8/1/2020	15	105.2	425,639	4	6.56	11,168,772.61	11.17
8/7/2020	13	170	687,820	6	6.56	27,072,595.20	27.07
8/14/2020	15	105.2	425,639	7	6.56	19,545,352.06	19.55
8/21/2020	16	84.4	341,482	7	6.56	15,680,871.81	15.68
	stop-mixed water column						
9/5/2020	19	38.3	154,962	10	6.56	10,165,494.08	10.17
9/15/2020	19	38.3	154,962	3	6.56	3,049,648.22	3.05
9/18/2020	15	105.2	425,639	8	6.56	22,337,545.22	22.34
	stop-mixed water column						
						Total Growing Season Load	263.39

APPENDIX E

Big Eagle 2019 Carp Assessment Report

January 15, 2020

2019 Common Carp Assessment Report Big Eagle Lake

for Big Eagle Lake Improvement Association

Mary Newman – Environmental Scientist
Jordan Wein – Environmental Scientist

Introduction

The Big Eagle Lake Improvement Association (BELIA) commissioned WSB to complete an assessment of the common carp population in 2019 in conjunction with a total maximum daily load (TMDL) study. This survey objective was initiated to assess the potential impact common carp may be having on the water quality and ecological integrity of Big Eagle Lake. This report summarizes results from the 2019 sampling period.

Common Carp Management

Although carp management is not the only action to improve water quality, it may be a necessary component of an overall lake management plan. Carp can cause loading of nutrients internally within a basin due to their feeding habits and excretion rates when biomass becomes elevated. An elevated carp biomass threshold value currently used and established by the scientific community is ~90 lbs/acre (Bajer, 2012).

By estimating the population size, resource managers may be able to assess existing carp density against this threshold value to determine if additional carp management is necessary. If future management is required and/or desired, additional components of an integrated pest management (IPM) approach, which may include collection of movement data (radio-telemetry, PIT tag monitoring), physical or chemical removal, and suppression of carp recruitment with the use of barriers to movement, predator species enhancement, habitat restoration, and a component of outreach and education, may be pursued.

Shallow lake basins in the Upper Midwest are prone to low oxygen levels that lead to winterkill events. These basins can support recruitment of young fish because of low predator abundance resulting from such events. Carp commonly use migration routes in the springtime to access shallow lake basins to exploit the absence of predator species to hatch young. Additionally, carp are able to withstand low oxygen conditions and live to exploit basins they overwinter in that also experience winterkill.

Project Area

Sherburne County is located in central Minnesota approximately 50 miles to the northwest of the Twin Cities Metropolitan Area.

MN DNR data shows that carp are present in these lakes but an abundance estimate is not provided. This project was completed to develop that abundance estimate and determine if carp may be having an impact on water quality.

Big Eagle Lake is a shallow (mean depth = 10.7 feet, maximum depth= 18 feet) lake. Roughly 71% of Big Eagle Lake is considered littoral area, and it is infested with curly leaf pondweed and Eurasian watermilfoil. Trophic state index values show that the lake is eutrophic by transparency index, chlorophyll-a and total phosphorous concentration index values.

Methodology

As part of this project we proposed to use two methodologies to estimate carp population and biomass. The first and most rapid is to employ an electrofishing catch per unit effort (CPUE) methodology. To do this a boat electrofisher is used to stun and capture carp and other fish species as it traverses representative habitat types in the lake littoral zones. Time spent electrofishing is recorded and all carp are captured, measured for length and weight, given a unique fin clip, and released. The number of carp captured is used as an input into an existing model that provides an estimate on the number of individual carp per acre. Average weights and lake acreage can be used to estimate carp density and overall abundance.

Multiple electrofishing CPUE events per waterbody are pursued during each season (late summer/early fall) to gain confidence in estimates developed through this method of estimation. On Big Eagle Lake, we sampled via boat electrofishing on two separate occasions, one on August 22 and the other on September 24, 2019. On both survey dates, at least three transects were traversed to capture the variability of carp abundance throughout the lake basin.

The second method is the mark-recapture estimate which takes additional effort but may be more accurate. If a large enough sample is marked and recaptured, this method can be used to confirm estimates developed by the electrofishing CPUE estimate. The typical mark that we utilize is a unique fin clip. Once carp are marked, they are released for eventual recapture. By using the number of recaptured carp, the total number of carp, and the total number captured, we can develop an estimate. This estimate will be used to report if a 95% confidence interval is achieved.

These two methods are typically completed simultaneously to reduce the amount of effort and cross validate estimates generated by each method.

Since only one follow-up visit to the lake was accomplished in this project period, a recapture event was not completed; therefore, numbers are not reported here. In addition to marking and capture, we measure and weigh each captured carp to calculate average weight to be used as in the CPUE model. Lengths and weights will also be used to develop a length-weight frequency to understand size structure of the population and to plot size frequency distribution which may be used as a surrogate for aging data to estimate recruitment intervals.

Results

Carp Population / Biomass Estimate

Using a boat electrofisher, nine (9) transects were traversed on Big Eagle Lake on two visits to the lake. Time spent electrofishing, number of carp captured, and length and weight data was collected to be used in a common carp catch per unit effort model. Each transect was averaged to report a daily CPUE and each date was averaged to report a yearly CPUE for the lake and variation between dates is used to calculate a standard deviation (Table 1). The results of the 2019 electrofishing CPUE survey indicate that biomass in Big Eagle Lake (171 ± 167.8 lbs/acre) is above the management threshold of 90 lbs/acre.

Lake	Date 2019	Event Type	# of Transects/ Total Time (hrs)	Total # Carp Captured	2019 Fin Clip	CPUE estimate (lbs/ac) By Date	2019 CPUE estimate (lbs/ac)
Big Eagle	22-Aug	CPUE/Fin Clip	5 / 1.88	11	Left Pelvic	99.6	**171.7**
Big Eagle	24-Sep	CPUE/Fin Clip	4 / 1.35	10		243.8	**± 167.8**

Table 1 – 2019 Sherburne County's Big Eagle Lake Electrofishing CPUE survey data.

Discussion

Results using the carp electrofishing CPUE model show that common carp biomass density is elevated in Big Eagle Lake; however, the variability between survey dates is high. Although a review of the CPUE estimate suggests that carp may be contributing to poor water quality in Big Eagle Lake, a closer look at the size distribution in Big Eagle Lake explains the variability in data and carp dynamics in the lake basin.

Plotting the size distribution over the two survey dates, data suggest that carp are not actively recruiting to the lake (see Figure 1 below). Zero (0) carp were sampled that were smaller than 24 inches, indicating that these fish are likely older than 5 years. Additionally, the size distribution in the sampling events can also help to describe the variability in the CPUE estimates reported on each survey date. Few fish were captured in each transect; however, the weight of each fish was between 5 and 28 pounds, with larger and heavier fish on average in the September survey date (see Figure 2 below).

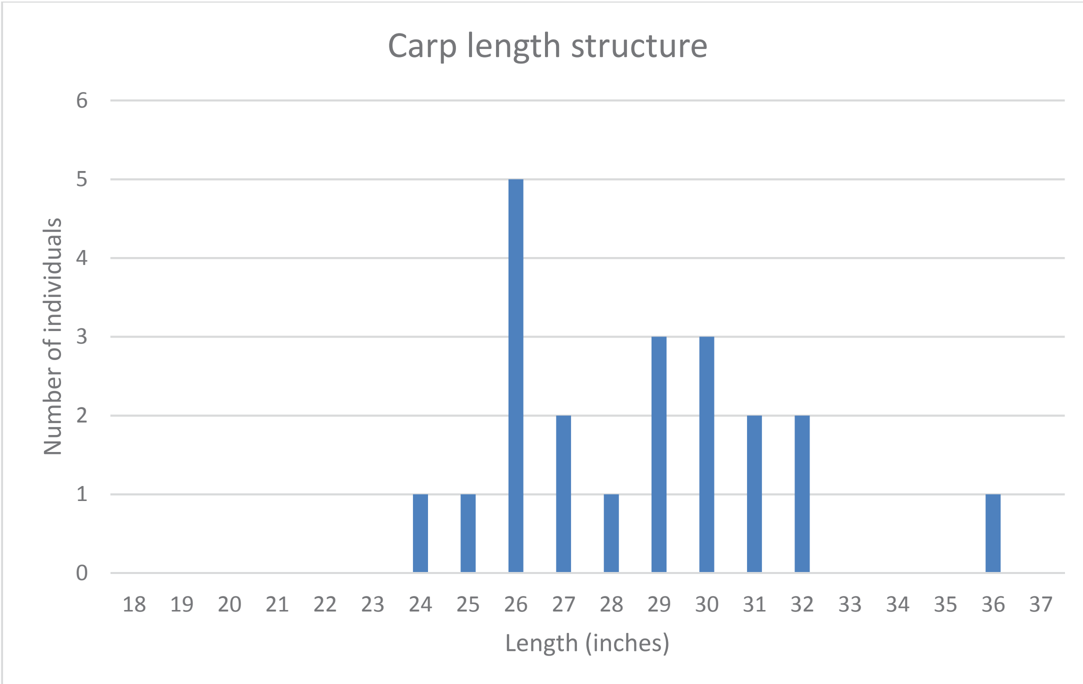

Figure 1: Length histogram of carp captured in Big Eagle Lake via boat electrofishing in 2019.

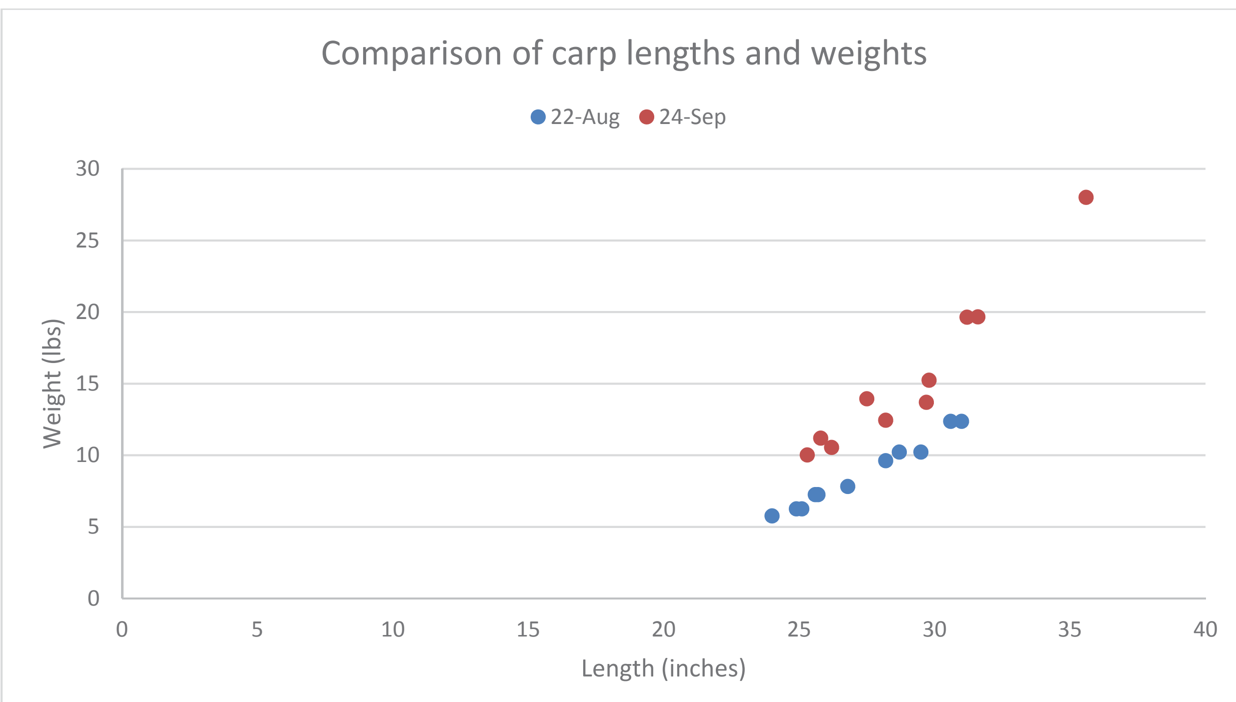

Figure 2: An illustration of the growth of carp in Big Eagle. Each dot is one of the carp captured during the electrofishing surveys.

In 2019, data suggests that carp may be contributing to poor water quality in Big Eagle Lake. With the large range of variability, it would be suggested that additional surveys in subsequent years be pursued before moving towards a carp management program. The carp barrier at outlet of Big Eagle Lake seems to be preventing the regular recruitment of carp into the lake basin and survey data collected in multiple years could help to support this hypothesis. If this is the case, the carp population will continue to decline naturally, although the size of carp may increase.

References:

Bajer, P.G., Sorensen, P.W. (2010). Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. Biological Invasions. 12(5): 1101-1112.

Bajer, P. G., Sorensen, P. W. (2012). Using boat electrofishing to estimate abundance of invasive common carp in small Midwestern lakes. *North American Journal of Fisheries Management*, 32:5, 817-822.