Appendix J

<u>Centerville Lake Diagnostic Studies</u>

Internal Load Investigation for Centerville Lake, Wenck Associates, 2019. 10p.

Centerville Lake Phosphorus Dynamics: Relative Impact of Backflow Phosphorus Loading on Centerville Lake, Houston Engineering, 2022. 30p.

Alum Longevity in Centerville Lake, Barr Engineering Company, 2023. 7p.

2022 RCWD Carp Management Report, Carp Solutions, 2023. 24p.

Centerville Lake Phosphorus Loading Summary, Rice Creek Watershed District, 2023. 3p.

Technical Memo

To: Matthew Kocian, Rice Creek Watershed District

From: Sarah Nalven, Wenck Associates, Inc.
Joe Bischoff, Wenck Associates, Inc.

Date: October 18, 2019

Subject: Internal Load Investigation for Centerville Lake

In this internal load study, we investigated internal loading in Centerville Lake to determine if another aluminum sulfate (alum) treatment is necessary, and if so, the dose and cost of a treatment.

Background

Centerville Lake is a high priority lake for management in the Rice Creek Watershed District (**Figure 1**). In 1998, after diagnostic studies determined that internal loading was the dominant phosphorus load in the lake (driven by anoxic release rates of 7.2 mg/m^2/day; Barr 1998), the lake received an alum treatment. During this treatment, approximately 120,000 gallons of 8.3% liquid aluminum sulfate were applied to all areas of the lake 5 feet or deeper, a dose of about 18 g Al/m^2. Following this alum treatment, phosphorus concentrations in Centerville Lake were greatly reduced (**Figure 2**). Internal load was also thought to have been greatly reduced. In fact, the 2013 Peltier Lake and Centerville Lake TMDL study did not report an existing internal load for Centerville Lake (EOR 2013). However, average summer surface total phosphorus (TP) concentrations continue to exceed the state standard of 40 µg/L. Consequently, the lake experiences frequent algae blooms, causing average summer surface chlorophyll-a concentrations to also exceed the state standard (14 µg/L).

Lake Stability and Hypolimnetic Phosphorus

Recent hypolimnetic TP concentrations indicate that internal loading may be partly responsible for deteriorating water quality. In many years, hypolimnetic TP concentrations continually increase throughout the summer, a signature of sediment phosphorus release (**Figure 3**), although it should be noted that hypolimnetic TP concentrations are still moderately low (typically less than 200 µg/L TP). The purpose of this study was to quantify internal loading in Centerville Lake and determine if another alum treatment is necessary.

Figure 1. Centerville Lake as seen from Main Street (photo from Google Street View).

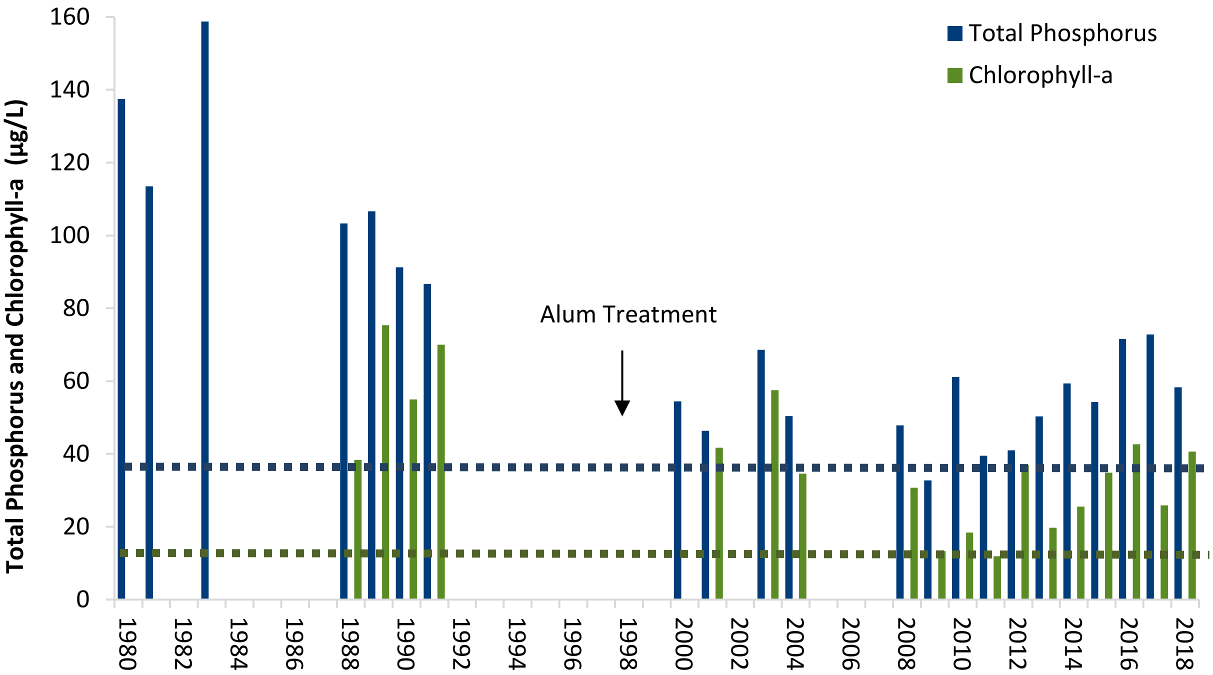

Figure 2. Average surface total phosphorus (TP) and chlorophyll-a (chla) concentrations of Centerville Lake from June through September, 1980 to 2018. The blue and green dotted lines represent the state standards for TP and chla, respectively. A 1998 alum treatment greatly reduce TP and chla levels.

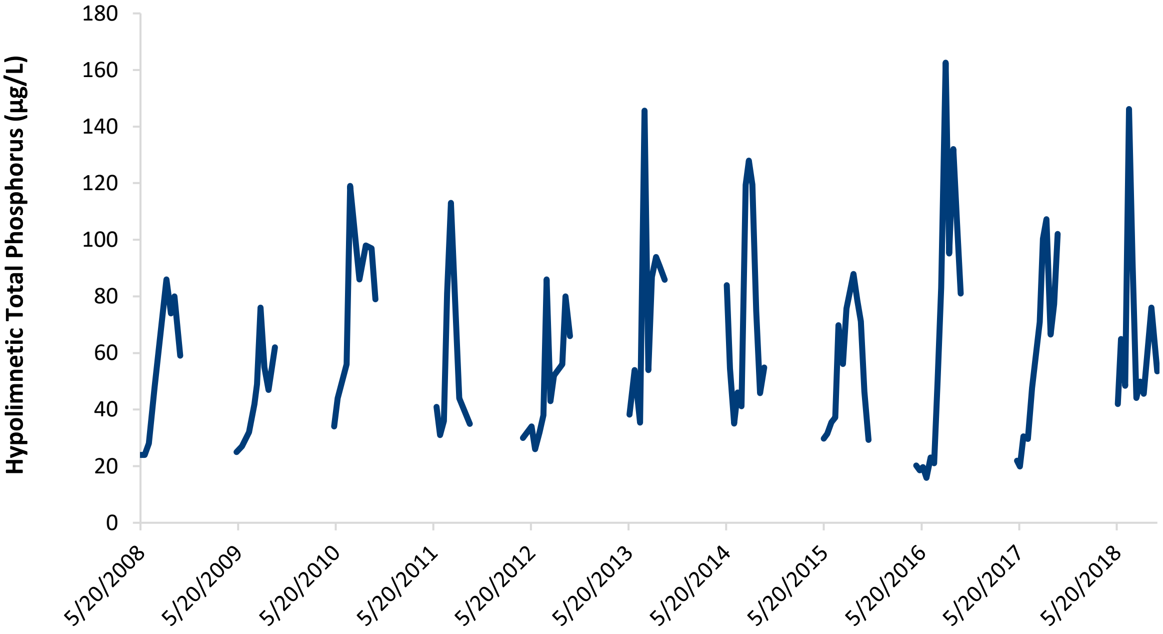

Figure 3. Hypolimnetic total phosphorus (TP) concentrations from 2008 to 2018. Most years saw increasing hypolimnetic TP concentrations throughout the summer.

While the phosphorus concentrations are relatively low in the hypolimnion, Centerville Lake is fairly shallow and may mix frequently throughout the summer if the lake only weakly stratifies. The Schmidt Stability index (St) is a measure of the strength of thermal stratification (Idso, 1973). The larger St, the more energy that is needed to mix the water column to a uniform temperature. Thus, a large St indicates a more stable water column stratification. Stable stratification allows for a persistent thermocline to physically separate the hypolimnion and the epilimnion. When St decreases, the stratification weakens allowing the hypolimnion and epilimnion to mix. St data in 2013 provides a good example of the potential impacts of weak stratification. In 2013, the St increases and peaks on 7/18/13 and then precipitously drops, indicating a mixing event which has weakened the water column stratification, mixing the epilimnion and hypolimnion. The St remains low though the rest of the season indicating the lake only weakly stratifies the rest of the summer and hypolimnetic P can easily mix into surface waters.

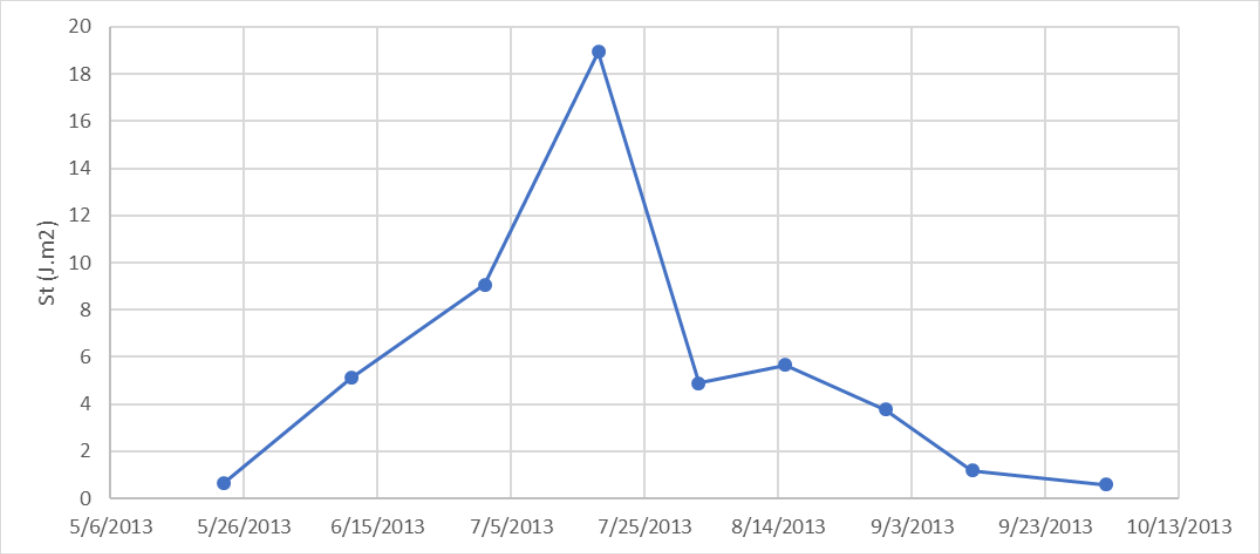

Figure 4. Schmidt Stability Index for Centerville Lake in 2013.

Hypolimnetic phosphorus follows a similar pattern with high concentrations at peak stability (around 150 µg/L) dropping to almost 50 µg/L after the mixing event (**Figure 5**). This mixing event caused a reduction in hypolimnetic phosphorus mass of 79 kg which could result in a 15 µg/L increase in surficial TP. The remaining instability of the lake through the remaining growing season would easily allow for sediment released phosphorus to mix into the photic zone. Bottom TP remains higher than surface TP suggesting sediment release may be contributing to surface TP concentrations.

It should be noted that not all of the years show this type of mid-summer mixing event (**Table 1**). Some of the mixing occurs later in the summer or fall when water is cooling, and algal blooms may be limited by water temperature. Further, not all of the hypolimnetic phosphorus will get mixed, since some settling will occur, and some fractions will be unavailable for algal growth. However, this analysis does suggest that the lake is weakly stratified and that in some years, hypolimnetic phosphorus may be contributing to algal blooms. A more detailed summer growing season data set would confirm this hypothesis.

Table 1. Total phosphorus mass mixed into the epilimnion and metalimnion following a growing season mixing event.

Date	Mass P Mixed (lbs.)
8/25/08 to 9/10/08	23
8/12/09 to 8/26/09	40
7/13/10 to 8/16/10	63
7/25/11 to 8/25/11	131
7/17/12 to 7/31/12	82
7/18/13 to 8/2/13	175
8/26/14 to 9/23/14	140
7/14/15 to 7/30/15	26
8/17/16 to 8/31/16	128
8/30/17 to 9/14/17	78
7/5/18 to 8/1/18	194

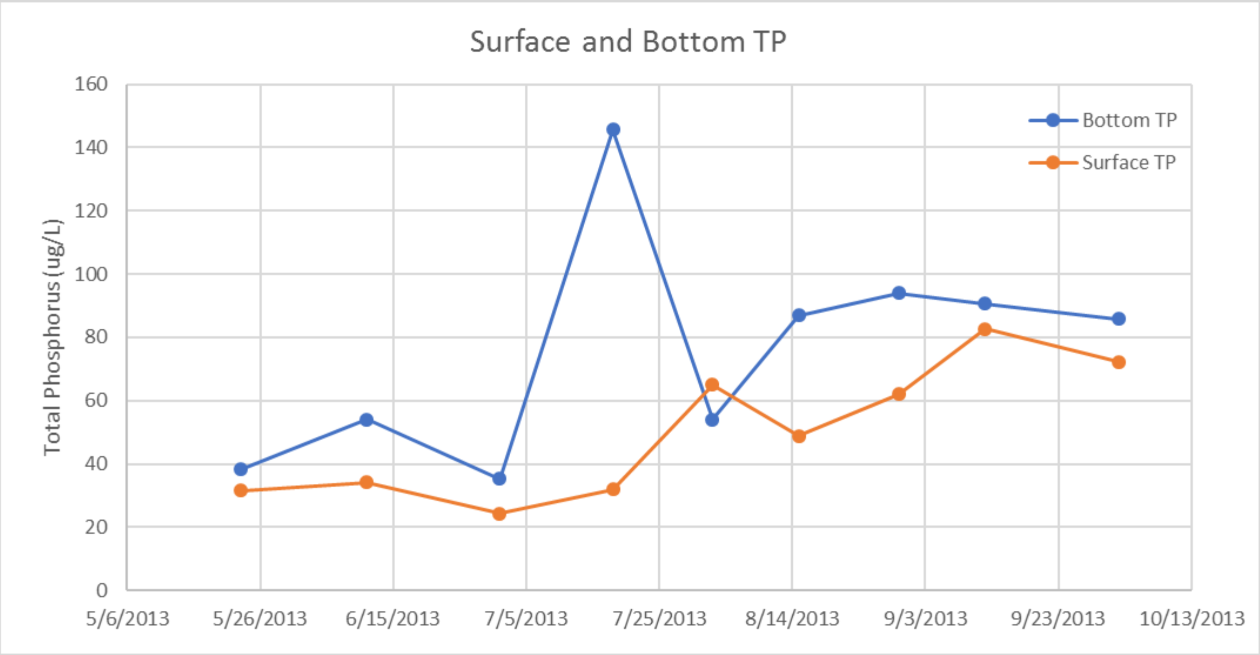

Figure 5. Surface and bottom total phosphorus in 2014 where a significant drop occurred in hypolimnetic phosphorus midsummer.

Field and Laboratory Methods

Sediment cores were collected from two locations on Centerville Lake on January 23, 2019 (**Figure 6**). Depth at the western location (-93.075762, 45.162356) was about 15.7 feet. Depth at the eastern location (-93.067027, 45.163814) was about 17.4 feet. A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner was used to collect sediment cores. To evaluate physical, textural and chemical characteristics of sediment, one core from each location was sectioned vertically into the following seven sections: 0 to 2 cm, 2 to 4 cm, 4 to 6 cm, 6 to 8 cm, 8 to 10 cm, 10 to 15 cm, and 15 to 20 cm. Three cores were also taken from each location to measure phosphorus release rates from sediment. These cores were incubated for 7 days at 20 to 25 degrees Celsius while phosphorus release was measured. An average of the triplicate measurements was used.

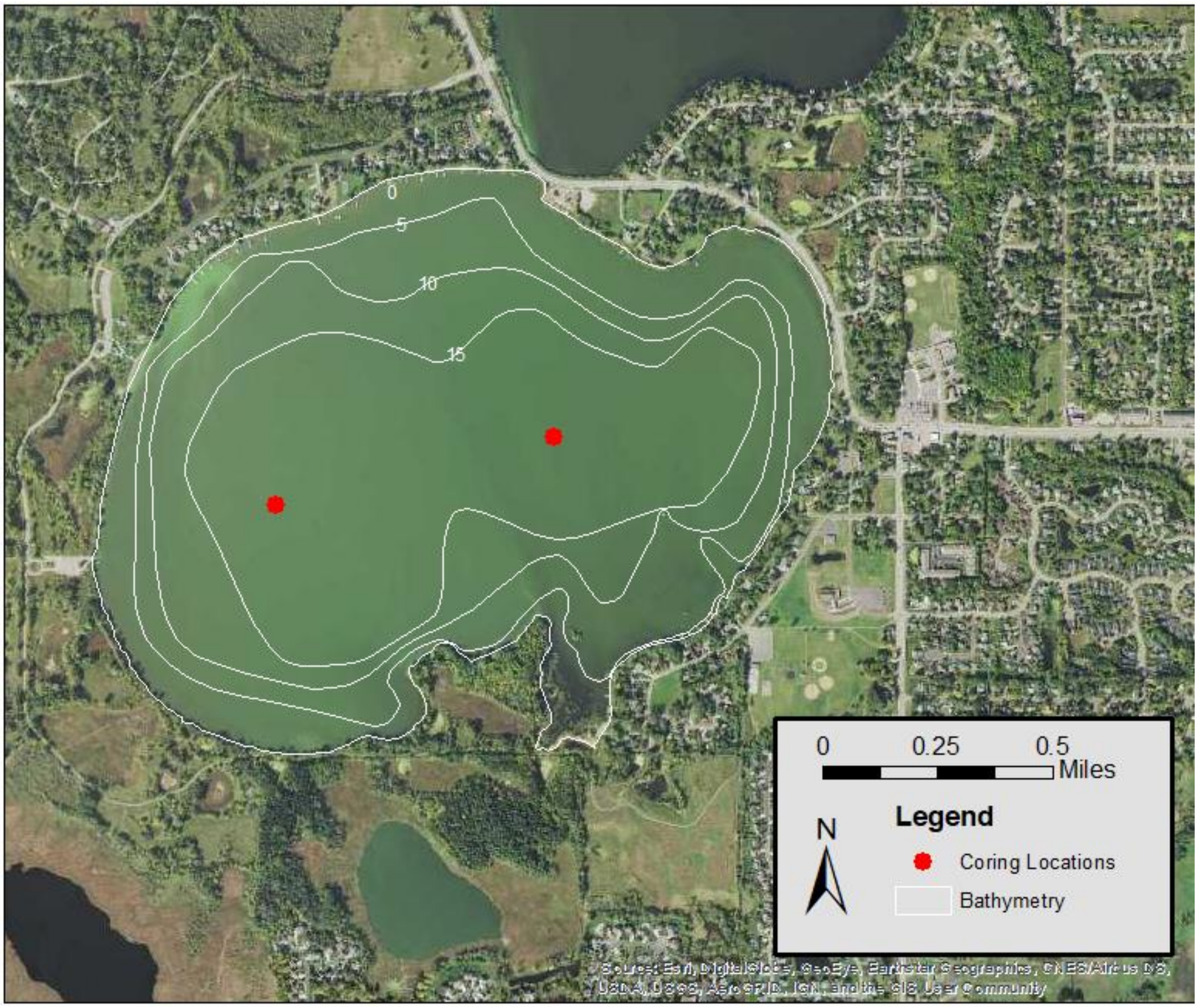

Figure 6. Centerville Lake bathymetry. Red circles represent sediment coring locations.

Internal Phosphorus Load

We estimated internal phosphorus load, or the load entering Centerville Lake due to sediment phosphorus release, using laboratory-measured sediment release rates (**Table 2**), water column dissolved oxygen data, and information on Centerville Lake bathymetry. First, because a certain type of sediment phosphorus release occurs only when bottom waters are anoxic, we quantified the duration and extent of Centerville Lake's anoxia by calculating the lake's anoxic factor. Using bathymetric information and four summers of dissolved oxygen data (2012-2015), we found that Centerville Lake has an average anoxic factor of 26 days per year. We then used an average measured anoxic release rate of 4.4 mg/m^2/day (**Table 2**) and an assumed oxic release rate of 0.5 mg/m^2/day to calculate internal load due to oxic and anoxic processes (**Table 3**). Based on these calculations, Centerville Lake has an internal load of about 278 pounds of phosphorus per year (**Table 3**). This internal load is large, especially considering it is almost double the lake's estimated TMDL watershed load of 151 pounds of phosphorus per year (EOR 2013).

Table 2. Anoxic phosphorus (P) release rates from west and east coring locations. Rates were measured by incubating cores in triplicate. Standard error is noted in parentheses.

Coring Location	Anoxic P release rate (mg/m^2/day)
West	4.02 (0.47)
East	4.78 (0.34)
Average	4.4

Table 3. Internal load in Centerville Lake caused by anoxic and oxic processes, and parameters used to calculate internal load.

Release Type	Lake Area (km^2)	Anoxic Factor* (days)	P release rate** (mg/m^2/day)	Internal P Load (lbs/yr)
Anoxic	0.78	26	4.4	196
Oxic	0.78	96	0.5	82
Total				**278**

** Anoxic factor of 26 calculated using 4 years of dissolved oxygen data. Oxic release was assumed to occur during all days in the growing season that were not anoxic.*

*** Anoxic P release used is average of P release at east and west coring locations (average of six incubations). Oxic P release was assumed to be 0.5 mg/m^2/day.*

Chemical Characteristics of Sediment

In addition to looking at phosphorus release rates in Centerville Lake, we investigated chemical characteristics of the sediment. We quantified iron-bound and loosely-bound phosphorus (together called redox-P), which are the fractions of phosphorus associated with sediment phosphorus release during anoxia. We also quantified labile organic phosphorus, which is released in all conditions as organic phosphorus is decomposed. Finally, we quantified aluminum-bound phosphorus to investigate if the 1998 alum treatment could be detected.

Sediment in both coring locations showed similar patterns (**Figure 7**). In both coring locations, iron-bound, loosely-bound and labile organic phosphorus concentrations were high and all in the 75th to 100th percentile of concentrations found in lake cores in the Twin Cities Metropolitan Area. In addition, concentrations of labile organic phosphorus were consistently higher than concentrations of iron-bound phosphorus. Finally, aluminum-bound phosphorus was quantified, and the signature of the 1998 alum treatment signature could not be detected, possibly because the 1998 alum dose was relatively low (about 18 g Al/m^2).

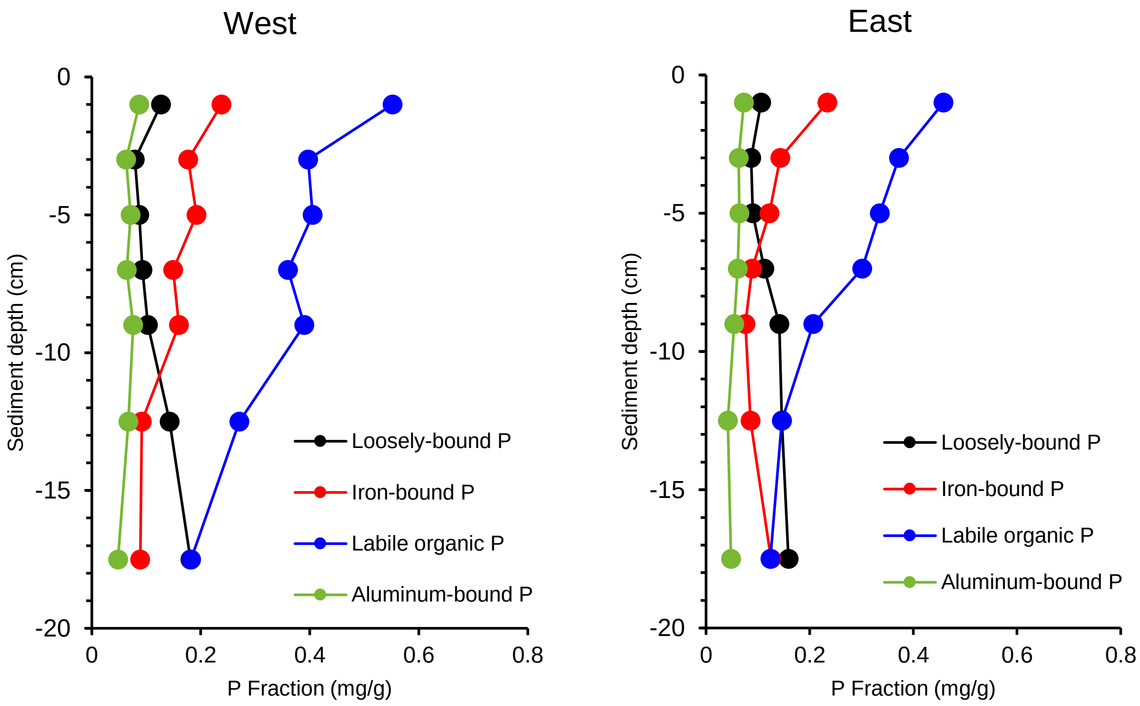

Figure 7. Phosphorus fractions in sediments at west and east coring locations.

Physical Characteristics of Sediment

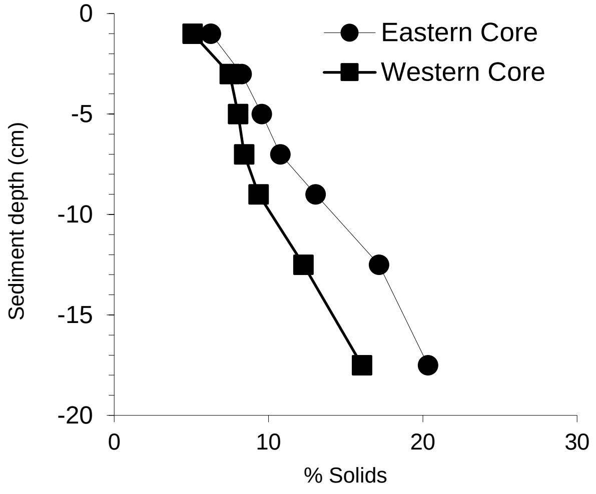

Figure 8. Percent solids, a measure of density, in both sediment cores.

Physical characteristics of Centerville Lake sediment were also assessed for alum dosing considerations. In lakes, we typically use the top 5-10 cm to determine the amount of alum needed to inactivate mobile phosphorus. We assume that the alum floc will incorporate into the upper 5-10 cm and convert redox-P to aluminum-bound P. Density of sediments, however, may reduce the ability of alum to sink into these sediments. Sediment in both cores had average density for lake sediment, at about 5-20% solids, with sediment becoming denser with depth (**Figure 8**). Therefore, sediment density should not present issues for an alum treatment on Centerville Lake.

Alum Dosing Costs & Recommendations

The information yielded by this study does not, unfortunately, lead to one clearly superior management strategy, but rather two main options exist moving forward: 1) proceed with an alum treatment or 2) gather more information about the hydrology of the system. We know that sediment phosphorus release is impacting the water quality of Centerville Lake. Anoxic sediment phosphorus release rates are 4.4 mg/m^2/day, and these rates, although lower than the pre-1998 alum treatment rates of 7.2 mg/m^2/day, are high enough to cause an internal load of 278 pounds of phosphorus per year. Considering that this internal load is nearly double Centerville Lake's watershed load (about 151 pounds of phosphorus per year; EOR 2013), it is probable that internal loading significantly contributes to the high phosphorus concentrations in Centerville Lake. Conversely, hypolimnetic P concentrations are relatively low for lakes with large internal loads. There is some evidence of periodic mixing throughout the season due to low stratification stability resulting in frequent mixing events that, even with lower hypolimnetic P concentrations, may be driving algal blooms. Further, the phosphorus load entering Centerville Lake as backflow from downstream Peltier Lake remains poorly understood and may be a stronger influence on the lake than internal loading.

Proceeding with an alum treatment is likely to improve water quality in Centerville Lake, and should not be eliminated as a management option. That said, the cost of an alum treatment is high which may warrant some further investigation of its role versus backflow from Peltier. Proceeding with an alum treatment next includes some degree of uncertainty regarding the extent to which Centerville Lake's internal load contributes to poor water quality. Alternatively, the District could conduct a small study that clarifies certain hydrologic and lake mixing processes in Centerville Lake, including the extent of backflow into Centerville Lake from Peltier Lake, and the extent lake destratification and mixing throughout the summer drives algal blooms. These studies would require continuous monitoring of temperature and DO profiles in the lake as well as an assessment of backflow with some additional monitoring. Continuous lake monitoring could be completed by deploying a continuous monitoring buoy in the middle of the lake that measures DO, temperature, level, and conductivity. There are a number of options available with the least expensive approach deploying sensors at selected depth intervals. More expensive, but more detailed, approaches included a motorized sensor that completes profiles on a set interval. Monitoring buoys can cost between $15,000 and $50,000 depending on the selected approach. These studies could be completed during or after an initial partial dose of alum.

If an alum treatment was chosen as the next step in management of Centerville Lake, we would recommend applying an overall dose of 60 g Al/m^2 of aluminum sulfate to all parts of Centerville Lake that are 5 feet or deeper, a 373-acre area (**Table 3**). This alum dose has been designed to inactivate 90% of redox-P in the top 4 cm of Centerville Lake's sediments. It should be noted that carp may be present in the lake and should be controlled prior to dosing. Carp can mix sediments (up to 13 cm in depth) potentially increasing the required alum dose in the shallower areas where carp might feed. A carp population survey would allow for a refinement of the approach and/or alum dose. This 60 g Al/m^2 dose should be split into three treatments of 20 g Al/m^2, applied every two to three years in order to inactivate the high amount of labile organic phosphorus in Centerville Lake's sediments (because labile organic phosphorus is released steadily over time as organic compounds containing phosphorus are decomposed). Note that a buffered aluminum solution is not necessary because even with a full dose of 60 g Al/m^2 spread over the lake's alum application area, the aluminum concentration in the lake would only be 15.7 mg/L. This concentration is still lower than the Centerville Lake's maximum allowable dose of 20 mg/L.

The recommended dose may have to be adjusted if there is trouble with aluminum sulfate flocculation at the low dose of 20 g/m^2. The second and third dose can also be adjusted based on sediment and water quality response to the first dose or based on available funds. As is, the recommended dose would cost approximately $839,000 (**Table 4**). This cost estimate includes $21,000 for mobilization (assuming $7,000 per application). The first application would cost one third of the total application cost at approximately $279,500 (**Table 4**).

Table 4. Alum quantities and costs for a second treatment of Centerville Lake.

Item	Unit	Quantity	Unit Cost	Total Cost
Total alum application (373 acres; top 4 cm; 60 g/m^2)				
Aluminum sulfate	Gal $Al_2(SO_4)_3$	408,820	$2.00	$817,641
Sodium aluminate	Gal $NaAlO_2$	0	$6.00	
Mobilization	Lump sum	3	$7,000	$21,000
			Total application cost estimate	**$838,641**
Alum application #1 (one third of total dose)				
Aluminum sulfate	Gal $Al_2(SO_4)_3$	204,410	$2.00	$272,547
Sodium aluminate	Gal $NaAlO_2$	0	$6.00	
Mobilization	Lump sum	1	$7,000	$7,000
			Application #1 cost estimate	**$279,547**

References

Barr Engineering 1998. Centerville Lake Sediment-Water Microcosm Experiment. Letter to Montgomery Watson.

EOR 2013. Peltier Lake and Centerville Lake Total Maximum Daily Load Study.
Idso, S.B. 1973, On the concept of lake stability, Limnology and Oceanography. 18 (1973) 681–683. doi:10.4319/lo.1973.18.4.0681.

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CENTERVILLE LAKE PHOSPHORUS DYNAMICS

RELATIVE IMPACT OF BACKFLOW PHOSPHORUS LOADING ON CENTERVILLE LAKE

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RELATIVE IMPACT OF BACKFLOW PHOSPHORUS LOADING ON CENTERVILLE LAKE

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4/11/2022
Date

TABLE OF CONTENTS

FIGURES

TABLES

1 EXECUTIVE SUMMARY

Centerville Lake is impaired for eutrophication and the phosphorus loads were not fully understood. Past studies, including the Peltier Lake and Centerville Lake Total Maximum Daily Load (TMDL) Report (EOR 2013) and the Internal Load Investigation for Centerville Lake, Technical Memo (Wenck 2019), quantified the watershed and internal load but also raised questions about the loading from Peltier Lake backflow. This study aimed to complete the final piece of the puzzle and quantify the load from Peltier Lake backflow and determine the best method for reducing phosphorus in Centerville Lake.

The District-Wide hydraulic and hydrologic model was reviewed to define the hydraulic relationship between Centerville and Peltier Lakes. Under typical conditions, water flows from Centerville Lake to Peltier Lake via the outflow structure at the north end of Centerville Lake. Results show that backflow into Centerville occurs when the precipitation exceeds 1.9 inches in a 24-hour period. This type of precipitation event occurs approximately 0-3 times per year in the past 20 years, translating to a very low load (2% of total) coming from Peltier Lake into Centerville Lake (Figure 1). This is an annual average condition that could vary year to year.

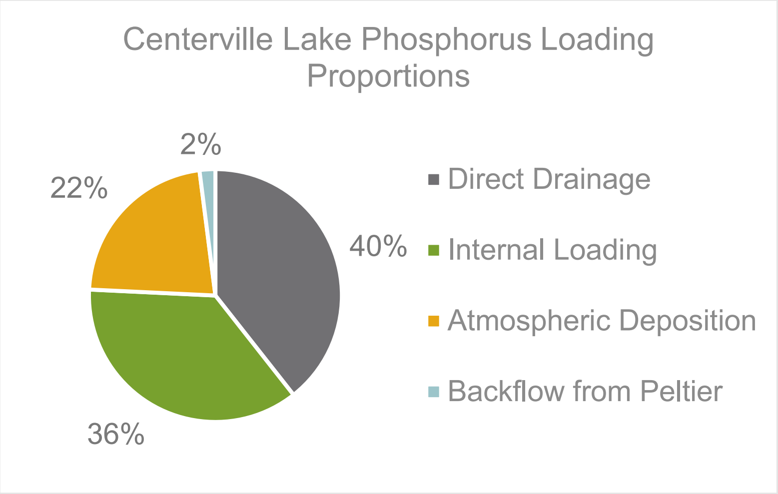

Figure 1. Centerville Lake Phosphorus Loading Proportions.

To reverse the declining water quality trend in Centerville Lake, efforts must be focused on treating direct drainage to Centerville Lake and internal loading in the lake. The RCWD and the City of Centerville have partnered together on prior projects to address untreated runoff into the lake, and continued collaboration on retrofit projects will collectively provide significant value, though it will take many of these projects to change lake trends. The most impactful way to address phosphorus loading may be to address the internal loading to the lake.

Saint Paul Regional Water Service had historically pumped water from Centerville Lake but has not withdrawn water from Centerville Lake since 1992 (Bolton and Menk, 2018). If the decision were made to begin pumping water from Centerville Lake at some point in the future, that could lead to significantly more backflow events from Peltier Lake into Centerville Lake. If pumping rates were high enough to lower the level of Centerville Lake relative to Peltier Lake, backflow to Centerville could become continuous. This could lead to a continual influx of water and phosphorus into Centerville Lake.

2 BACKGROUND

2.1 LOCATION AND PHYSICAL CHARACTERISTICS

Centerville Lake is located within the central portion of the Rice Creek Watershed District. With no major tributaries flowing to Centerville, the landscape immediately surrounding the lake is the major source of inflow. The combination of low-to-medium intensity developed land, open space, and emergent wetlands has the potential to play a major role in determining nutrient loading to the lake. However, other nutrient sources may also greatly impact water quality within the lake. A culvert at the north end of Centerville Lake serves as the outlet, connecting Centerville Lake to Peltier Lake and the downstream portions of Rice Creek.

2.2 REASON FOR STUDY

At present, Centerville Lake is considered a eutrophic lake and does not meet Minnesota water quality standards. It is impaired by excess nutrients, particularly phosphorus; however, the phosphorus loads to the lake are not fully understood. Aside from phosphorus loading from the landscape, there are several other potential sources of phosphorus to the lake. Atmospheric deposition, internal loading, groundwater input, and point sources all affect the total loading of phosphorus to the lake and thus play a role in the water quality within Centerville Lake.

Compared to the overall size of the lake, the land area that drains to Centerville Lake is quite small (watershed/surface area ratio ≈ 1). As a result, in-lake or near-shore projects targeted at reducing phosphorus have the potential for a significant reduction in phosphorus loading to the lake and potential improvement in the lake’s water quality. However, not all the other inputs of phosphorus to the lake have been fully analyzed.

2.2.1 RECENT STUDIES

Past studies including the Peltier Lake and Centerville Lake Total Maximum Daily Load (TMDL) Report (EOR 2013) and the Internal Load Investigation for Centerville Lake, Technical Memo (Wenck 2019) quantified various phosphorus sources to the lake. These analyses did clarify some of the loads to the lake, but also raised questions about the loading from Peltier Lake backflow.

2.3 CONNECTION TO PELTIER LAKE

Unlike Centerville Lake, Peltier Lake has a much larger watershed/surface area ratio (≈140) due to inflow from Rice Creek, Hardwood Creek, and Clearwater Creek. As a result, Peltier has significantly larger inputs of water and phosphorus than Centerville, which leads Peltier to have consistently higher phosphorus concentrations than Centerville. Under typical flow conditions, Centerville Lake flows into Peltier Lake via Centerville Lake’s outlet culvert under CSAH 14 (Main Street) that connects the two lakes. However, under certain conditions such as immediately following a large storm event, the water level of Peltier Lake rises faster than in Centerville Lake and, at a certain point, backflows from Peltier Lake into Centerville Lake.

During these backflow events, water and phosphorus is carried into Centerville Lake from Peltier and serves as a temporary source of phosphorus to Centerville.

The previous Centerville BATHTUB water quality model was constructed with the best available information at the time it was developed but required assumed values for phosphorus load from Peltier Lake backflow and internal loading due to resuspension of phosphorus within the lake. In the intervening time since the TMDL, the Internal Load Investigation was released which quantified the internal loading component of the overall phosphorus load to Centerville Lake.

This study aims to determine the conditions under which backflow from Peltier Lake to Centerville Lake occurs, quantify the phosphorus load from Peltier Lake backflow, and create an updated water quality response (BATHTUB) water quality model for Centerville Lake that incorporates the newly estimated internal loading and Peltier backflow loading to Centerville Lake. The updated lake response model will be instrumental in future decision making and strategic management of Centerville Lake. It will highlight the largest sources of phosphorus to the lake and simulate expected water quality improvement from reducing those phosphorus inputs. The updated BATHTUB model will help identify appropriate management strategies for reducing phosphorus concentrations and improving overall water quality of Centerville Lake. The following describes the data and methodology used to develop the Centerville Lake model and summarizes the results.

3 PELTIER LAKE BACKFLOW ANALYSIS

The District-Wide hydraulic and hydrologic model was reviewed to define the hydraulic relationship between Centerville and Peltier Lakes. Under typical conditions, water flows from Centerville Lake to Peltier Lake via the outflow structure at the north end of Centerville Lake. Under certain conditions, the water level in Peltier Lake rises above Centerville Lake and the water flow is temporarily reversed. For this study, a bi-direction rating curve was created to allow flow between the lakes to be estimated in both directions, under existing conditions. The average annual runoff reaching each lake was determined and the rating curve was then used to estimate the average annual volume exchange between the lakes.

3.1 CONDITIONS THAT LEAD TO BACKFLOW

The conditions that lead to backflow from Peltier Lake to Centerville Lake were determined by developing a water balance model and calculating when backflow occurs based on rainfall event depth. The existing RCWD hydraulic models were used to inform the development of a water balance to determine the occurrence of backflow from Peltier Lake to Centerville. Flows and rating curves for the inflows into the lakes, connection between the lakes, and outflows from the outlet for Peltier Lake for the 2-year and 10-year event were extracted from the RCWD's HEC-RAS models.

3.1.1 THE WATER BALANCE MODEL

A simple water balance model was created to estimate the backflow from Peltier Lake into Centerville Lake based on precipitation depth of a rainfall event. The water balance approach accounts for all of the inflows, outflows, and change in storage of the lakes, and can be expressed as:

$$\text{Inflows} - \text{Outflows} = \text{Change in Storage}$$

The inflows account for any water entering the lake, including tributary flows, direct runoff, precipitation on the lake's surface, and flows through the connection between Centerville Lake and Peltier Lake, if the flow is positive (into Centerville Lake). The outflows account for any water leaving the lakes, including flow through the outlet, evaporation, and flows through the connection between Centerville Lake and Peltier Lake, if the flow is negative (out of Centerville Lake). The water balance approach was used at a storm timescale, short enough that evaporation can be assumed to be zero as it will be significantly smaller than the other inflows/outflows.

The water balance model was developed within Microsoft Excel to estimate the volume of water backflowing to Centerville Lake through the connection with Peltier Lake. It calculates the flow through the system at an hourly timescale for 14 days based on a given precipitation depth. The rating curves, stage-storage curves, and inflow hydrographs used to develop the model are discussed below.

3.1.1.1 RATING CURVES, STAGE-STORAGE CURVES, AND INFLOW HYDROGRAPHS

The rating curves, stage-storage curves, and hydrographs for the various inflows and structures in the lakes were obtained from the RCWD's HEC-RAS models. A brief discussion of each is provided below.

3.1.1.1.1 CONNECTION BETWEEN PELTIER LAKE AND CENTERVILLE LAKE

The discharge through the connection between Peltier and Centerville Lakes was modeled for the 2-year and 10-year storm simulations by the District's HEC-RAS model (**Figure 2**). A rating curve is also presented as the discharge from Centerville Lake to Peltier Lake (or vise-versa) based on the head differential between the two lakes (**Figure 3**).

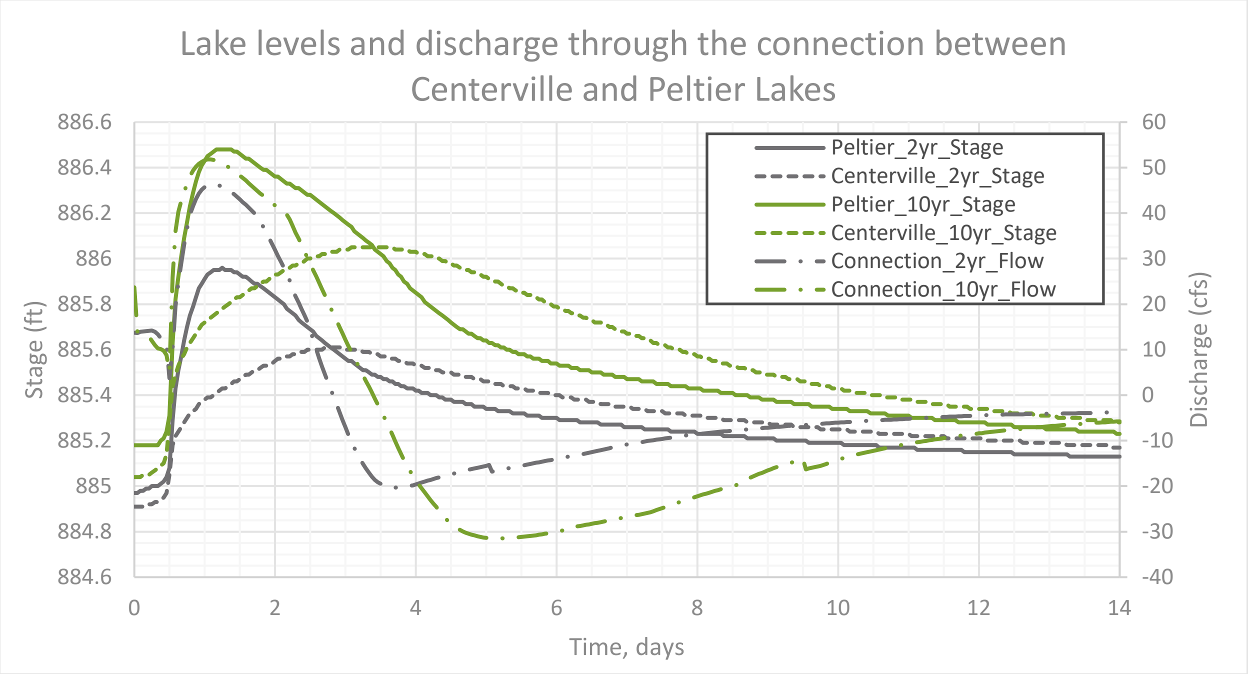

Figure 2. Stage and flows through the connection between Peltier and Centerville Lakes.

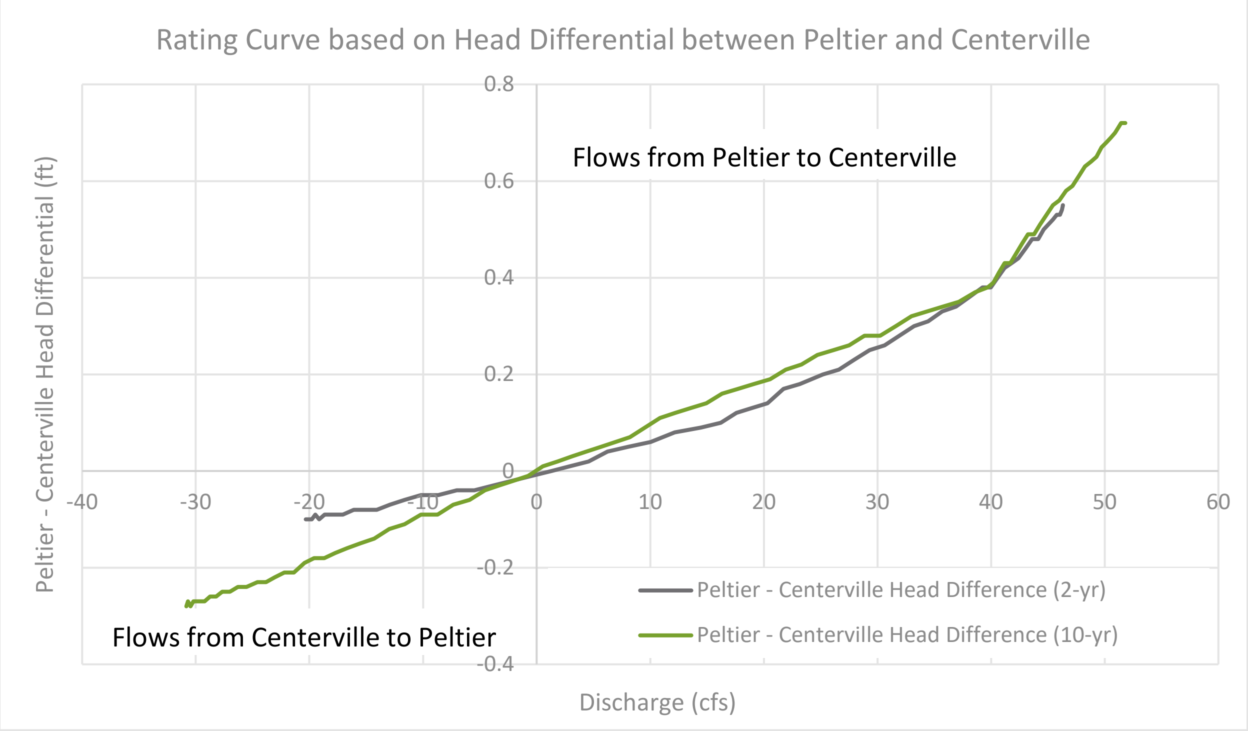

Figure 3. Stage/flow curves based on the elevation difference between Centerville and Peltier Lakes. Positive flows from Peltier to Centerville.

3.1.1.1.2 STAGE-STORAGE CURVES

The stage-storage curve below provides the storage volume of each lake based on its lake surface elevation. **Figure 4** provides the stage-storage relationships for Peltier and Centerville Lakes.

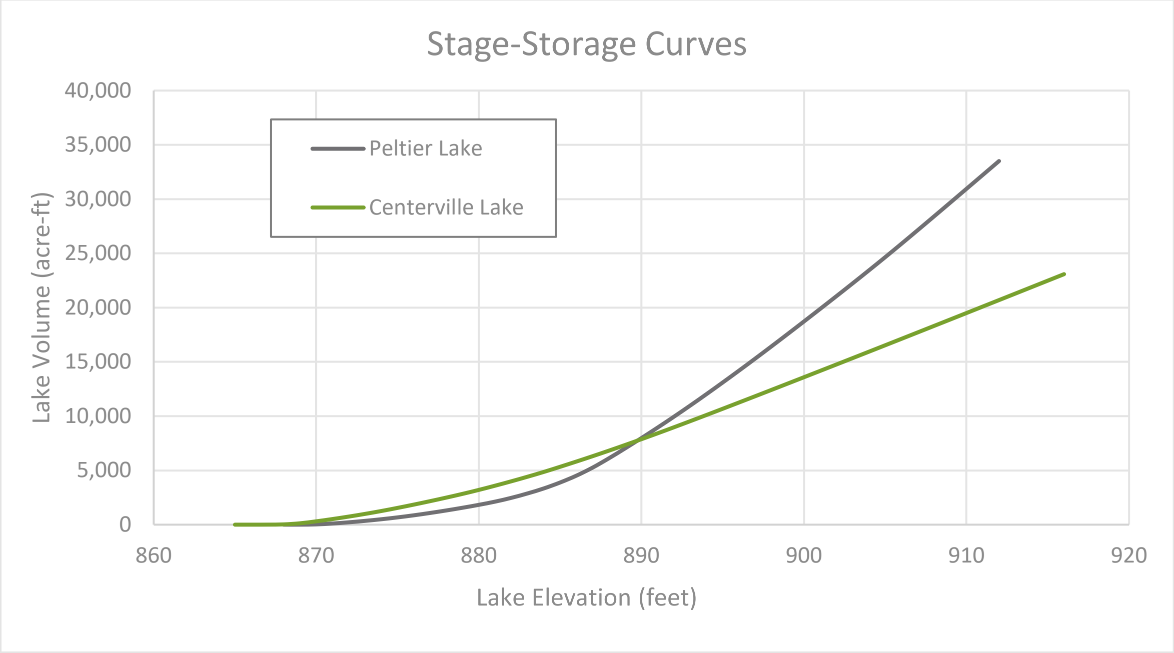

Figure 4. Stage-Storage Curves for Peltier and Centerville Lakes.

The stage-storage curve is used to find the water surface elevations (WSEL) based on the change in storage of each lake. According the MNDNR, the ordinary high-water level (OHW) is 885 feet for Centerville Lake and 884.7 feet for Peltier Lake. The OHW level defines the boundary of the lake and defined as an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape, commonly the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial (MN Statute 103G.005 subd. 14). Because the OHW defines the extent of a lake, the OHW is typically used to define the morphology (i.e., depth and volume of the lake) when modeling a lake to ensure the full extent of the lake is modeled. For the water balance model, the initial lake surface elevation for both lakes are assumed to be 885 feet.

3.1.1.1.3 INFLOW HYDROGRAPHS AND RUNOFF DEPTHS

There are three inflows into the lakes, two for Peltier and one for Centerville Lake. The 2-year and 10-year inflows were extracted from the HEC-RAS model and used to develop hydrographs for the various inflows into the lakes (**Figure 5**). Based on the 2-year and 10-year events, unit hydrographs for each inflow were constructed and are provided in **Figure 6**.

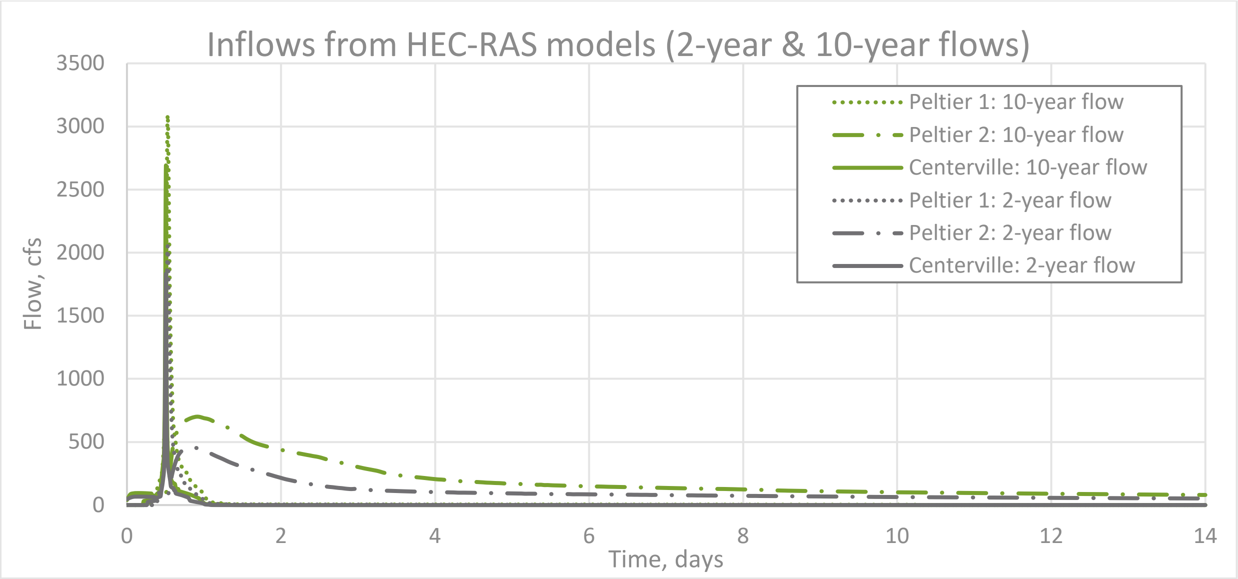

Figure 5. 2-year and 10-year flows for inflows into Peltier and Centerville Lakes.

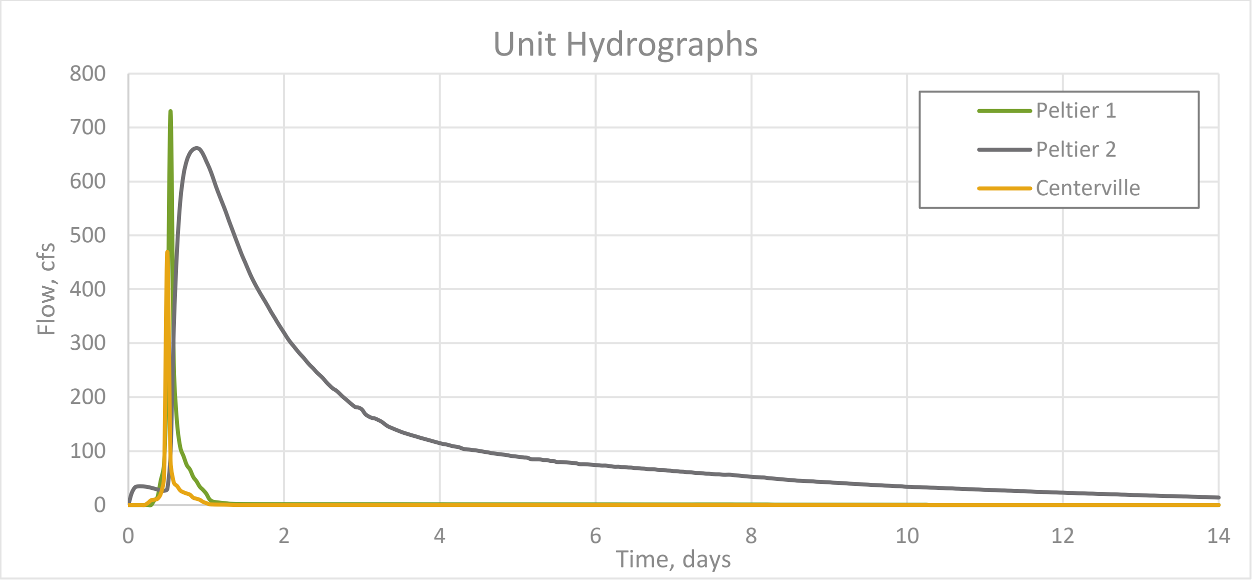

Figure 6. Unit Hydrographs for inflows to Peltier and Centerville Lakes.

3.1.1.1.4 PELTIER OUTFLOWS

The rating curve for the outlet of Peltier Lake was extracted from the HEC-RAS model and is provided in **Figure 7**. Discharge was determined based on water surface elevation of Peltier Lake for the previous timestep within the model output.

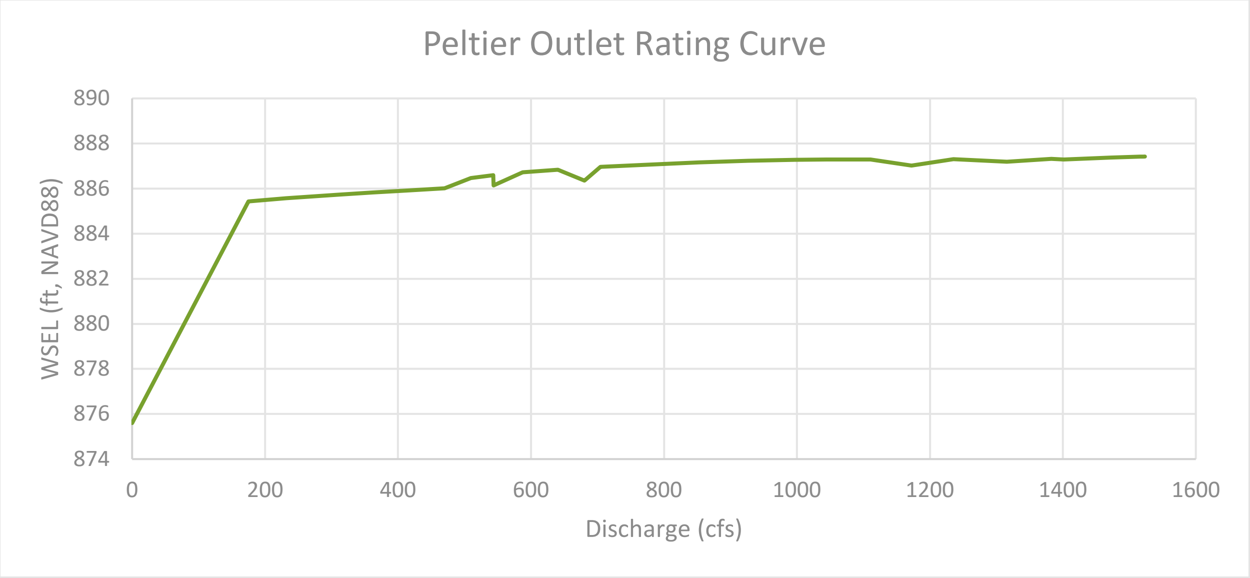

Figure 7. Peltier Lake Outlet Rating Curve.

3.1.2 MODEL RESULTS

The water balance model estimated that backflow into Centerville occurs when the precipitation exceeds 1.9 inches in a 24-hour period. Therefore, the volume of backflow was calculated for daily precipitation events exceeding 1.9 inches, at an incremental increase of 0.01 inches. **Figure 8** shows the resulting backflow volumes for each incremental storm event, from 1.9 inches to 4.1 inches.

To estimate the total annual backflow from Peltier Lake to Centerville Lake, the runoff volumes by rainfall event (**Figure 8**) was applied to the precipitation record. The total number of events above the 1.9 inch threshold for backflow and the total annual backflow volumes are provide in **Table 1**.

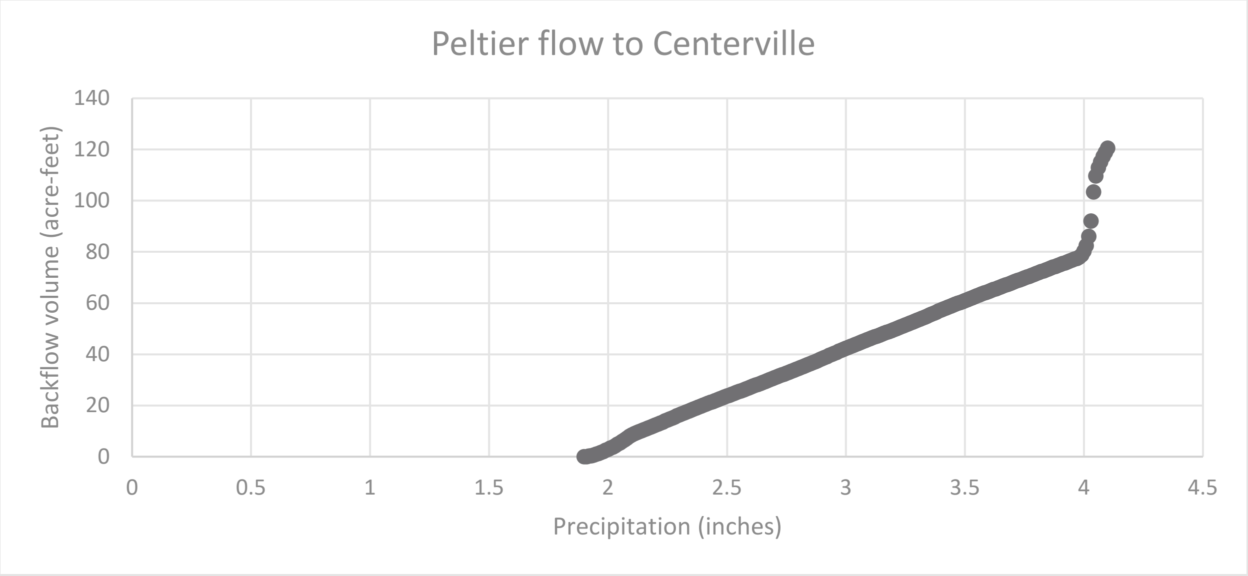

Figure 8. Backflow volumes from Peltier Lake into Centerville Lake, by precipitation depth.

Table 1. Total estimated backflow volumes by year into Centerville Lake, from Peltier Lake.

Year	Number of rainfall events greater than 1.9 inches	Total Backflow Volume (ac-ft)
2007	0	0.0
2008	0	0.0
2009	2	53.4
2010	3	98.3
2011	3	88.3
2012	1	42.7
2013	0	0.0
2014	2	91.4
2015	1	2.5
2016	2	139.7
2017	0	0.0
2018	3	57.0
2019	0	0.0
2020	0	0.0
2021	1	10.8

4 BATHTUB (CNET) LAKE RESPONSE MODEL

Centerville Lake modeling and analysis was conducting using a modified version of the BATHTUB water quality model that is currently available as a “beta” version from Walker (1989). The version of BATHTUB used, called CNET, operates in a spreadsheet environment (Microsoft Excel) which allows for additional functionality above what is capable from the standard BATHTUB download. At their core, the two versions of BATHTUB are similar. BATHTUB is a steady-state water quality model that simulates eutrophication-related water quality conditions in lakes and reservoirs by applying a selection of empirical eutrophication models, formulating water and nutrient balances that account for advective transport, diffuse transport, and nutrient sedimentation.

The standard BATHTUB model utilizes single value data inputs with the option of supplying a coefficient of variation to represent variability in the input data. The version of BATHTUB used for this study is a stochastic BATHTUB model called CNET. Unlike BATHTUB, CNET allows for data series to be input and uses probability distributions of the input data during analysis. Monte Carlo simulation is used to run the model 10,000 times using 10,000 different combinations of inputs, as defined by each input variable’s probability distribution. The benefit of using stochastic simulation over the static BATHTUB model is that model output is provided as a distribution of potential water quality outcomes rather than a few discrete values, and uncertainty in the loading data and modeling outputs can be quantified in a meaningful way over a range of conditions.

4.1 MODEL CONSTRUCTION

The construction of the BATHTUB model began by collecting data to develop water volume and phosphorus mass budgets for Centerville Lake. The water budget is an accounting of the amount of water entering and leaving the lake over a specified time period. It accounts for additions of water to Centerville Lake (e.g., precipitation, surface water runoff, tributary inflow, advection flow, and/or groundwater inflow) as well as losses (e.g., evaporation, surface outflow, and groundwater outflow) from the lake. Each of these affects the total volume of water in Centerville Lake (i.e., storage). The amount of water moving in and out of the lake varies from year-to-year, dictated primarily by the seasonal variation of precipitation occurring in the area. It is important to quantify the water budget because different sources of water can contain different quantities of pollutants, and the amount of water entering and leaving the lake determines the hydraulic residence time which impacts the eutrophication response of the lake. Additionally, the water budget is important because it is used during hydrologic and water quality modeling for model calibration and validation purposes. The water budget components accounted for in this study are:

- **Precipitation** - the amount of water entering Centerville Lake directly from precipitation landing on the lake’s surface;
- **Direct drainage inflow** - the surface water flowing to Centerville Lake from the contributing drainage area;

- **Tributary inflow** - the amount of water flowing into Centerville Lake from upstream basins, usually from stream sources. In the case of Centerville Lake, Tributary inflow is defined as the volume of backflow from Peltier Lake;
- **Evaporation** - the water leaving the surface of Centerville Lake through evaporative processes;
- **Surface outflow** - the water leaving Centerville Lake through surface outlets (e.g. via a stream); and
- **Storage** - the change in the water stored in the lake due to lake level increases or decreases. Any groundwater flows are lumped into direct drainage, tributary flow, and/or outflow. The BATHTUB model is a steady-state model, meaning change in storage is zero.

Similar to the water budget, a phosphorus mass balance was developed for Centerville Lake which accounts for the mass of phosphorus entering and exiting the lake annually. Phosphorus loads (mass per time) are estimated by considering the concentration of phosphorus in the source water and the volume of water entering and exiting the lake from the different sources over the defined time period. The phosphorus mass balance accounts for both “gains” (e.g., surface water runoff) as well as “losses” (e.g., outflows) from the lake. The Centerville Lake phosphorus mass balance incorporates mass loading gains from the direct drainage area, tributary loading (Peltier Lake backflow), atmospheric deposition, and internal loading; and mass losses from sedimentation/retention, advection, dispersion, and outflow. Each of the water and phosphorus mass balance components is discussed in more detail below.

4.1.1 LAKE MORPHOLOGY

The required inputs to the CNET lake model include basic morphology characteristics of Centerville Lake such as surface area, mean depth, and drainage area. **Table 2** lists the required morphometric characteristics for Centerville Lake. The values displayed in **Table 2** are in U.S. customary units and are converted to the international system of units (SI) (i.e., the metric system) for use in the lake model. The primary data sources used for lake morphometric characteristics were the MN DNR LakeFinder website (http://www.dnr.state.mn.us/lakefind/index.html) and a hydrologic assessment of direct drainage area to the lake using the XPSWMM model that was previously created for the area.

Table 2. Morphology of Centerville Lake.

Lake Name	WID	Surface Area (acres)	Average Depth (feet)	Max depth (feet)	Drainage Area (acres)
Centerville	02-0006-00	473.86	12	19	384.24

4.1.2 WATER QUALITY DATA

Water quality data for Centerville and Peltier Lakes were obtained through the RCWD and the MPCA through their Environmental Quality Information System (EQuIS) database and Environmental Data Application (EDA) data portal (https://www.pca.state.mn.us/quick-links/eda-surface-water-data). For this modeling effort, the average water quality condition is taken as the period from 2000 through 2020. **Table 3** provides the number of samples and average (mean) measurements during the sampling period for total phosphorus (TP) and Chlorophyll-a (Chl-a) concentration, and Secchi Disk depths. 96% of the sampling dates were between the months of May and October.

Table 3. Recent lake nutrients conditions in Centerville and Peltier Lakes.

Lake Name	**WID-Station ID(s)**	**Observation Period**	**TP (µg/L)**		**Chl-*a* (µg/L)**		**Secchi Disk Depth (m)**	
			n	**Average**	**n**	**Average**	**n**	**Average**
Centerville	02-0006-00-100, 02-0006-00-202, 02-0006-00-203, 02-0006-00-204,	1990-1991, 2000-2004, 2008-2020	194	**52.9**	171	**28.0**	189	**1.57**
Peltier*	02-0004-00-451	1993-2007, 2009-2015, 2018-2019	212	**210**	--	**--**	--	**--**

* Peltier Lake phosphorus data was needed for estimating backflow load only.

4.1.3 CLIMATE DATA

4.1.3.1 PRECIPITATION DATA

Precipitation data, used to define direct inputs of water to Centerville Lake, as well as to define annual precipitation and runoff trends, were collected from the National Oceanographic and Atmospheric Administration-National Centers for Environmental Information (NOAA-NCEI) (www.noaa.gov) for the atmospheric station at Vadnais Lake (Station USC00218477). For BATHTUB model use, daily precipitation data were aggregated to annual rainfall amount.

4.1.3.2 EVAPOTRANSPIRATION DATA

Evapotranspiration data was collected from the US EPA BASINS system. The BASINS data uses the North American Land Data Assimilation Systems (NLDAS; https://ldas.gsfc.nasa.gov/nldas) gridded meteorological datasets. These datasets are hourly climate data at a 4 km grid across North America and are downloaded through the BASINS platform. Daily potential evapotranspiration data was gathered, and a 0.7 multiplier (estimated evaporation pan coefficient) was used to estimate daily evaporation. Daily evaporation values were aggregated to annual values which were then used as inputs for the BATHTUB model.

4.1.4 ATMOSPHERIC PHOSPHORUS LOAD

Atmospheric deposition refers to the phosphorus deposited directly to the surface of Centerville Lake from the atmosphere. This include phosphorus that enters the lake contained within rain droplets (wet deposition) and particulate phosphorus that is windblown (dry deposition). The rate of atmospheric deposition of phosphorus onto Centerville Lake was estimated to be 0.36 lb/ac/yr, the value presented in the MPCA's state-wide phosphorus study for the upper Mississippi area (Barr, 2007). More specifically, that value represents the 2007 atmospheric deposition estimates.

4.1.5 DIRECT DRAINAGE PHOSPHORUS LOAD

The amount of water and phosphorus entering Centerville Lake from its direct drainage (non-tributary) area was estimated using a combination of geospatial data and runoff coefficients. The direct drainage area was defined using the existing InfoSWMM (version 13.0 Service Pack 1 Update #2) catchment delineations by selecting and aggregating catchments that drain to Centerville Lake. The selected drainage area for the lake has been informed by local knowledge of culverts, ditches, etc. and is a reasonable approximation of the contributing runoff area to the lake.

For the TMDL, it was assumed that direct drainage to Centerville Lake would match runoff depth and phosphorus concentrations measured in the tributary streams to Peltier Lake. However, the land use distributions within the contributing area to each tributary to Peltier Lake are different enough from the land use within the drainage area of Centerville Lake to justify a more extensive investigation. 2019 national land cover database (NLCD) data was used to quantify land use types within the RCWD. Land use comparison of Centerville Lake to the three major tributaries to Peltier Lake is provided in **Table 4**. The area that drains to Centerville Lake has a much higher proportion of developed land than the tributaries that drain to Peltier Lake, and less agricultural land, which could greatly affect the volume of water and mass of phosphorus leaving the landscape within the direct drainage area, as compared to the Peltier Lake tributaries.

Table 4. Land use within Centerville Lake direct drainage and Peltier Lake tributaries.

	Centerville Lake Direct Drainage	**Clearwater Creek**	**Hardwood Creek**	**Upper Rice Creek**
Total Area (mi^2)	1.36	43.2	28.7	30.3
Percentage of watershed land area*				
Developed, Open Space	20.9	15.8	4.1	7.6
Developed, Low Intensity	27.9	15.1	3.2	6.4
Developed, Medium Intensity	18.7	8.9	1.5	5.8
Developed, High Intensity	2.1	2.0	0.2	2.3
Barren	0.0	0.0	0.0	0.1
Deciduous Forest	4.5	8.8	10.7	9.4
Evergreen Forest	0.6	1.3	1.0	1.0
Mixed Forest	0.7	5.1	3.2	1.0
Shrub	0.0	0.1	0.2	0.0

Grassland	0.5	0.7	0.6	0.3
Hay/Pasture	11.1	20.5	37.6	12.3
Cultivated Crops	0.3	7.7	13.3	11.0
Woody Wetlands	0.4	3.0	4.7	6.1
Emergent Herbaceous Wetlands	12.4	11.1	19.8	36.8

* Open water area excluded

4.1.5.1 RUNOFF VOLUME

Runoff coefficient within the direct drainage to Centerville Lake was defined based on an analysis of 2019 NLCD land use, hydraulic soil group, and landscape slope (**Table 5**) as outlined in the Minnesota Pollution Control Agency (MPCA) Minnesota Stormwater Manual (https://stormwater.pca.state.mn.us/index.php/Main_Page). The land area was segmented into distinct areas with each land use/soil/slope combination and then area-weighted to produce a single aggregated runoff coefficient for the entire area. That aggregated runoff coefficient (0.282) was multiplied by the annual precipitation volume to estimate total overland runoff delivered to Centerville Lake for each year of precipitation data.

Table 5. Runoff coefficients for land use/soil/slope combinations present within the direct drainage area of Centerville Lake.

	Hydrologic Soil Group A			**Hydrologic Soil Group B**			**Hydrologic Soil Group C**			**Hydrologic Soil Group D and Combination Soils**		
Land Use Class \ Slope	**>2%**	**2-6%**	**>6%**	**>2%**	**2-6%**	**>6%**	**>2%**	**2-6%**	**>6%**	**>2%**	**2-6%**	**>6%**
Developed, Open Space	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.16	0.21	0.28
Developed, Low Intensity	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
Developed, Medium Intensity	0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
Developed, High Intensity	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Deciduous Forest	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
Evergreen Forest	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
Mixed Forest	0.05	0.08	0.11	0.08	0.11	0.14						
Herbaceous				0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
Hay/Pasture	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
Cultivated Crops										0.18	0.23	0.31
Woody Wetlands				0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
Emergent Herbaceous	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40

4.1.5.2 PHOSPHORUS LOAD

Phosphorus loading from the landscape was estimated similarly, using land use-based phosphorus loading coefficients also obtained from the Minnesota Stormwater Manual (**Table 6**). The area of each land use type within the direct drainage area were determined and then the runoff yield values were applied. An estimated 299.4 lbs/yr of phosphorus is delivered from the direct drainage area to Centerville Lake under "typical" precipitation conditions. Annual loading values were then estimated by scaling the typical loading rate by the ratio of annual precipitation to average annual precipitation from the 20 years of record.

Table 6. Phosphorus yield estimates for each NLCD land use type present within the direct drainage area of Centerville Lake.

Land use	Phosphorus Runoff Yield (lb/ac/yr)
Developed, Open Space	0.40
Developed, Low Intensity	1.10
Developed, Medium Intensity	1.30
Developed, High Intensity	2.00
Deciduous Forest	0.13
Evergreen Forest	0.13
Mixed Forest	0.13
Herbaceous	0.10
Hay/Pasture	0.70
Cultivated Crops	2.20
Woody Wetlands	0.10
Emergent Herbaceous Wetlands	0.10

4.1.6 PELTIER BACKFLOW (TRIBUTARY) PHOSPHORUS LOAD

Water volume and phosphorus mass loading from Peltier Lake to Centerville Lake was able to be estimated once the bi-directional rating curve was created between the lakes. It was determined that any storm event that results in greater than 1.91 inches of rainfall causes the level of Peltier Lake to rise above that of Centerville enough to result in backflow from Peltier to Centerville.

The estimated volume of backflow water for each incremental (0.01 inch) simulated storm event greater than 1.91 inches was calculated and those volume estimates were applied to the precipitation records. Each daily precipitation record with greater than 1.91 inches was assigned the corresponding backflow volume to determine the volume of Peltier Lake water flowing into Centerville Lake.

While the District-Wide Model provides the volume of water backflowing from Peltier to Centerville Lake, the phosphorus concentration of the water in both lakes is necessary to determine the loading. Existing water quality monitoring data was analyzed to determine the phosphorus concentration of each lake throughout the year. Lake water phosphorus concentration data for Centerville and Peltier Lakes were obtained through the RCWD. The initial data received was supplemented with additional data from the MPCA through the EQuIS database and EDA data portal.

The measured phosphorus concentration from Peltier Lake nearest in time to each backflow event was applied to the calculated volume so that the advective phosphorus load from Peltier Lake to Centerville Lake could be determined for each individual storm event. Events were summed by year to determine total annual phosphorus load (advective) from Peltier Lake to Centerville Lake (**Table 7**).

Longitudinal dispersion of phosphorus was also estimated for diffuse transfer from Peltier Lake to Centerville Lake. A dispersion equation outlined in Fischer et al. (1979) and adapted by Walker (1985), not adjusted for numeric dispersion, was used to estimated diffusive flow through the connection between the lakes and estimate diffuse phosphorus load. The equation considers flow between the lakes, length and cross-sectional area of the connecting culvert, and the mean advective velocity through the culvert to estimate diffusive movement of water between the lakes. The annual diffuse volume transferred into Centerville Lake was multiplied by the annual average difference in concentration between the two lakes to determine the annual diffuse load of phosphorus. Diffuse and advective loads were summed to arrive at the annual loading from Peltier Lake to Centerville Lake (**Table 7**).

Table 7. Annual advective and Diffuse Loading from Peltier to Centerville Lake

Year	backflow (ac-ft)	Advective TP load from Peltier to Centerville (lbs)	Centerville Ave TP conc (ug/L)	Peltier Ave TP conc (ug/L)	TP Difference (ug/L)*	Diffusive load (lbs)	Total Backflow load (lbs/yr)
1999	43.861	35.4	51.8	101.3	49	0.31	35.7
2000	52.810	52.5	51.5	157.9	106	0.67	53.2
2001	29.222	14.6	44.4	250.8	206	1.34	15.9
2002	53.403	23.9	28.0	160.8	133	0.84	24.7
2003	3.316	0.8	58.8	138.5	80	0.53	1.3
2004	22.459	11.9	49.5	180.1	131	0.86	12.8
2005	74.732	64.6	51.8	209.1	157	0.97	65.6
2006	37.430	24.1	51.8	258.6	207	1.33	25.4
2007	0.000	0.0	51.8	214.8	163	1.09	1.1
2008	0.000	0.0	46.1	166.4	120	0.8	0.8
2009	0.000	0.0	41.8	197.5	156	1.04	1.0
2010	8.485	5.0	59.6	169.7	110	0.73	5.7
2011	20.826	8.7	37.5	141.3	104	0.68	9.4
2012	40.352	12.1	38.8	197.0	158	1.02	13.1
2013	10.485	3.1	50.3	154.9	105	0.69	3.8
2014	12.549	4.3	58.0	141.9	84	0.55	4.8
2015	52.297	12.1	52.8	95.4	43	0.27	12.4
2016	138.034	68.5	63.1	139.8	77	0.44	68.9
2017	2.879	2.2	66.5	161.4	95	0.63	2.8
2018	51.565	22.2	54.6	135.0	80	0.51	22.7
2019	10.574	5.9	52.7	127.2	74	0.49	6.4
2020	2.879	0.9	78.6	161.6	83	0.56	1.4

* positive value suggests diffusive flow from Peltier into Centerville (and vice versa)

4.1.7 INTERNAL PHOSPHORUS LOAD

Internal loading is the re-release of phosphorus from lakebed sediments, which is typically a result of one or more chemical or physical mechanisms within the lake. Anoxic conditions (dissolved oxygen concentrations < 2.0 mg/L) near the lakebed can chemically release phosphorus back into the lake water that had been chemically bound (adsorbed) to the lake sediments. Bottom-feeding fish such as bullhead and carp (present in Centerville Lake) foraging along the lake bottom, and other physical disturbances in shallow depths such as wave action from wind energy and motorized boats that resuspend lake sediments can all reintroduce phosphorus back in the water column. Internal phosphorus loading can be a substantial part of the mass balance in any lake, especially in lakes with a history of high phosphorus loads. In fact, if a lake has a long history of high phosphorus concentrations, it is possible to have internal loading rates higher than external loads.

According to the Internal Load Investigation for Centerville Lake (Wenck, 2019) 278 lbs of phosphorus is released from the lake sediments back into the water column annually within Centerville Lake. This is a considerable amount of phosphorus being internally re-released into the water annually.

4.1.8 SURFACE OUTFLOW PHOSPHORUS LOAD

The mass of phosphorus exiting Centerville Lake through the outflow culvert is known as surface outflow load and was calculated by taking the in-lake phosphorus concentration and applying it to the lake’s outflow volume. This is not an input to the CNET model but is provided in as an output for review. Estimated phosphorus mass leaving Centerville Lake via the outflow culvert is 16.1 lb/yr.

4.1.9 CALIBRATION

The BATHTUB model relies on a variety of sub-models (i.e., empirical equations for estimating phosphorus sedimentation, chlorophyll-a concentration, and secchi disk depth) for computing eutrophication dynamics within a lake, providing the ability to simulate eutrophication dynamics with differing in-lake processes. Phosphorus, Chlorophyl-a, and Secchi disk depth each have several models to choose from when calibrating the BATHTUB model.

The modeling period for the Centerville Lake model was 1999 through 2020. All available in-lake water quality data were used in calibrating the Centerville Lake model. The model was calibrated to the period-averaged condition (**Table 8**) and individual years were used to validate the models (**Table 9**). The average condition was used to calibrate the models due to the variability in precipitation and water quality data over the modeled period. An annual scale was used to develop the precipitation, inflow, and phosphorus loading inputs to simulate water quality within the Centerville Lake BATHTUB model.

Table 8. Calibration results (Average)

Water Quality Parameter	Observed Value	Modeled Value
TP (ug/l)	51.6	51.6
Chl-a (ug/l)	27.1	27.1
Secchi Disk Depth (m)	1.57	1.57

Table 9. Validation results (2015)

Water Quality Parameter	Observed Value	Modeled Value
TP (ug/l)	52.8	51.6
Chl-a (ug/l)	28.0	27.1
Secchi Disk Depth (m)	2.23	1.57

4.2 RESULTS AND DISCUSSION

Total phosphorus loading to Centerville Lake was estimated to be 767 pounds per year, with nearly 40% from direct drainage inputs and a third from internal cycling of phosphorus already contained within the lake (**Table 10, Figure 9**).

Table 10. Average Annual Loading Summary to Centerville Lake

Phosphorus Source	Total Phosphorus Load (kg/yr)	Total Phosphorus Load (lbs/yr)	Percent of Total Load
Atmospheric Deposition	78	172	22%
Direct Drainage	136	299	39%
Backflow from Peltier	8	18	2%
Internal Loading	126	278	36%
Point Sources	0	0	0%
Groundwater Discharge	*	*	*
Total	348	767	100%

*Negligible

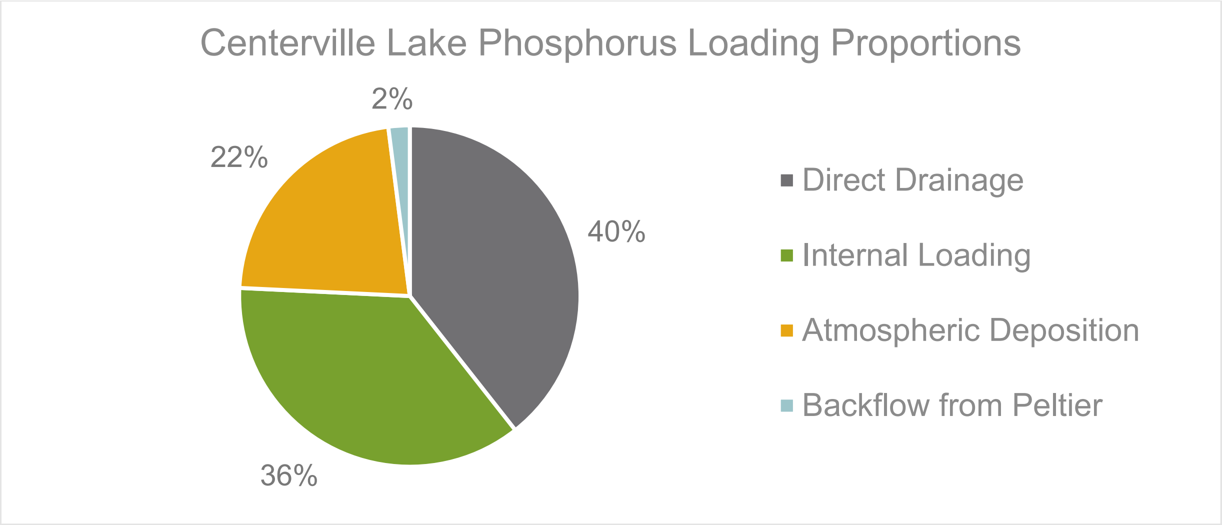

Figure 9. Centerville Lake Phosphorus Loading Proportions.

Peltier Lake makes up only 2% of the phosphorus loading to Centerville Lake. Even with further refinement of phosphorus loading estimates from the various sources, direct drainage, internal loading, and atmospheric deposition will likely remain the only major sources of phosphorus to the lake.

Under typical conditions, backflow from Peltier Lake is minimal, which minimizes negative water quality impacts to Centerville despite the significantly elevated phosphorus concentrations found within Peltier Lake. But backflow must still be considered when making future management decisions. The very long hydraulic residence time and small outflow phosphorus load from Centerville (**Appendix A: Table 1**) suggest that any significant additions of phosphorus to Centerville Lake could remain in the lake for extended periods of time and could negatively affect water quality.

Saint Paul Regional Water Service had historically pumped water from Centerville Lake but has not withdrawn water from Centerville Lake since 1992 (Bolton and Menk, 2018). If the decision were made to begin pumping water from Centerville Lake at some point in the future, that could lead to significantly more backflow events from Peltier Lake into Centerville Lake. If pumping rates were high enough to lower the level of Centerville Lake relative to Peltier Lake, backflow to Centerville could become continuous. This could lead to a continual influx of water and phosphorus into Centerville Lake.

To reverse the declining water quality trend in Centerville Lake, efforts must be focused on treating direct drainage to Centerville Lake and internal loading in the lake. The RCWD and the City of Centerville have partnered together on prior projects to address untreated runoff into the lake, and continued collaboration on retrofit projects will collectively provide significant value, though it will take many of these projects to change lake trends. The most impactful way to address phosphorus loading may be to address the internal loading to the lake.

5 HISTORIC BACKFLOW

The St. Paul Regional Water Service (SPRWS) had historically utilized Centerville Lake as a source of water. Records indicate that raw water was drawn from the Centerville system 62 years during the 121-year record (1897 to 2018) (Bolton and Menk, 2018), with 1988 being the last year for any water withdrawal, according to SPRWS. The Centerville pumps provided a nominal capacity of 40 MGD (122.8 acre-ft/day). Pumping water from Centerville Lake would create conditions were backflow from Peltier Lake would occur more frequently than current conditions, as modeled above.

To determine the magnitude of backflow when the Centerville pumps were functional, an analysis was conducted on pump records and lake level records for 1988, the year both were available from SPRWS. The following assumptions were made to determine the historic backflow:

- Prior to 2007, there were three pipes connecting the lakes, but little information is available at the time of this study. The three connections included the current connection and two 36-inch RCPs. The two 36-inch RCP were removed in 2007. The current rating curve (relationship between lake level and flow) for the connection between Centerville and Peltier Lakes was used to determine flow between the two lakes. This assumption is conservative, considering only the current, existing connection and ignoring the other two connections, and could lead to an underestimation of the backflow. To address this, a water budget was preformed to see if the backflows were realistic.
- To estimate phosphorus in the backflow flow, the average total phosphorus concentration for Peltier Lake (166 µg/L) was assumed a constant concentration in 1988.

Figure 10 shows the lake surface elevations for Centerville and Peltier Lakes, the difference between the lake surface elevations (positive means Peltier is higher), water pumped from Centerville Lake pumping station, and estimated flow through the connection with positive flows flowing into Centerville Lake. As shown in Figure 10, Peltier Lake is higher than Centerville Lake for most of the year, creating conditions for water to flow from Peltier Lake to Centerville Lake. It should be noted, the lake surface elevation for Peltier Lake from July 11, 1988, through the remainder of the year look off, with lake elevations held constant for three periods. The flow volumes for this period (July 11, 1988 to December 29, 1998) tended to cancel out, with overall slightly more water flowing out of Centerville Lake than into the lake. Because these flow balance each other out, there were included in the analysis to get a picture of the whole year. The estimated backflow, outflow, and phosphorus load to Centerville Lake for 1988 is as follows:

- Flow from Peltier Lake to Centerville Lake (backflow): 10,718 acre-feet/year;
- Flow from Centerville Lake to Peltier Lake (outflow): 5,087 acre-feet
- Phosphorus load from Peltier Lake to Centerville Lake: 4,850 lbs/year

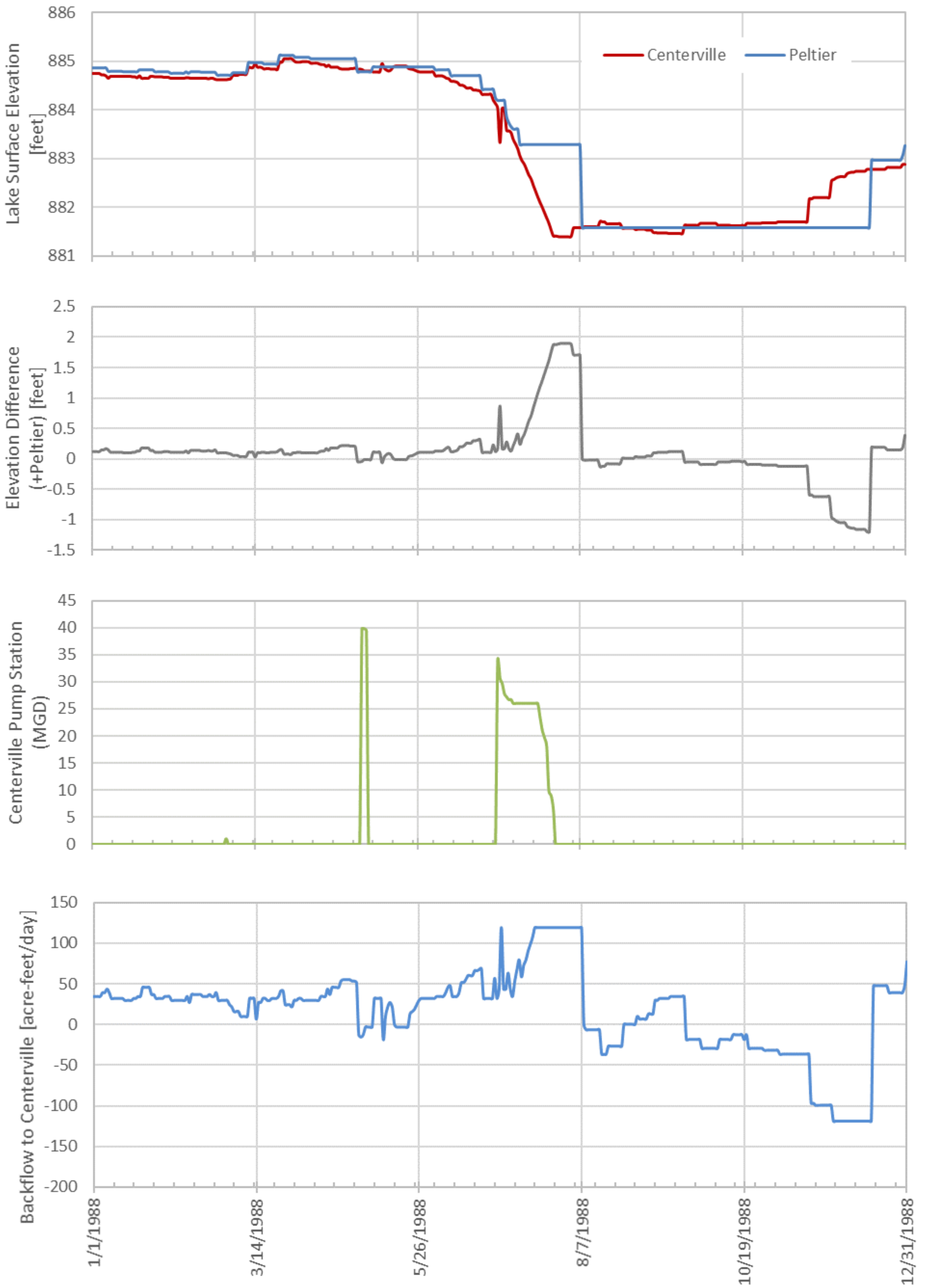

Figure 10. Lake elevations, water withdrawals, and backflow flows in Centerville Lake for 1988.

To account for the uncertainty in the rating curve for the connection between Peltier and Centerville Lake, a range of 50% to 150% should be considered. This provides a range of phosphorus loading to Centerville Lake from Peltier Lake of 2,425 lbs/year to 7,275 lbs/year. Even at the lower part of this range (2,425 lbs/year), the phosphorus load from Peltier Lake to Centerville Lake is much higher than the current estimated total load (see Table 10). Not all this phosphorus stayed in the lake, some flowed back to Peltier Lake when the flow direction changed, some was removed through the Centerville pumps, but some of it settled into Centerville Lake and most likely the cause of the internal loading in the lake.

To check the validity of assumptions, a water balance was performed. To estimate the water balance, a runoff volume, a precipitation/evaporation difference, and groundwater flow assumptions were necessary. The runoff volume was taken as the runoff volume used for the BATHTUB modeling, or ~308 acre-feet of water per year. The precipitation/evaporation difference was assumed to be typical of lakes the region, or about 15 inches more annual evaporation than annual precipitation, which equals about 592 acre-feet more of water per year leaving Centerville Lake than is entering the lake through precipitation. For groundwater flow, it was assumed to be negligible and assumed zero. Accounting for the estimated inflows and outflows through the connection, water extracted by the SPRWS, and the volume change in the lake through the year, the water balance showed an excess of 3,914 acre-feet/year of water in Centerville Lake, unaccounted for by the water balance. This excess of water means either the assumption of negligible groundwater flows is wrong or the assumed flows through the connection are too high, for at least 1988.

As for groundwater infiltration, it is assumed negligible. There is no information on magnitude of groundwater recharge from Centerville Lake, or even if the lake is a source of groundwater recharge for the underlying aquifer. Most likely there is some groundwater recharge but without monitoring or a hydrogeological study, it will remain unknown. As for the flow between the connection, some factor can cause discrepancies between the assumed flows and the water balance. First, the current rating curve was assumed good enough to estimate the flows between Peltier and Centerville Lakes. Although the two 36-inch RCPs were basically ignored when determining a rating curve for the connect, adding them would have only increased the excess water since they would have increased the potential flow rate between the lakes because of the increased number of connections. Alternatively, the assumed flow rates between the lakes could be an overestimation due to blockages in the pipe. Sediment could have accumulated in or at the inlet or outlet, restricting the flows between the lakes, reducing the annual volume of backflow and outflow from/to Centerville Lake.

Regardless of the cause of excessive flow volume into Centerville Lake, the flows through the connection were adjusted to balance the water budget of the system to see what impact it has on the phosphorus entering Centerville Lake. The water budget balanced when the connecting flows were reduced to 30.5% of the assumed flow rates. At 30.5% flow rate, 3,269 acre-ft of water flowed form Peltier Lake to Centerville Lake. At the assumed concentration, this resulted in 1,479 lbs/year of phosphorus entering Centerville Lake. Although lower than the unadjusted flow rate scenario, this phosphorus loading is still twice of the total phosphorus budget used to develop the current conditions model.

In conclusion, although there is high uncertainty in the backflow and phosphorus loading from Peltier Lake, it has been shown that the magnitude of phosphorus loading was much higher than all the current sources combined. Much of high phosphorus likely settled in Centerville Lake and resulted in the significant internal loading rates the lake is currently experiencing. Therefore, if the internal loading of phosphorus is treated, it is most likely not going to return due to the reduced backflow from Peltier Lake and reduction in a large source of external loading to the lake.

6 APPENDICES

Table 1. Lake Model Summary for Centerville Lake (02-0006-00).

Lake Name:	Centerville		**WID:**	02-0006-00	
Eco-region:	NCHF		**Depth Class:**	Deep	
Models, Calibration Coefficients, and Predicted & Observed Values					
Parameter	**Model**	**Calibration Coefficient**	**Observed**	**Predicted**	**Units**
Phosphorus	CB-LAKES	0.983	51.6	51.6	ppb
Chlorophyll-a	P L Q	1.125	27.1	27.1	ppb
Secchi Disk Depth	Chla & Turb	1.19	1.57	1.57	m
Overall Water and Nutrient Balances					
Overall Water Balance		Averaging Period =		1	year
	Flow	**Units***	**%Total**		
Precipitation Flow	1.51	hm3/yr	79.5%		
Specified Flow	0.35	hm3/yr	18.4%		
NonPoint Flow	0.00	hm3/yr	0.0%		
Point Flow (Backflow)	0.04	hm3/yr	2.1%		
Total Inflow	1.90	hm3/yr	100.0%		
Evaporation	1.76	hm3/yr	92.6%		
Outflow	0.14	hm3/yr	7.4%		
Overall Phosphorus Mass Balance					
	Load		**%Total**	**Conc.**	
Precipitation Load	78	kg/yr	20.3%	52	ppb
Specified Load	296	kg/yr	77.1%	846	ppb
NonPoint Loading	0	kg/yr	0.0%	0	ppb
Point Load (Backflow)	10	kg/yr	2.6%	250	ppb
Total Load	384	kg/yr	100%	202	ppb
Sedimentation	377	kg/yr	98.2%		ppb
Outflow	7	kg/yr	1.8%	50	ppb
Model Information					
Reservoir Volume (hm3):	7.014		Retention Coefficient:		3.932
Hydraulic Residence Time (yrs):	51.009		Reservoir P Conc (ppb):		53.9
Overflow Rate (m/yr):	0.1		Mass Residence Time (yrs):		0.985
Inflow P Conc (ppb):	2792.2		Turnover Ratio:		1.016

* hm3 = cubic hectometer (1,000,000 m^3)

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Technical Memorandum

To: Matt Kocian, Rice Creek Watershed District
From: Joe Bischoff, Senior Aquatic Ecologist
Subject: FINAL Alum Longevity in Centerville Lake
Date: February 28, 2023
Project: 23621454

The purpose of this technical memorandum is to assess how long an alum treatment in Centerville Lake could be expected to last.

Background

Centerville Lake is a high priority lake for management in the Rice Creek Watershed District that has undergone numerous diagnostic studies and management actions to improve water quality. Internal phosphorus loading has been under particular scrutiny since the lake weakly stratifies and has responded to an alum dose in the past even tough it was a very light dose compared to modern alum treatments. However, poor water quality persists in Centerville Lake.

Summer average total phosphorus concentrations continue to exceed state water quality standards in Centerville Lake with the past three years demonstrating particularly high phosphorus concentrations (Figure 1). The high P concentrations resulted in severe, nuisance algae blooms in the lake with summer average chlorophyll-a concentrations almost tripling state water quality thresholds. These poor water quality conditions and high P concentrations persist despite District efforts to reduce watershed P loading suggesting that sediment P release may be a large P source to the lake and an in-lake P control project is likely required to improve water quality in the lake.

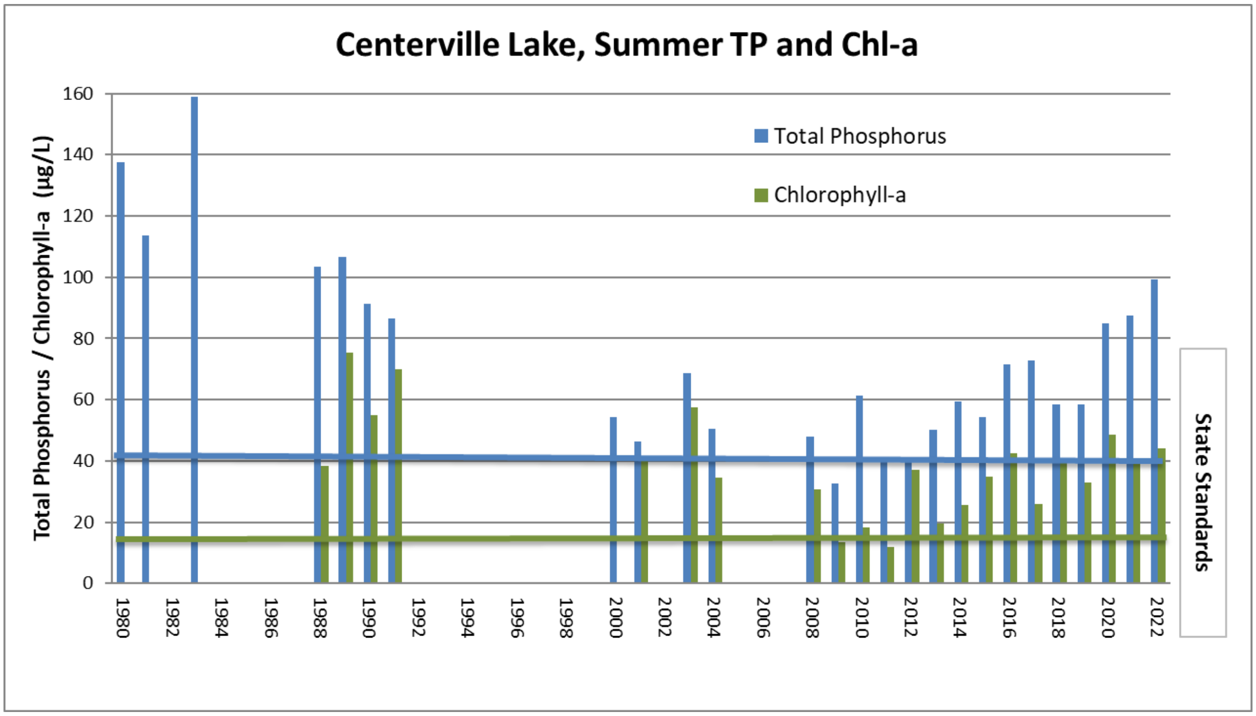

Figure 1. Summer growing season total phosphorus and chlorophyll-a concentrations in Centerville Lake. Figure provided by the Rice Creek Watershed District.

Assessing Alum Longevity

While alum treatments on lakes to inactivate sediment P can be traced back to the 1970s, significant advancements occurred over the last decade in application strategies and dosing techniques. Early applications were simply dosed by calculating the capacity of the water column to buffer the treatment to maintain pH above 6 to prevent aluminum toxicity. In the late 1990s, Rydin and Welch (1998; 1999) developed a technique using sediment chemistry to calculate the amount of aluminum required to inactive mobile P fractions in lake sediments. This research led to numerous improvements in dosing including predicting required Al:P ratios based on sediment redox-P (James and Bischoff 2015), addressing labile P in sediments (Kuster et al. 2020), and other techniques (Agstam-norlin et al. 2020). Because of the rapidly changing approaches in developing alum doses and application strategies, it can be difficult to evaluate historical alum treatments to estimate longevity for new treatments.

The most comprehensive assessment of the factors affecting the longevity of an alum treatment was conducted by Huser et al. (2016) where the researchers evaluated historical alum treatments to determine the most important factors affecting longevity. Looking back in time and including lakes dosed with outdated approaches, alum treatments lasted between 0 and 45 years, a broad range in effectiveness. The study determined that the alum dose, watershed:lake area ratio, and Osgood Index (OI; a measure of shallowness) were the most important factors affecting longevity. It should be noted that the OI only described 3% of the variability in the model and many of the included lakes were not dosed using modern techniques. Instead, the OI should be viewed as a surrogate for the many factors beyond P loading that can affect water quality in shallow lakes including carp, aquatic plants, and other biological interactions. Sediment P inactivation has been used a tool for shallow lake restoration in several local lakes. This study suggests that alum can last a long time if dosed appropriately and watershed loading, and subsequent burial of the alum layer, are addressed.

The above factors were evaluated to estimate alum longevity in Centerville Lake.

Lake Morphometry

Centerville Lake is a relatively small, shallow lake with a very small watershed (Table 1). The low watershed to lake area ratio suggests the lake is a good candidate for alum since watershed phosphorus loading should be low. The Osgood index does suggest it is a relatively shallow polymictic lake, however with an average depth of 12 feet, the lake is deep enough to limit wind disturbance of the sediments. Osgood index values less than 6 typically represent polymictic lakes with values greater than 6 indicating strong stratification is likely to occur.

Table 1 Centerville Lake characteristics.

Parameter	Centerville Lake
Surface Area (acres)	474
Drainage Area (acres)	384
WA:SA ratio	0.8
Average Depth (feet)	12
Maximum depth (feet)	19
Osgood Index	2.6

Alum Dose

The most important factor affecting alum longevity is the development of an accurate dose required to inactivate mobile P in lake surficial sediments. Centerville Lake was treated with alum in 1998 using an effective dose of 18 g Al/m^2 (Huser et al. 2016). The dose applied in 1998 was based on the water column's capacity to buffer aluminum sulfate to maintain a pH above 6 and not mobile P in the sediments. Since the dose was so low and didn't account for mobile P in the sediment, Huser et. al. (2016) estimated that the alum treatment only lasted less than 1 year. This dose is significantly less than more recent alum treatments where sediment chemistry was used to determine the amount of aluminum required to activate mobile P in the sediments (Table 2). Recent alum doses calculated using James and Bischoff (2015), James (2011) and jar testing ranged between 73 and 180 g Al/m^2 suggesting that Centerville Lake was grossly under dosed in 1998. Wenck (2019) collected sediment cores from Centerville Lake and estimated an alum dose using James and Bischoff (2015) and determined that 60 g Al/m^2 is required to inactive redox P in the upper 4 centimeters of sediment to reduce sediment P loading. Even this dose is on the low end of alum doses calculated for other lakes and may underestimate the required aluminum to effectively minimize internal loading. It's possible that dosing may need to account for deeper sediments (4 to 6 centimeters) increasing the overall cost of the treatment.

Table 2 Recent alum (as Al) dosages for various lakes.

Lake	Al Dose (g Al m^{-2})	Reference
Centerville Lake	**18**	**Huser et al. 2016**
Susan Lake[1]	160-180	(unpubl. data)
Rice Marsh Lake[2]	100-125	(unpubl. data)
Lake Riley	100	(unpubl. data)
Bald Eagle, MN	100	(unpubl. data)
Black Hawk, MN	145	(unpubl. data)
Holz Lake, MN	145	(unpubl. data)
Thomas Lake, MN	167	(unpubl. data)
Bald Lake, MN	108	(unpubl. data)
Como Lake, MN	73	(unpubl. data)
Tiefwarensee, Germany	137	Wauer et al. (2009)
East Alaska, WI	132	Hoyman (2012)
Half Moon, WI[3]	115	James (2011)
Susser See, Germany	100	Lewandowski et al. (2003)
Green, WA	94	Dugopolski et al. (2008)

[1] Over the upper 4-cm sediment layer
[2] Over the upper 10 to 12.5 cm sediment layer
[3] West and east arm dosages were 150 and 75 g/m^2, respectively

Unfortunately, few polymictic lakes treated with alum using modern dosing techniques were available to estimate longevity in the Huser et al. (2016) study. Polymictic lakes dosed using sediment chemistry and treated after 2000 demonstrate a broad range of estimated longevity (Table 3). Green Lake and Långsjön Lake are most similar to Centerville Lake with low WA:LA ratios and a calculated dose greater than 60 g Al/m^2. These lakes demonstrated positive water quality effects for 8 and 16 years following their alum treatments respectively. Banana Lake had a high WA:LA ratio which may account for the short longevity of that alum treatment. Both Sunfish Lake and Centerville Lake were likely underdosed resulting in limited water quality benefits.

Table 3 Polymictic lakes dosed and treated with alum since 2000 included in the Huser et al (2016) study.

Lake	Al Dose (g Al m^{-2})	WA:LA	Estimated Longevity
Banana Lake, FL	104	55.9	3
Green Lake, WA	96	7.6	16
Spring Lake, MI	80	27.5	6

Lake	Al Dose (g Al m^{-2})	WA:LA	Estimated Longevity
Långsjön, Sweden	75	8.4	8
Powderhorn Lake, MN	45	25.7	6
Bryant Lake, MN	37	18.3	9
Schwandter See, Germany	16	12.4	7
Sunfish Lake, MN	8	8.5	0.1
Centerville, MN	18	0.8	0.5

Alum Burial

The second most important factor affecting alum longevity is the potential burial of the alum layer because of watershed loading and sedimentation. Huser et al (2016) used the watershed area to lake area ratio as a surrogate for watershed loading and sedimentation rate. Since watershed models were developed for Centerville Lake, the sedimentation term can be used to estimate the burial rate for a proposed alum treatment. The time period it takes to replace inactivated P was calculated using several models developed for Centerville Lake (EOR 2013; Houston 2022) and the following assumptions:

- The inactivated P pool was estimated by calculating the total redox-P in the top 4 centimeters of sediment in the expected 373-acre alum treatment zone and assuming 90% is inactivated (Wenck 2019).
- The amount of redox-P in the model derived sedimentation term was estimated to be at 41%, the percentage of redox P in the mobile P (redox-P plus Labile P) in the top 4 centimeters of Centerville Lake.
- Sedimentation was assumed to occur evenly over the lake so 75% (the area equal to the treatment area) of the sedimentation term was used to estimate burial

Using this approach, we estimated that an alum treatment could last between 10 and 31 years depending on the model selected for assessment (Table 4). Since the Houston model represents current conditions and minimal backflow, the 10-year estimate is likely most representative of current conditions if water quality doesn't change following the alum treatment. This would only occur if the role of internal loading was significantly overestimated, and watershed loading is the primary water quality driver. Water quality is expected to improve following the alum treatment and should remove 90% of the sediment released P and subsequent resettling of the released P. The Houston model was not available at the time of the development of this memo, so to estimate water quality benefits, we reduced the settling rate by 40% to represent removal of sediment P release. This approach estimated an alum treatment would last approximately 16 years (Table 4).

Table 4 Estimated alum longevity based on modeled sedimentation and inactivated redox P in the sediment. The estimated longevity is the time required to replace inactivated P through sedimentation and burial.

Selected Model	Sedimentation Rate (kg/yr)	Estimated Mobile P Sedimentation (kg/yr)[1]	Estimated Alum Longevity (years)
TMDL 2004	216	66	17
TMDL at lake standard	118	36	31
2022 model (4 cm dose)	150[2]	70	16
2022 model (6 cm dose)	150[2]	70	24

1 assumes 41% of sedimented P is redox P and 75% of sedimented P settles in the alum treated zone

2 assumes water quality improves which reduces P sedimentation following an alum treatment

Summary and Recommendations

A previous alum treatment completed on Centerville Lake in 1998 resulted in minimal water quality benefits that lasted only a short period. Our review suggests that the lake was significantly underdosed using the water column technique. A more recent alum dose was developed for Centerville Lake using James and Bischoff (2015) and sediment chemistry suggesting 60 g Al/m^2 is required which is almost three times this original applied dose. Based on this review, Centerville Lake was underdosed leading to limited water quality benefits.

The most important factor for an effective alum treatment is the applied alum dose according to Huser et al (2016). This is reflected in more recent alum applications where the alum dose ranged between 73 and 180 g Al/m^2. Selecting an alum dose requires estimating a treatment area and a depth in the sediment profile where mobile P needs to be inactivated. It is important to note that this is typically 6 to 8 centimeters depending on the mobile P profile in the sediment. For Centerville Lake, Wenck targeted to top 4 centimeters over 75% of the lake at a total of cost of almost $850,000. While this is a very reasonable starting point, it may be that deeper sediments need to be treated and this will only be determined after an initial alum treatment and follow up sediment coring. If the top 6 centimeters is required, the cost could jump to $1.3M for the alum treatment but the treatment should last 24 years. The best approach is to apply alum in split doses with follow up monitoring recognizing that the overall cost may be between $850,000 and $1.3M depending on how the sediment react to the alum.

Using this approach, the District can expect an alum treatment to last a minimum of 10 years, with a more likely benefit of 15 years. Since each alum treatment strips the water column and reduces internal loading, water quality benefits can be expected during the alum treatment process. So, if a split dose approach is used over a 2-to-3 year period, water quality will be improved through water column stripping and then 10 to 15 years of benefit should follow, extending the overall water quality benefits. One approach could be to apply the first split dose and monitor water quality until signs of degradation occur and then apply the next dose. This adaptive approach can extend the water quality benefits in Centerville Lake. However, based on the recent dosing and sediment chemistry, the District should be prepared to spend between $850,000 and $1.3M for at least 15 years of water quality benefits. If watershed loading is reduced, these benefits could last even longer.

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2022 RCWD Carp Management Report
February 6, 2023
Rice Creek Watershed District
Attn.: Matt Kocian

Prepared by:
Carp Solutions, LLC
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Summary

In the spring of 2022, Carp Solutions continued operation of the barrier and trap system using the Electric Guidance System (EGS) and a Passive Integrated Transponder (PIT) antenna in Rice Creek just upstream of Long Lake. Throughout the spring, 13,580 carp were removed using this system; approximately 67.6% of the spawning run. PIT antenna data indicated that the EGS was about 92.1% effective at preventing carp from moving up from Long Lake into the Lino Lakes chain to spawn. In the summer of 2022, electrofishing was conducted to mark carp with a fin clip and a PIT tag. Box netting was conducted and another 1,379 carp were caught and removed, for an annual total of 14,959 carp removed. Using the mark-recapture method, the post-removal population (fall 2022) was estimated to be around 4,200 with an estimated biomass density of 102 kg/ha, just above the critical threshold of 100 kg/ha. A large portion of this population appears to be dominated by relatively young carp, likely largely made up of the 2018 year class that recruited in Lino Lakes.

Methods and Results

Electric Guidance System

As a continuation of the ongoing project with RCWD, Carp Solutions ran the electric guidance system (EGS) in Rice Creek in the spring of 2022. The goal of this effort was to halt the annual migration of common carp to their spawning sites. On March 21, Carp Solutions prepared the Rice Creek spring migration carp trapping system for the spring carp migration out of Long Lake by installing a 16’ PIT antenna with remote access just downstream of the EGS and activated the PIT antenna system upstream just below the old Highway 8 bridge. A map showing the relative locations of the Highway 8 PIT antenna and the EGS system is shown in Figure 1. The EGS was turned on the next day, March 22. Over the next three weeks, work was done to prepare the area for carp removal. The trap fence was checked, repaired, and slightly changed so that the carp would be moved towards the upstream area of the trap instead of downstream as in 2021 and 2020. The conveyors were installed at the downstream end of a channel that ran about 30 feet from the upstream end of the trap. A gate was placed at the downstream end of this channel that would allow carp to get into the channel when moved upstream by the electrodes in the main enclosure. More electrodes in the channel were placed to move the carp in the channel onto the conveyors and stun them. Finally, the conveyors were moved into place and tested on April 8 and 9.

The first PIT tagged fish was detected at the EGS antenna on March 29, but the first major aggregation did not occur until April 9, when 80 individual tagged carp were detected at the EGS antenna. The first carp removal occurred two days later on April 11. An additional PIT antenna was installed at the upstream end of the trap on April 13. Throughout the spring, a total of twenty one removals were conducted in the trap until May 31, resulting in the removal of 13,580 carp (Table 1). Up to 50 of the carp captured each day were measured for length, except that on May 7, 9, 13, and 19, no carp were measured. Figure 2 shows the size distribution of the 996 carp measured in this way. Two size classes were observed among the migrating carp; a strong mode around 450 mm and a much looser group between 550 and 700 mm, of which the former was dominant.

Overall, 330 PIT tagged common carp were detected at the EGS throughout the migration season. Of those 330 carp, 223 (67.6%) were removed in the trap. An additional 3 PIT tagged carp were removed that had not been detected at the EGS PIT antenna. Of the remaining 107 PIT tagged carp that were not removed, 26 (7.9%) were detected at HWY 8, meaning that 92.1% of the mitigating carp were unable to cross the EGS (either removed or blocked). Of the 330 PIT tagged carp detected at the EGS, 304 (92.1%) were detected in the trap, of which 203 (66.8%) were removed in the trap. An additional 20 PIT tagged carp detected at the EGS were not detected at the trap antenna because they were removed before that PIT antenna was installed. Based on the percentage of carp removed with a PIT tag, we estimate that around 20,000 carp participated in the migration, of which 13,580 were removed, an estimated 2,000 made it through the EGS, and the remaining roughly 4,400 carp were contained in Long Lake. Figure 3 shows the number of unique PIT tagged carp detected per day at the three antennas throughout the spring. Figure 4 shows the time of day that carp were detected at the antennas below the EGS and inside the trap. Interestingly, carp were detected more during the dark hours of the day at the EGS antenna, but were spread throughout the day at the antenna inside the trap, although more were detected in the morning, especially early morning, compared to after noon. As shown by Figure 5, the number of dates an individual carp was detected at each antenna differed greatly between the three, with carp being detected on more days at the EGS than inside the trap and far more at both than the HWY 8 antenna, where the carp were not restricted in their movement. The peak day of carp activity at the EGS was April 24 when 204 (61.8% of the total) PIT tagged carp were detected. Because the waterbody where PIT tags were implanted into carp was known, it was possible to determine the origin of the tagged carp. A vast majority of the carp detected during the 2022 spawning run were originally tagged in Long Lake, while 16 individuals that were tagged in Rice Lake, Marshan, Reshanau, and George Watch lakes were also detected(Table 2). An additional 22 carp did not match any data from PIT tagging efforts, but were known to be carp since they were removed later were also detected.

There were not any significant power outages or other events that led to the EGS shutting off for an extended period of time. The EGS was shut off for the season on June 4 at 7:10 pm CST. The conveyors and other removal equipment were removed on June 2. The EGS and enclosure PIT antennas were both uninstalled on June 7.

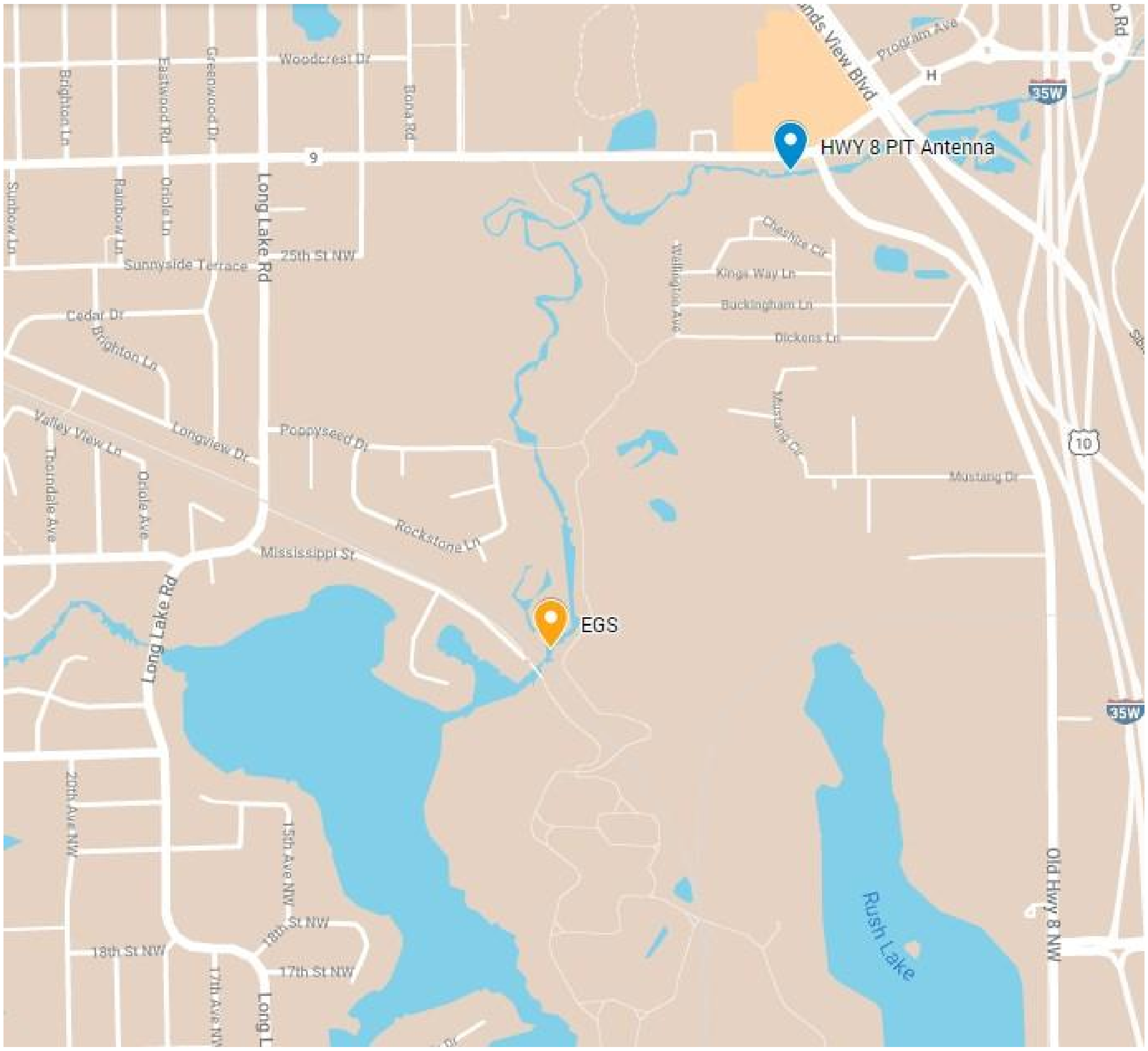

Figure 1: Map of Rice Creek above Long Lake showing the location of the EGS and HWY 8 PIT antennas.

Table 1: Catch numbers per EGS pulls.

Date	Catch	PIT Recaptures	Average Length (mm)
4/11/2022	157	3	578
4/12/22	753	17	522
4/22/2022	276	8	537
4/29/2022	201	4	538
4/30/2022	1000	23	546
5/2/2022	712	11	504
5/3/2022	737	15	533
5/4/2022	2271	23	481
5/5/2022	562	3	486
5/6/2022	888	11	511
5/7/2022	817	24	N/A
5/8/2022	317	9	533
5/9/2022	335	1	N/A
5/10/2022	562	11	543
5/11/2022	854	13	532
5/12/2022	1104	16	492
5/13/2022	748	11	N/A
5/17/2022	134	3	478
5/18/2022	480	8	477
5/19/2022	571	11	N/A
5/31/2022	101	1	497
Average	646.7	10.8	516
Total	13580	226	

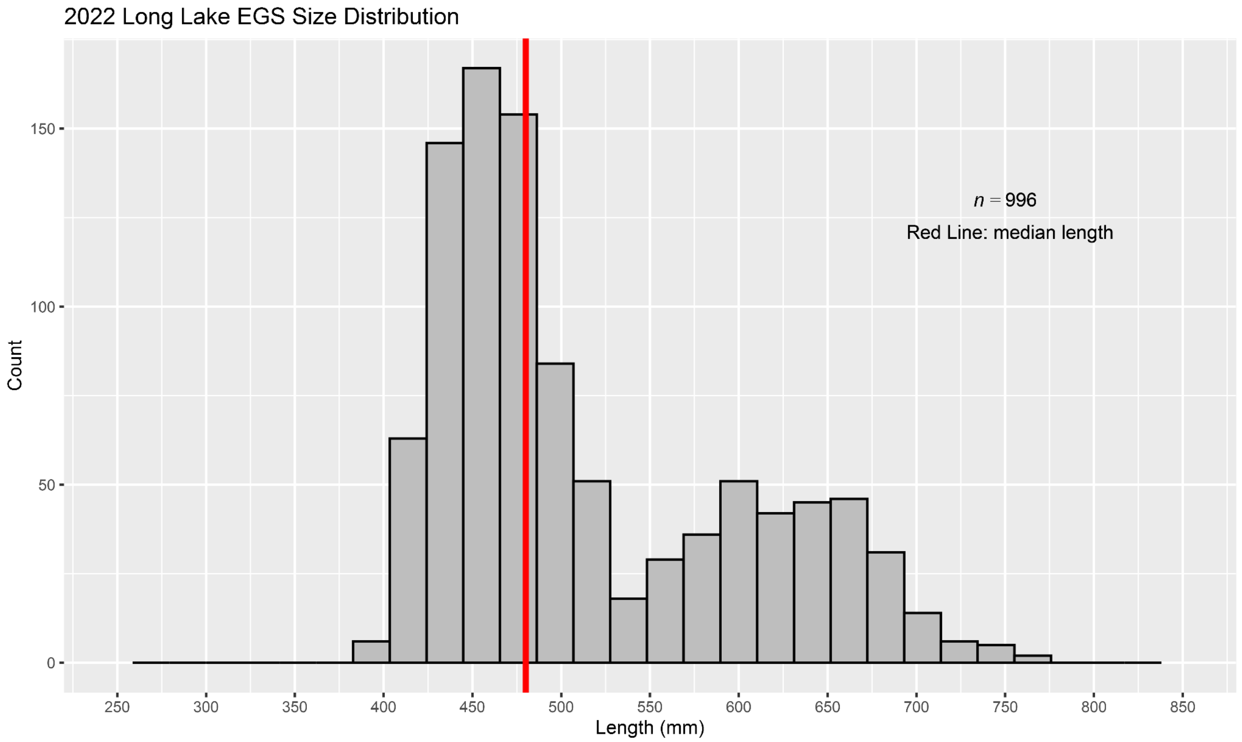

Figure 2: The distribution of size of collected carp (N=996) from the Rice Creek EGS trap.

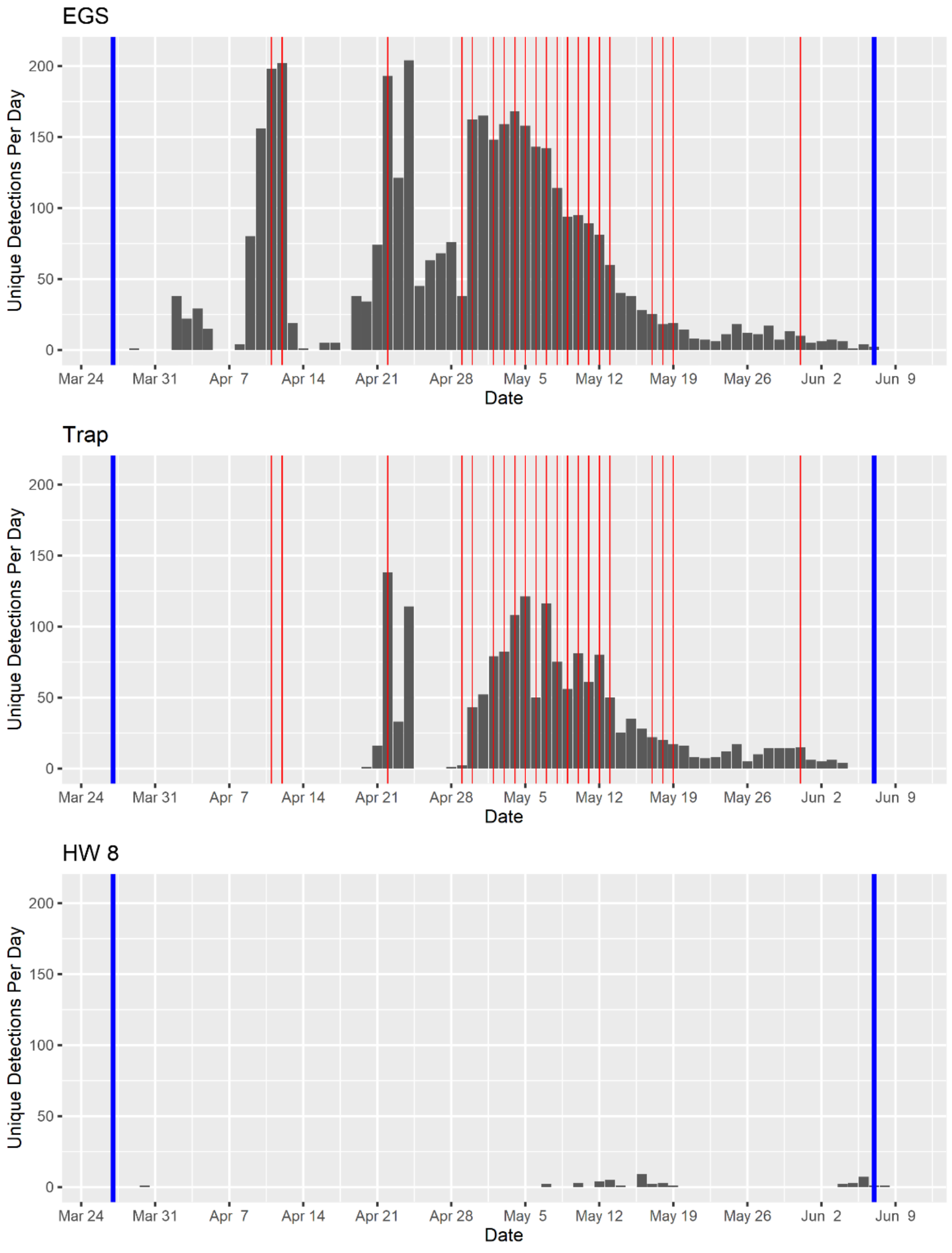

Figure 3: Unique PIT tags detected at readers by day. Blue lines indicated start and end dates. Red lines indicate removal dates.

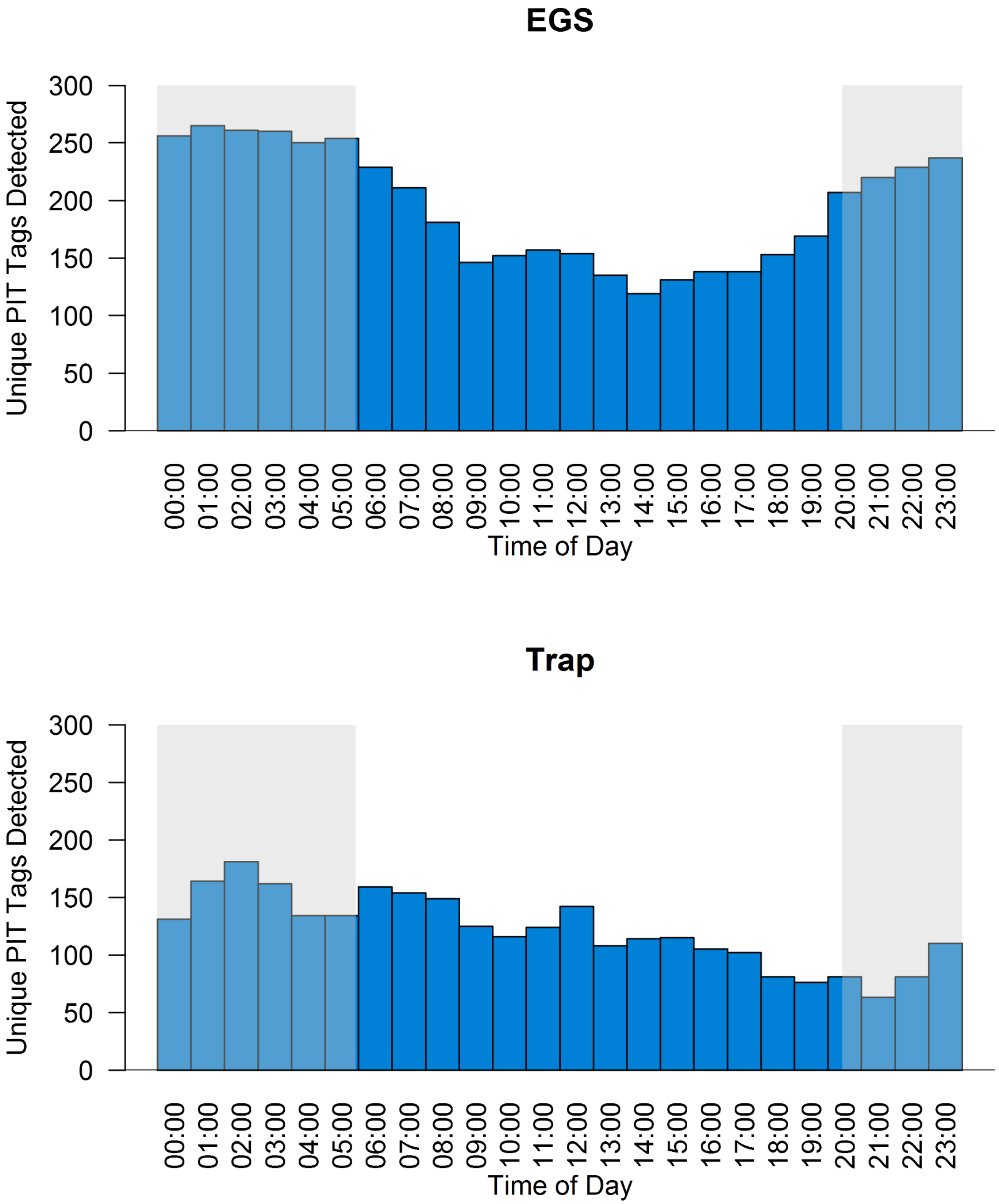

Figure 4: Hourly PIT detections at the PIT antennas below the EGS (top) and inside the trap (bottom).

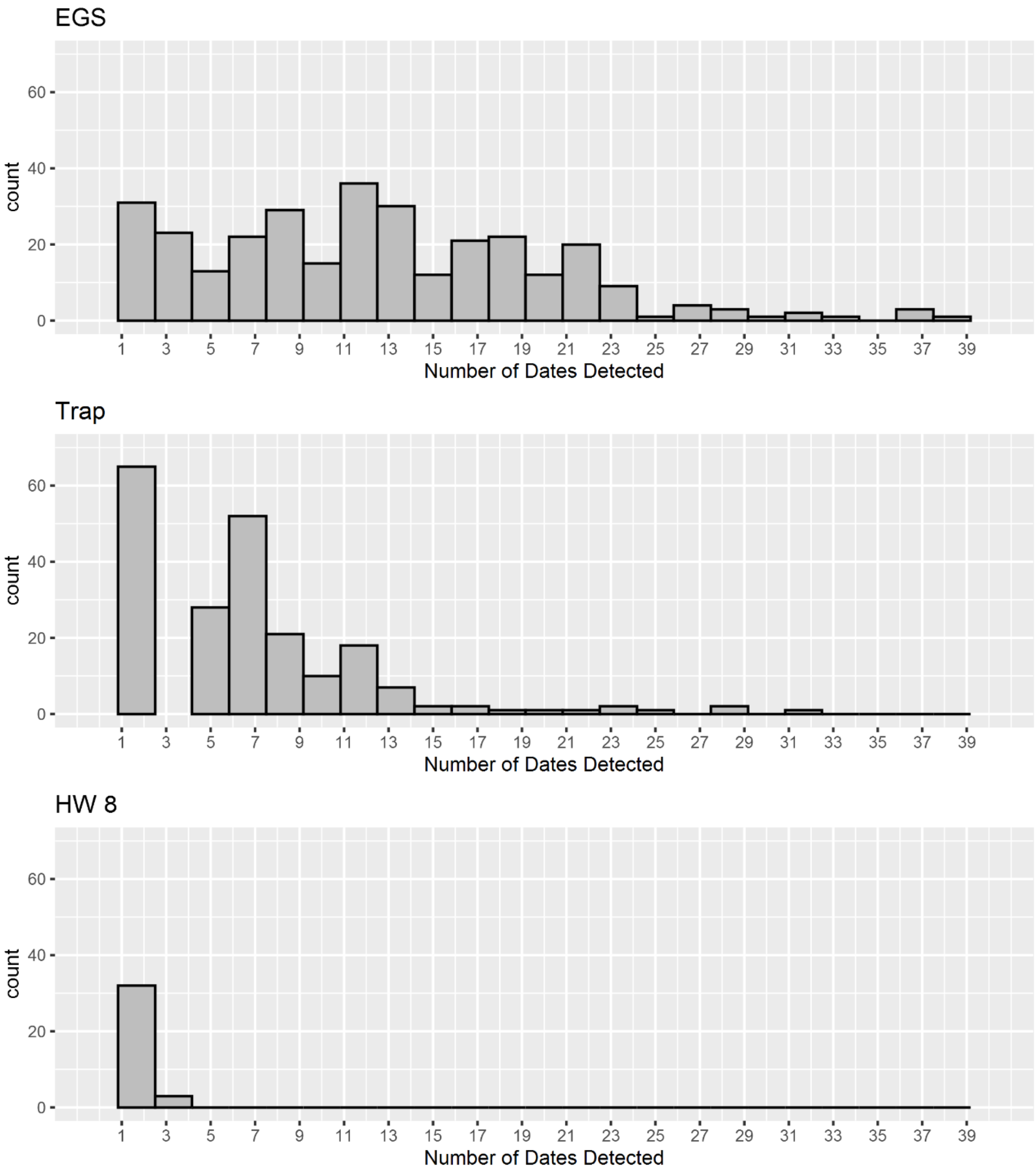

Figure 5: The number of days an individual carp was detected at the PIT antennas below the EGS (top), inside the trap (middle), and upstream at old HW 8 (bottom).

Table 2: Tagging location and size of the carp detected at the EGS PIT antenna in 2022. Unknown waterbody indicates PIT ID numbers that do not match any in the PIT tagging database but are known to be carp since they were removed during 2022.

Water Body	Number	Percentage	Average Length when tagged (mm)
George Watch	4	1.21%	254
Long Lake	290	87.88%	505
Marshan	3	0.91%	659
Reshanau	2	0.61%	624
Rice Creek	2	0.61%	158
Rice Lake	7	2.12%	524
Unknown	22	6.67%	
Total	330		

Johanna Creek PIT antenna

A PIT antenna was installed on the Johanna Creek inlet of Long Lake on April 5. The location of this antenna is shown in Figure 6. This antenna was checked weekly until it was uninstalled on June 13. Issues with the power supply for this antenna were noted on April 25 and May 23, although the exact amount of time that the reader was not working is unknown. A total of 79 carp were detected at this antenna throughout the spring. An additional 15 PIT tags of unknown origin were detected at this antenna. Interestingly, no other PIT tagged fish of other species were detected at this antenna even though 869 individuals were tagged in 2018. Of the 79 carp detected, 7 (8.9%) were also detected at the EGS, one of which was removed there. Figure 7 shows the number of carp detected per day at this PIT antenna. The peak movement occurred on April 16, when 28 unique PIT tagged carp were detected. Figure 8 shows the number of days on which an individual carp was detected at this antenna. Tagged carp were detected an average of 2.4 days at this antenna although carp were detected up to 8 days. Unlike the carp at the EGS and in the trap, this shows that the carp were able to move freely between Long Lake and the wetlands to the southeast and did not aggregate at this site. As shown by Table 3, almost all of these carp were originally tagged in Long Lake itself, with the remaining 2 having been tagged in Rice Lake and unknown.

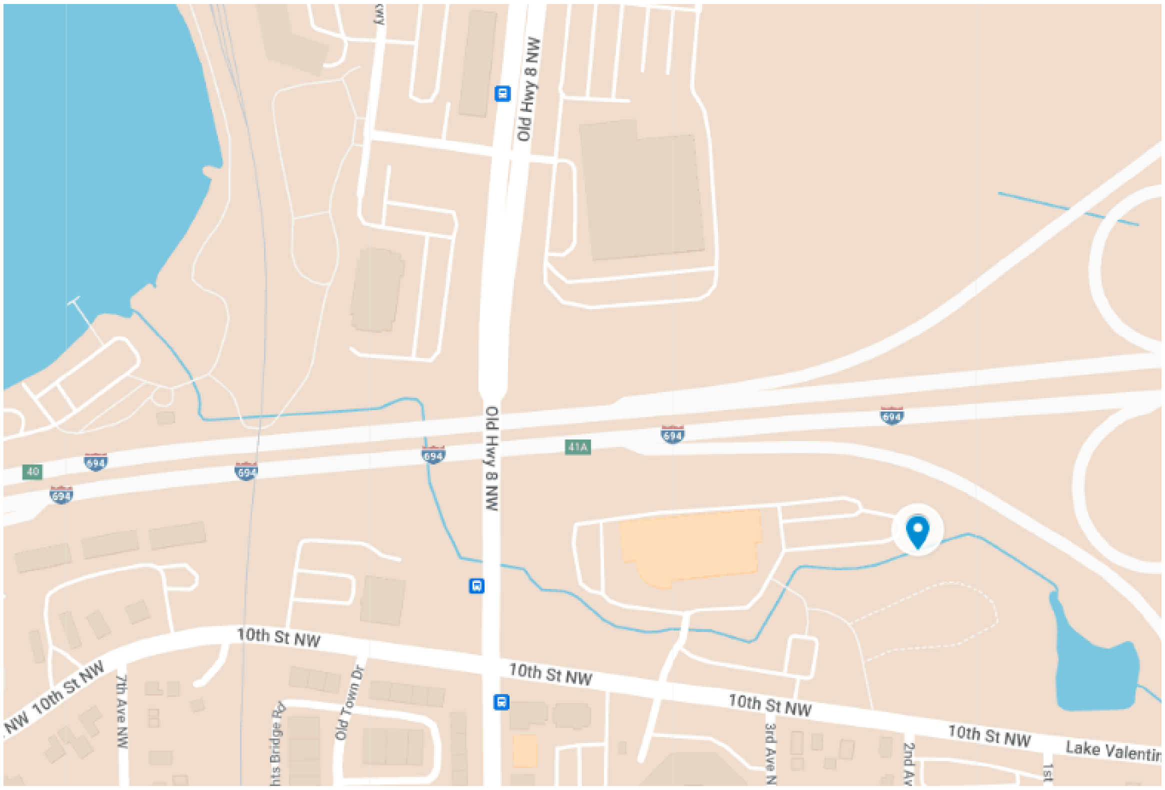

Figure 6: A map showing the location of the Joanna Creek PIT antenna.

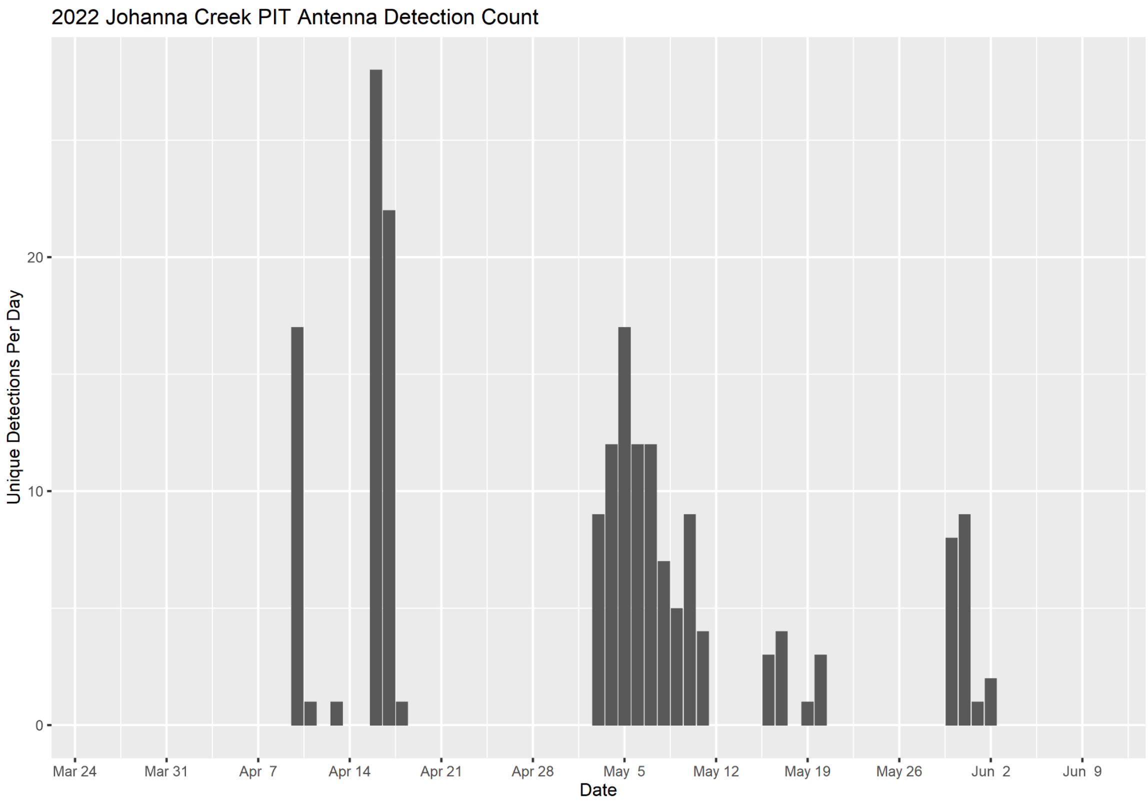

Figure 7: The number of detections per day at the Johanna Creek PIT antenna during the spring of 2022.

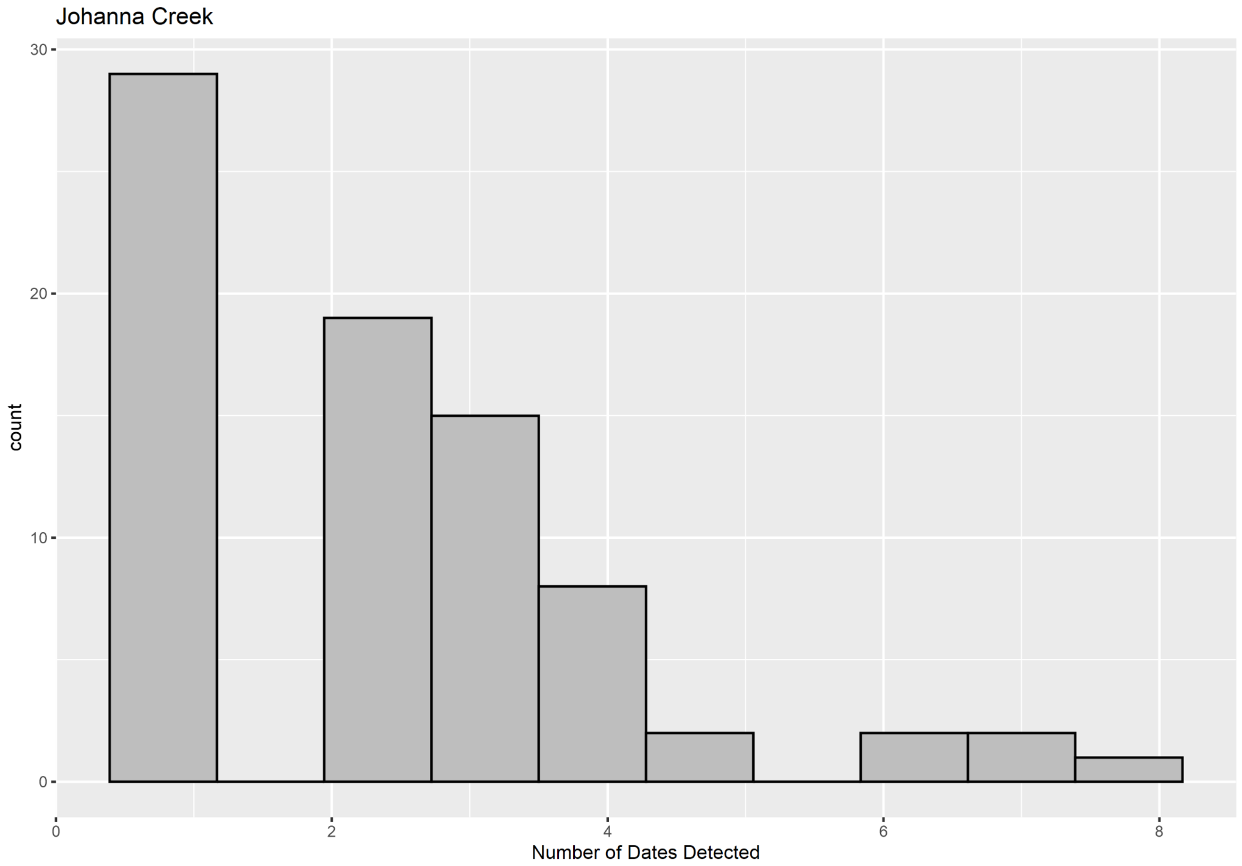

Figure 8: The number of dates an individual carp was detected at the Johanna Creek PIT antenna

Table 3: Tagging location and size of the carp detected at the Johanna PIT antenna in 2022. Unknown waterbody indicates PIT ID numbers that do not match any in the PIT tagging database but are known to be carp since they were removed during 2022.

Water Body	Number	Percentage	Average Length when tagged (mm)
Long Lake	77	97.47%	Long Lake
Rice Lake	1	1.27%	Rice Lake
Unknown	1	1.27%	Unknown
Total	79		Total

Long Lake Electrofishing

Three boat electrofishing surveys were conducted on Long Lake between July and August. These surveys aimed to collect common carp to mark with PIT tags. These efforts yielded in the tagging of 60 carp that were measured for length, had their left pelvic fin clipped, were implanted with a PIT tag, and released back into the water. The distribution of lengths is shown in Figure 9.

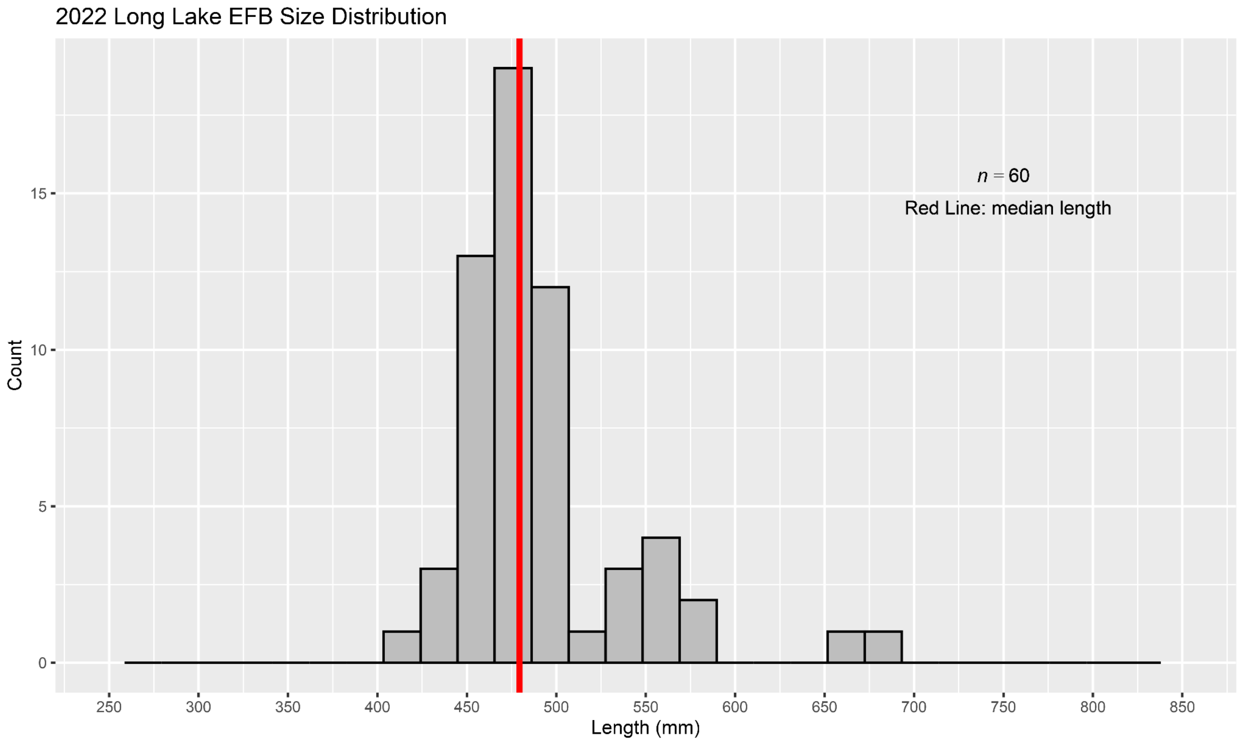

Figure 9: Length distribution of carp captured (n=60) while electrofishing Long Lake.

Box Netting

Four box nets were placed in shallow water around the perimeter of Long Lake on August 5. The locations of these box nets is shown in Figure 10. Three of the box nets were 30'X60' and one 30'X80' and were baited with cracked corn to attract carp. These nets were each tripped five times between August and October of 2022.

An experimental remote feeder system and a remote tripping system were both installed at Net 1. The remote feeder was a 30 gallon hopper to hold and funnel the corn through the trap door on the bottom. It was placed on a floating raft in the center of the net and automatically released cracked corn.

A total of 1,379 carp were removed across 5 removal days (Table 4). The mean catch per net pull was 69 carp. The length distribution of the 228 carp measured from these removals shows that the carp were relatively small and dominated by 450mm - 550mm Individuals. A distribution of these lengths is shown in Figure 11. A total of 32 PIT tagged carp were captured among the harvested carp, including 14 of the 60 (23%) of the carp tagged in 2022, and 18 tagged carp from previous years electrofishing efforts (Table 4).

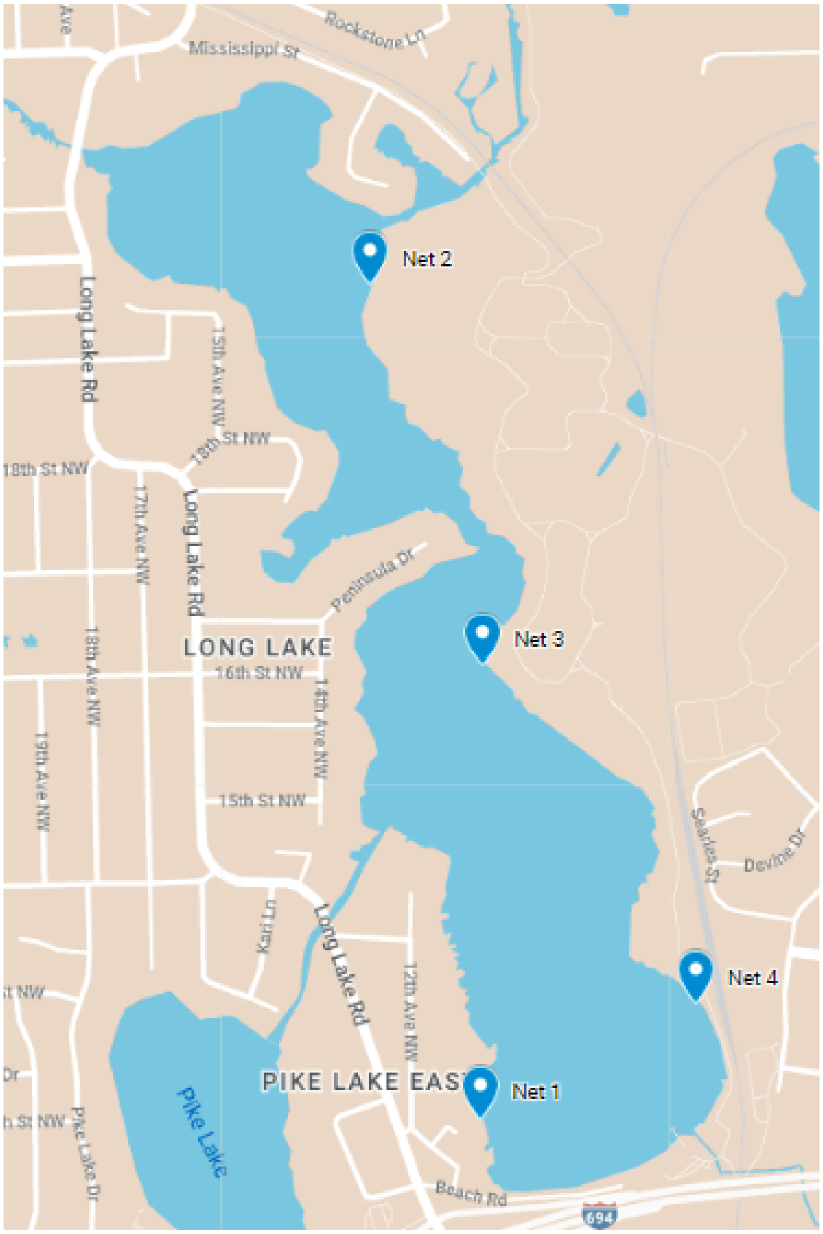

Figure 10: Box net locations on Long Lake.

Table 4: Catch numbers from the five box net pulls on Long Lake. Also noted are the recapture numbers and average lengths.

Date	Catch	PIT Recaptures	New Clip Recaptures	Average Length (mm)
8/19/22	246	6	3	484
9/1/22	451	14	5	485
9/8/22	377	11	6	504
9/30/22	28	1	0	514
10/7/22	277	0	0	500
Average	276	6.4	2.8	496
Total	1,379	32	14	

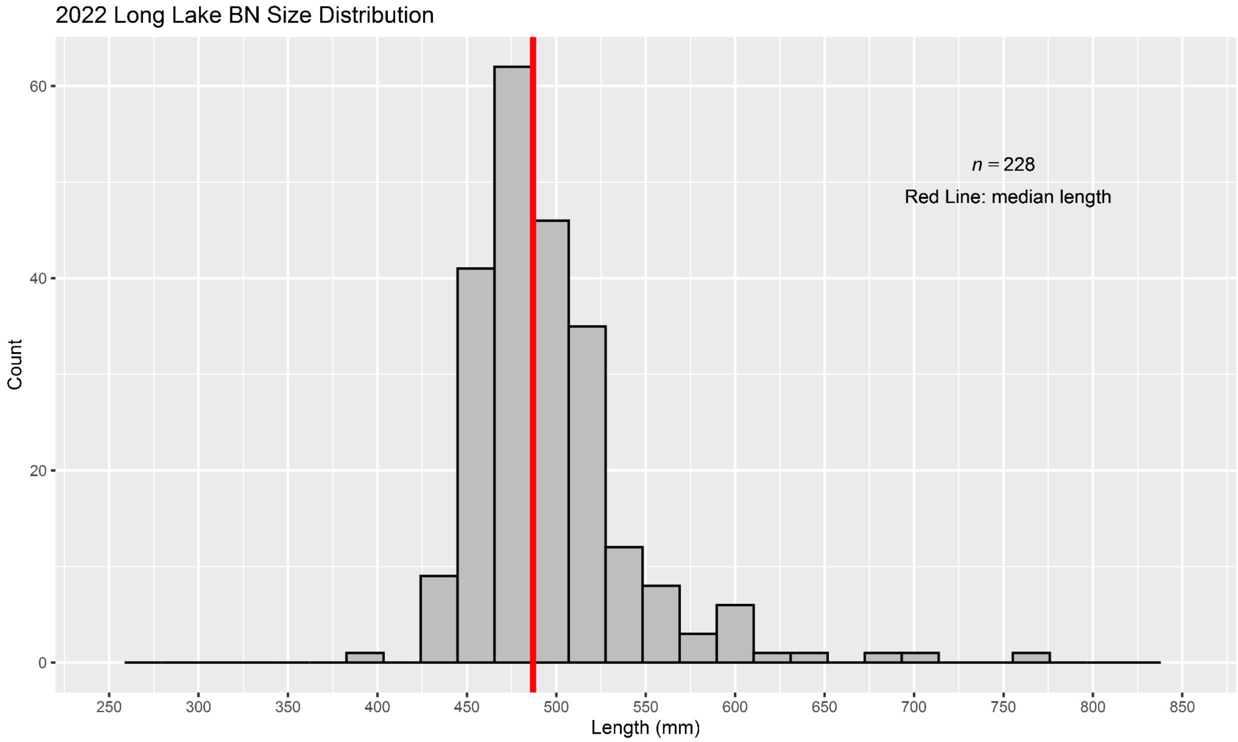

Figure 11: The distribution of size of collected carp (n=228) from box nets in Long Lake.

Trap Netting

A trap net survey was conducted on Rice Lake on September 12 and 13. Five trap nets were randomly placed around the perimeter of the lake in shallow water and left overnight. The following day, the contents of the nets were analyzed and the species within them were identified. Species included black bullhead, black crappie, bluegill, bowfin, green sunfish, hybrid sunfish, largemouth bass, northern pike, pumpkinseed, and yellow perch. The list of species and the numbers of individuals are represented in Table 5. A distribution of lengths for each species is shown in Figure 12.

Table 5: Distribution of species and number of individuals observed in trap nets in Rice Lake.

Trap Net #	Black Bullhead	Black Crappie	Bluegill	Bowfin	Green Sunfish	Hybrid Sunfish	Largemouth Bass	Northern PIke	Pumpkinseed	Yellow Perch	Total
1	75	1	141	3	4	1	4	0	4	0	229
2	11	0	1	0	0	0	0	1	0	0	13
3	42	1	18	0	1	0	0	0	0	1	62
4	51	1	0	0	0	0	0	0	0	0	52
5	2	0	25	0	0	0	0	0	0	0	27
Total	181	3	185	3	5	1	4	1	4	1	383
CPUE(Fish per Net)	36.2	0.6	37	0.6	1	0.2	0.8	0.2	0.8	0.2	
Average Length (mm)	50	81	48	168	54	61	79	201	70	89	

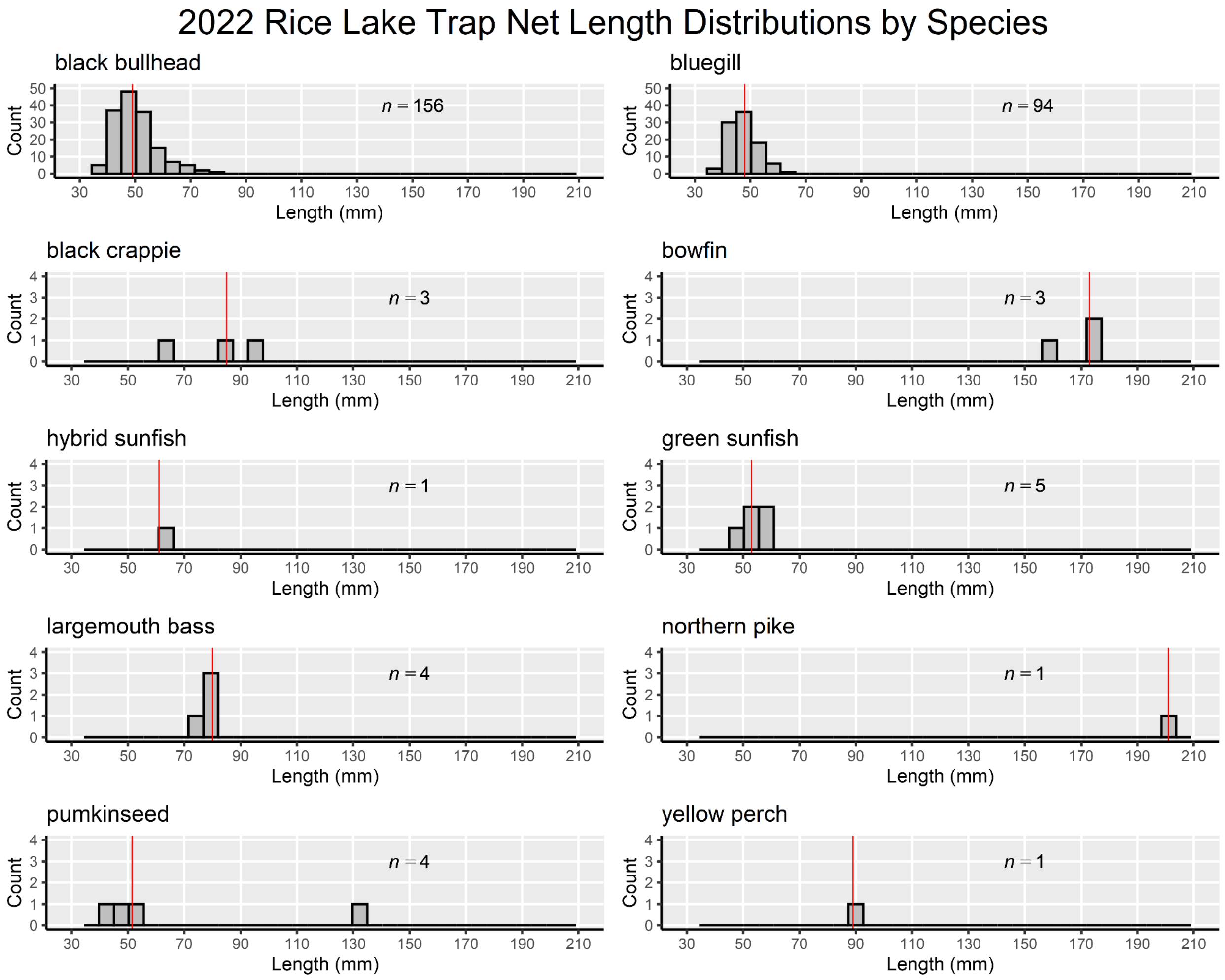

Figure 12: Distribution of lengths by species from Rice Lake trap nets.

Centerville Electrofishing

Additionally, three boat electrofishing surveys were performed on Centerville Lake throughout the month of July. The purpose of these surveys was similar to that of the electrofishing surveys in Long Lake. Once collected with dip nets, these carp had their left pectoral fin clipped, had their length measured, had a PIT tag inserted, and released. The average length was 483 mm for the 31 collected carp. Lengths from these fish are shown in Figure 13. A total of thirty one carp were collected and tagged in these surveys. The average CPUE was 6.88 carp per hour, with an estimated population of 6,793 (3,578 - 10,009) carp and an estimated biomass density of 55.3 (90% CI: 47-64) kg/ha. Collected data from these efforts is shown in Table 6.

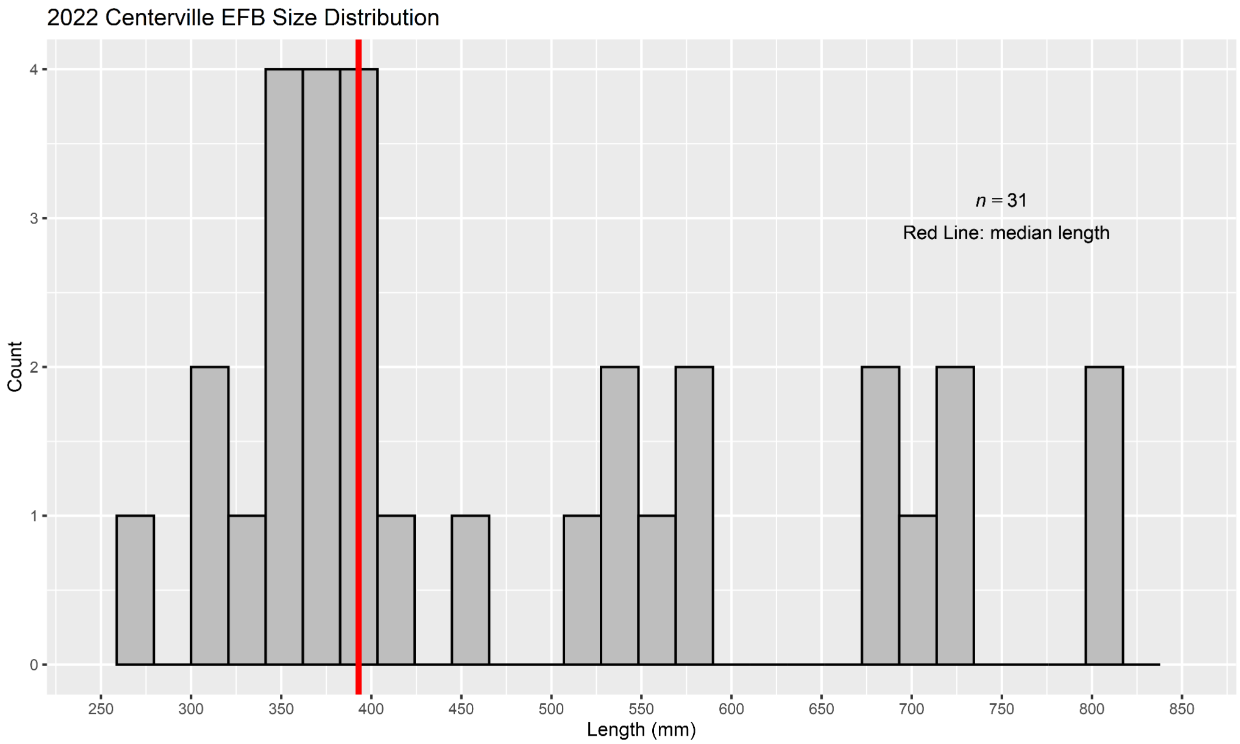

Figure 13: Distribution of carp lengths (n=31) from Centerville. The red line indicates mean length.

Table 6: Transect data collected from boat electrofishing surveys.

Date	Transects	Catch	CPUE	Average Length (mm)	Population Estimate	Biomass Density Estimate (kg/ha)
7/8/2022	5	16	10	462	9254	66.6
7/12/2022	4	12	7	467	7086	52.5
7/26/2022	4	3	2	660	2615	50.4
Average	4.3	10.3	6.4	483	6318	51.4
Total	13	31				

Discussion

2022 provided another year to document the spring spawning migration of carp in Rice Creek and to test removal technologies. The overall timing of the migration has been similar since tracking began in the spring of 2016, with carp being first detected in mid to late March, a peak of activity in April, and continued activity throughout May. Based on the number of PIT tags detected, the overall size of this migration has varied somewhat. For example, 591 PIT tags were detected at the EGS in 2020, 671 in 2021, and 330 in 2022. As in 2021, we were able to remove most of the migrating carp, with 68% of the spawning run being removed in 2022. With improvements to on-site security and a new configuration of the aggregation system, no incidents involving loss of power to the EGS occurred in the spring of 2022. The new trap design also allowed changes to be made to the layout of the aggregation system, ultimately leading to more seamless removals. Carp appeared to be more willing to swim into the trap this year after widening the gate on the downstream side of the trap. Carp also tended to aggregate much closer to the conveyors, and were less resistant to being moved with the stimuli generated by the EGS, as swimming upstream, towards the conveyors, is their natural instinct.

The effectiveness of the EGS as a barrier remained high in the spring of 2022. In the spring of 2018 approximately 90% of migrating carp were stopped between April 22nd through May 1st. In the spring of 2019 PIT data analysis revealed that the effectiveness of the barrier was >95% during periods when the barrier's operation was not interrupted by weather events or vandalism. In both 2020 and 2021 the EGS performed quite well outside of interruptions to the power supply. The spring of 2022 was no different as a total of 330 carp were detected at the EGS PIT antenna below the trap, and 26 of these carp were also detected at the HWY 8 antenna while the EGS was on (92.1% effective). An additional 9 tagged carp were detected after the EGS was turned off meaning that it was 89.7% effective throughout the spring. No power outages or known vandalism events contributed to the movement of carp past the barrier. Structural issues that arose with the trap fence across the stream from the barrier are believed to be the cause for carp moving up to the HWY 8 barrier. These issues were addressed by reinforcing this fence. Renovations to this fence are planned for the spring of 2023, along with the addition of new electrodes here when the new EGS was installed.

Due to the large number of carp already removed, box netting was less successful in previous years, but still added a significant number to the total removed and provided a mark-recapture population estimate. With 4 nets pulled in 5 days, 1,379 carp were removed. Among these were 14 of the 60 carp that had been tagged and marked by boat electrofishing, for a recapture rate of 23.3%. Using these numbers with the mark-recapture method, the carp population in Long Lake was estimated to be around 5,600 (90% CI: 3,618-7,604) carp before box netting removals. The biomass density was estimated to be around 135 kg/ha (90% CI: 87-183 kg/ha). After box netting these estimates fall to around 4,200 carp and a biomass density of around 102 kg/ha; this estimate does not include carp that might have immigrated into Long Lake from upstream lakes late in the fall of 2022. The average catch per day the nets were pulled was 276 carp and per net pull was 69 carp. These numbers are significantly less than those from previous years, with an average of 770 carp per day and 379 carp per net in 2021 and 3,081 carp per day and 513 carp per net in 2020. These decreasing numbers show that the carp population is being reduced to the point where box netting is far less efficient than using the EGS. Nevertheless, baited box nets removed around 23% of the carp population in 5 days of removal.

The PIT antenna system at Johanna Creek revealed a second, smaller spring spawning migration of carp. A total of 79 unique PIT tagged carp were detected at this antenna during the spring. This is only 23.9% of the 330 unique PIT tagged carp detected at the EGS. The peak of movement was relatively early on April 16, eight days before the peak at Rice Creek. Interestingly, seven of the carp detected at this antenna were also detected at the EGS antenna. All of these carp were detected at the EGS after they were detected at Johanna Creek. One carp was first detected at Johanna Creek, then the EGS, and then Johanna Creek again. This means that the carp migrating in Johanna Creek are not an entirely separate group of carp than those migrating up Rice Creek. One of the carp detected at the Johanna Creek antenna was tagged in Rice Lake in 2017, well up Rice Creek. The data also shows that the carp do not attempt to migrate up Rice Creek and then return to the lake after being blocked by the EGS and then migrate up Johanna Creek instead. However, there is a clear and significant movement of carp through Johanna Creek towards the wetlands to the southeast of Long Lake. The carp are likely reproducing in these wetlands, meaning that in order to prevent reproduction in this system, carp need to be stopped in Johanna Creek as well as Rice Creek. Depending on the location of the barrier, this could also present another opportunity for removing carp in the spring as well.

The carp population estimate in Long Lake has varied greatly over the years, partially due to removal efforts and also recruitment/immigration of young carp. 53,596 carp have been removed from Long Lake/Rice Creek since 2016 (Table 7). This resulted in a significant population decline from 2015 to 2019. However, the population subsequently increased to ~34,000 carp in 2020 and 2021 before reducing drastically (more than can be accounted for by removals) in 2022 (Figure 14). During the drastic increase, the size structure of common carp in Long Lake became dominated by relatively small carp (Figure 15). This sudden increase in the population size and abundance of small carp is most likely driven by young carp immigration from external nurseries either in the Lino Lakes chain or the wetlands to the southeast of Long Lake, connected by Joahnna Creek as no young-of-the-year (YOY) carp have been found in Long Lake itself. From trap netting and boat electrofishing surveys in the Lino Lakes chain, it was known that carp successfully recruited there in 2015 and 2018. We also observed (from PIT tag data) that some of the carp tagged as YOY in Lino lakes in 2018 have now joined the adult population. This year, PIT antenna data from Johanna Creek showed that carp are migrating in relatively significant numbers towards the wetlands in the southeast, although no trap netting surveys or PIT tagging of YOY carp in those wetlands has been done.

Unlike in 2021, the difference in lengths between the different methods is much less. In 2021, carp caught at the EGS (585 mm) were over 100 mm longer than those caught by boat electrofishing (430 mm) or box nets (464 mm). Importantly, large carp dominated the spring run but was largely absent during boat electrofishing and box netting conducted in the summer . This was important because the spawning run in 2021 consisted of approximately 16,000 carp compared to the carp population in the lake estimated at ~34,000 carp. In contrast, the carp lengths in 2022 were far more similar between methods (Figure 16). The carp captured with the EGS and by boat electrofishing both had a median length of 480 mm while carp captured by box netting had a median length of 487 mm. These medians are so similar because all three distributions are dominated by the smaller (400-550 mm) carp. Relatively more of the larger (550+ mm) were captured at the EGS compared to in the lake. This is important because this smaller cohort of carp made up less than half of the spawning run in 2021 while it vastly dominated the summer boat electrofishing and box netting populations. This is likely due to the fact that most of the smaller carp were not migrating yet. In 2022, there were still relatively more larger carp in the spring run than there were during the summer sampling, but the smaller carp had begun to migrate in great numbers and made up most of the catch in all three methods. This likely explains why the box netting was relatively far less effective compared to the EGS in 2022 versus 2021. In 2021, around 10,300 carp were caught with the EGS compared to around 6,200 with box nets. In 2022, around 13,600 carp were caught with the EGS compared to only around 1,400 in box nets. In 2021, the box nets were able to capture many of the smaller carp that remained in Long Lake and did not attempt to migrate up Rice Creek. In contrast, in 2022, these smaller carp attempted to migrate up Rice Creek and were captured in relatively similar proportions with all three methods.

The size distribution of the carp population over the years shows the effects of recruitment events. In 2020, we also observed large numbers of small (<400 mm) carp in Long Lake. This suggests the immigration of small carp from external nurseries (including Lino Lakes). The size distribution of carp from 2015-2021 (Figure 15) clearly shows this. In this figure, at least one smaller year class under 400 mm appears in 2016. 2017 shows a bimodal distribution, with a much smaller dominant size class than in 2016. An even smaller size class appears again in 2019 and then dominates the population in 2020, 2021, and 2022. These smaller (~400 mm this year) carp are assumed to be primarily from the 2018 year class although some data is lacking to definitively conclude this. No electrofishing or box netting was carried out in 2018, and only a small amount of electrofishing was carried out in 2019 that did not capture any of the 2018 year class. The small carp under 400 mm captured in box nets in 2019 made up about 18% of the population. Through aging analyses in 2019, these small carp were determined to be predominantly (60%) from the 2018 year class. However, due the relatively large mesh size of box nets which do not reliably capture carp under 350 mm, this likely missed a large proportion of the 2018 year class and hence its contribution to the overall population. This contribution only appeared in the data starting in 2020, where it became clear that this size class is dominating the carp population in Long Lake. Since then, this class has continued to be the dominant size class.

In order to successfully manage the carp population in the Long Lake system in the future, it is important to evaluate the effectiveness of techniques employed so far. The EGS has proven to be effective at both blocking the migration of carp and providing an opportunity for removal. The carp aggregation and removal system using a second NEPTUN with chains of electrodes and two conveyors that was tested in the fall of 2019 and the spring of 2020 proved to be very successful in 2021 and 2022. The main failure point of the EGS system so far has been when the system and hence the barrier turned off due to power loss, a malfunction of the EGS system itself, or vandalism involving someone entering the site and pushing the safety shut-off switch. Solutions to these issues were introduced in the spring of 2021 and proved highly successful in 2022. Specifically, the text notification system of the NEPTUN and site security including a better fence and active security monitoring of the site during the migration period all proved highly successful. Baited box net removals later in the summer proved to be less relatively successful than in previous years, likely due to the reduced population from significant removals. Continued removals at the EGS and most importantly, prevention of significant recruitment by blocking the spawning migration with the EGS should keep the population in check and allow for the population to be reduced and kept well below the management threshold of 100 kg/ha.

While Centerville Lake had a biomass density estimate below 100 kg/ha, the large number of smaller carp found there is concerning. The catches from the three days of electrofishing were relatively consistent and the biomass density estimates were all well below 100 kg/ha. However, the carp were relatively small, with an average length of 483 mm and a minimum length of 262 mm. There were multiple size classes of carp up to 816 mm, meaning that there is consistent carp reproduction in this system. So while there is a relatively low density of carp in the lake now, this could change in the future.

Table 7: Carp removal numbers from 2016-2022.

Year	Total Carp Removed
2016	5,814
2017	3,447
2018	0
2019	5,104
2020	7,762
2021	16,511
2022	14,958
Total	53,596

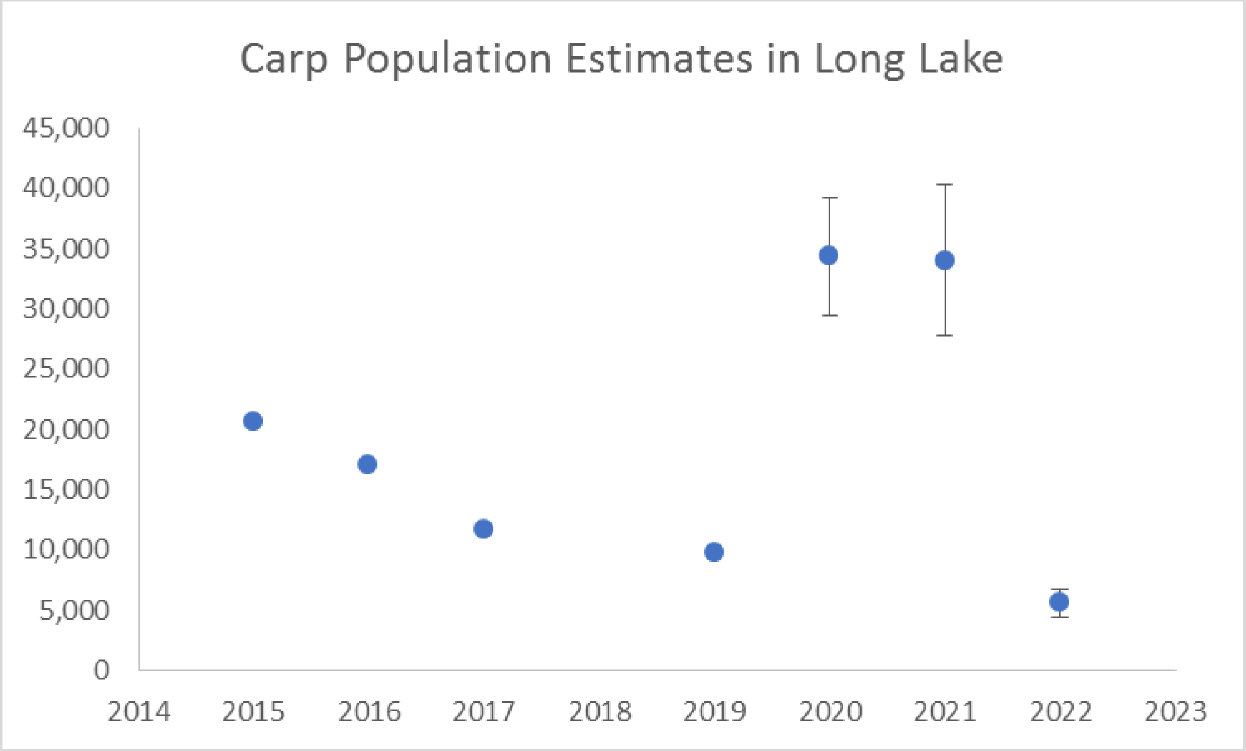

Figure 14: Carp population estimates in Long Lake from 2016-2022. Estimates in 2015, 2017, and 2019 are based solely on the CPUE estimates from boat electrofishing. No estimate was made in 2018. Estimates in 2016, 2020, 2021, and 2022 were made using the mark-recapture method with carp marked by boat electrofishing and recaptured in box nets.

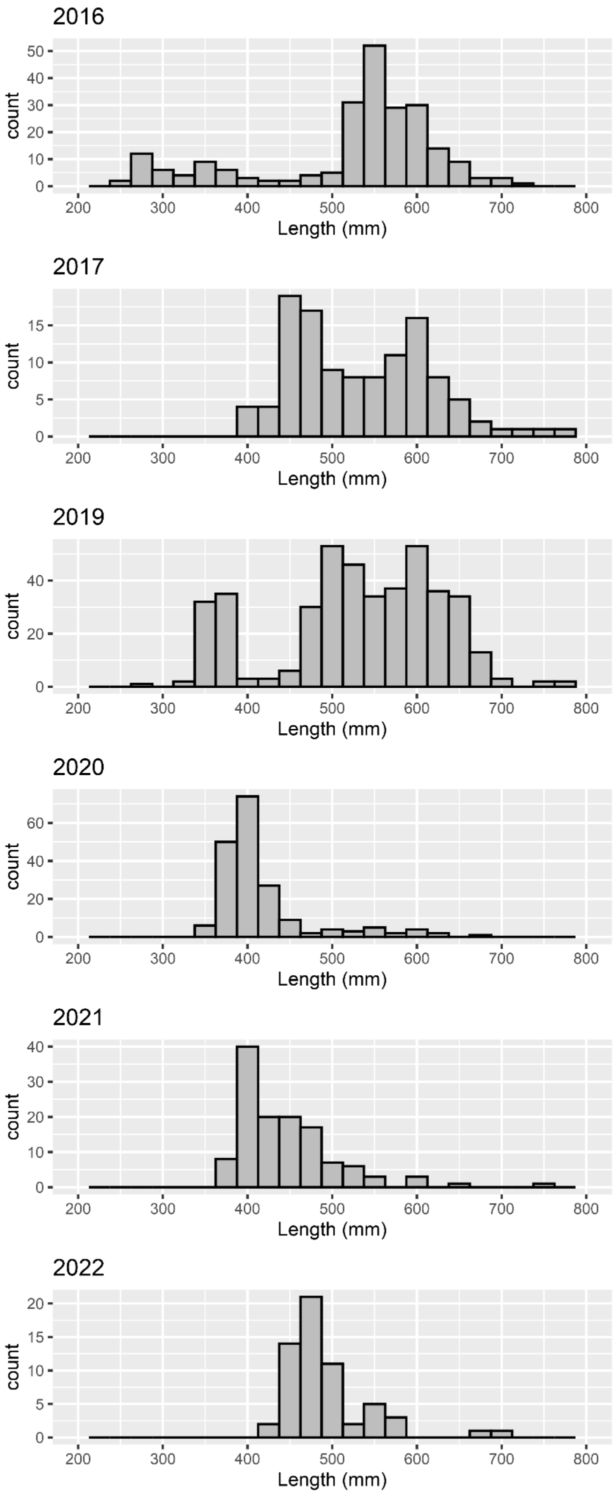

Figure 15: Length distributions of carp from 2015-2022 in Long Lake. Lengths from 2016, 2017, 2020, 2021, and 2022 are from boat electrofishing. No electrofishing or box netting was carried out in 2018. Due to very limited electrofishing in 2019, lengths for that year are from box netting.

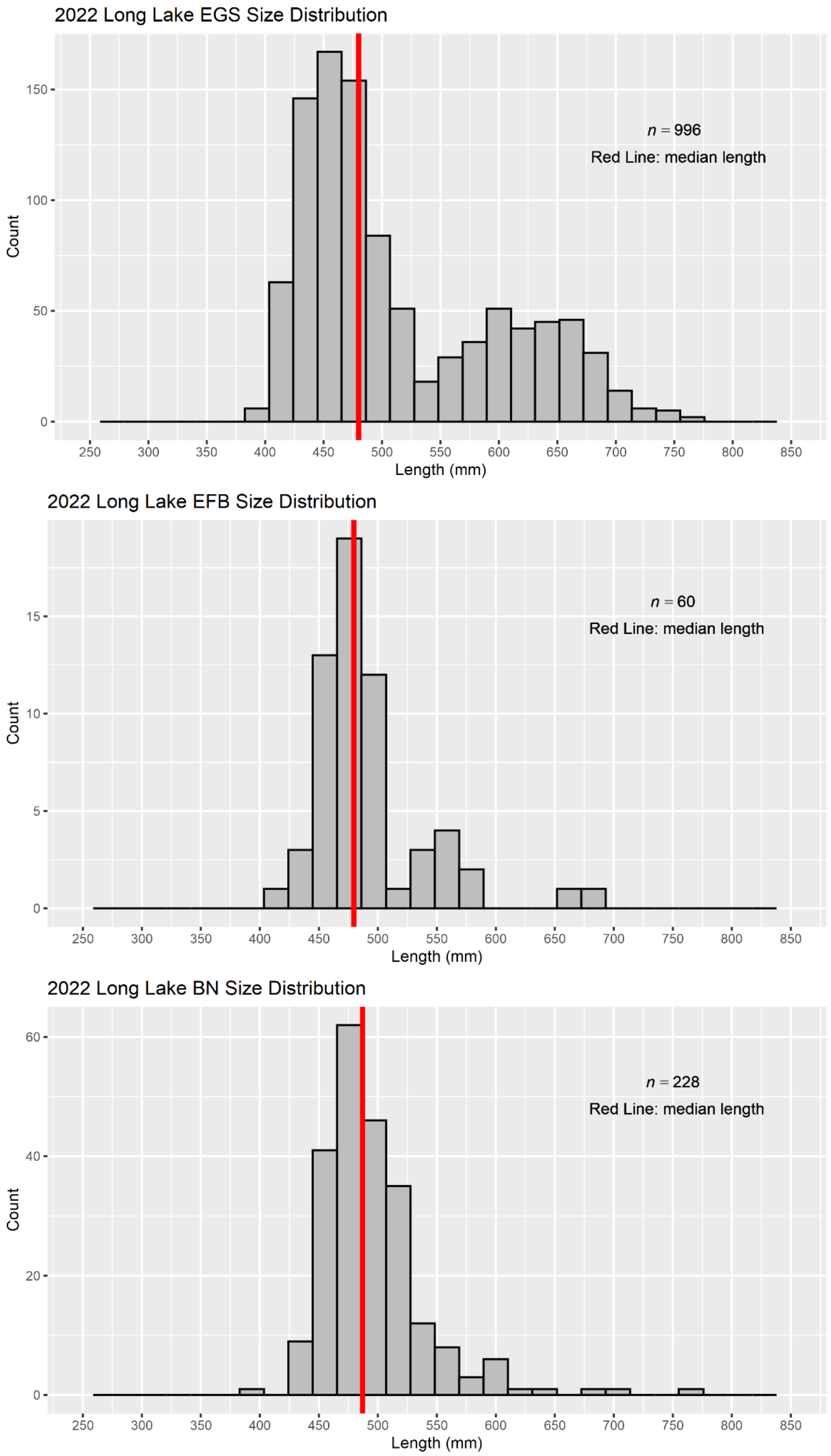

Figure 16: Length distributions of carp captured at the EGS (top), boat electrofishing (middle), and box netting (bottom) in 2022.

Management Recommendations

Based on the success of management methods thus far, we recommend continuing their use with certain improvements. The EGS has proven to be effective at preventing the upstream migration of carp out of Long Lake, so its operation should be continued. In order to prevent its shutdown through vandalism, security measures at the site should be maintained. Since the barrier was never shut off in the spring of 2022, these measures seem to be the most effective way to prevent any issues. Since the trap, aggregation system, and conveyors proved to be both a very effective and efficient method of removal, it should be continued. To monitor the size structure of the population, add more PIT tagged carp to the system, and obtain an accurate population estimate, at least three days of electrofishing to implant PIT tags and fin clip carp should be done. If conditions allow, the trap net surveys of Rice Lake to survey for YOY carp should continue. Box netting might still be considered as an auxiliary removal method in Long lake, especially if stream removal in 2023 appears less effective (due to stream dredging) and/or to remove carp that migrate up Johanna Creek if spring removal in Johanna Creek is ineffective.

Additionally, we recommend that a barrier be installed at the Johanna Creek inlet on the southeast end of Long Lake that leads to the wetland adjacent to Mounds View High School and Valentine Hills Elementary School. PIT antennas on either side of this barrier could be used to monitor its effectiveness. Smaller scale removals, likely just using a backpack electrofishing unit, could be conducted at this barrier. Also, it would be beneficial to perform late summer or early fall small mesh trap netting surveys on at least the main wetland adjacent to Mounds View High School. If it was possible to launch an electrofishing boat, it would be helpful to survey the adult carp in the wetland and tag them to see how long carp are staying in the wetland to get a better idea of the seasonal variability of the Long Lake carp population.

Centerville management recommendations involve biennial electrofishing surveys to monitor the carp population. Though the biomass density was estimated to exist below the management threshold, the population consists of a sizable number of small, young carp. This could lead to a population increase in future years if monitoring does not continue.

Citations

Bajer PG , Hundt PJ Kocian M (2022) Field test of an electric deterrence and guidance system during a natural spawning migration of invasive common carp. *Management of Biological Invasions* 13 (in press).

MEMORANDUM
Rice Creek Watershed District

Date: **July 17, 2023**
To: **RCWD File**
From: **Matt Kocian, Lake and Stream Program Manager**
Subject: **Centerville Lake Phosphorus Loading Summary**

Introduction

This memo will provide an updated phosphorus budget for Centerville Lake, integrating information from multiple recent studies, including the 2023 Centerville Lake Subwatershed Assessment.

Background

Centerville Lake experiences severe and frequent blue-green algae blooms. The lake is listed as *impaired* for excess nutrients. Recent summer phosphorus and chlorophyll-a means have exceeded State Standards by a factor of 1.5-2. Over the past ten years, a significant increase in both total phosphorus and chl-a has been observed (Mann-Kendall, $p < 0.1$) (Figure 2).

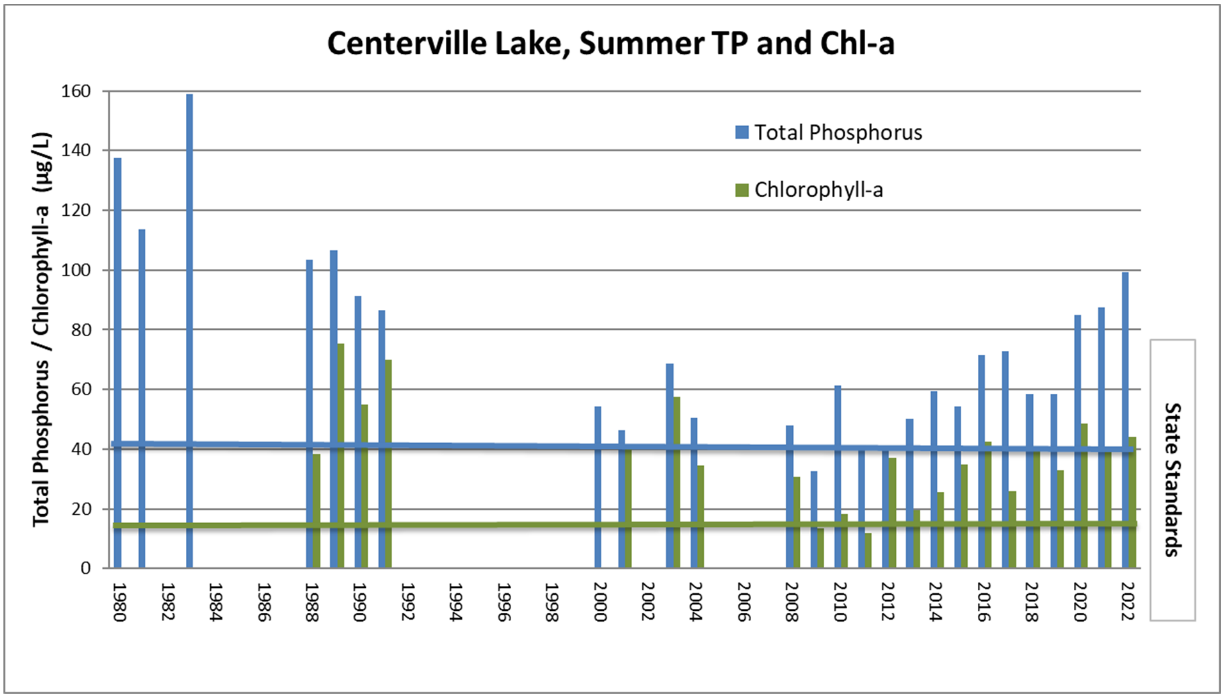

Figure 1. Mean annual summer total phosphorus and chlorophyll-a in Centerville Lake.

Recently completed diagnostic studies[1] suggest the internal phosphorus loading – specifically, sediment-phosphorus release – is a significant contributor to the overall phosphorus budget, and a driver of algae

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[1] *Internal Load Investigation for Centerville Lake*, Wenck Associates, 2019;

blooms. Other potential phosphorus sources have been assessed, including backflow loading from Peltier Lake[2], atmospheric deposition[3], and common carp[4].

In 2023, the Anoka Conservation District completed a Subwatershed Assessment (SWA) for Centerville Lake[5]. The purpose of this project was to identify and rank potential stormwater retrofit projects to improve water quality in Centerville Lake. The work included the construction of a detailed watershed nutrient loading model (WinSLAMM). Although watershed loading models have been produced in past projects (e.g. *Peltier and Centerville TMDL Study*, 2013, and *Centerville Lake Phosphorus Dynamics*, 2022), this was the first model that accounted for reductions from recent stormwater management projects. Thus, the recently completed SWA model provides the most accurate estimate of watershed nutrient loading for Centerville Lake. **The Centerville SWA study found that watershed phosphorus loading was at approximately 170 lbs per year.** All phosphorus loading estimates, broken down by source category and study reference, are shown in *Table 1*.

Phosphorus Load Source	Annual Phos. Load (lbs)	Reference:
Sediment-P Release	278	*Internal Load Investigation for Centerville Lake*, Wenck Associates, 2019
Watershed	170	*Centerville Lake Subwatershed Assessment,* Anoka Conservation District, 2023
Atmospheric	128	*Peltier-Centerville TMDL Study*, Emmons and Olivier Resources, 2013
Backflow from Peltier	18	*Centerville Lake Phosphorus Dynamics*, Houston Engineering, 2022

Table 1. Phosphorus loading sources to Centerville Lake, by source category and study reference.

Phosphorus loading from sediment-P release is the highest portion of the annual budget for Centerville Lake, followed by watershed loading. Atmospheric loading (wet and dry deposition), estimated in the 2013 Peltier-Centerville TMDL study, contributes 128 lbs. Backflow loading, estimated in the 2022 Centerville Lake Phosphorus Dynamics study, contributes 18 lbs annually. The 2022 RCWD Carp Management Report found that carp densities are about 55 kg/ha – about 50% below the density at which they typically impact water quality. Thus, common carp are deemed a negligible contributor to the annual phosphorus budget. A breakdown of the annual phosphorus budget is shown in Figure 2.

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[2] *Centerville Lake Phosphorus Dynamics*, Houston Engineering, 2022
[3] *Peltier-Centerville Total Maximum Daily Load Study*, Emmons and Olivier Resources, 2013
[4] *RCWD Carp Management Report*, Carp Solutions, LLC, 2023
[5] *Centerville Lake Subwatershed Assessment*, Anoka Conservation District, 2023

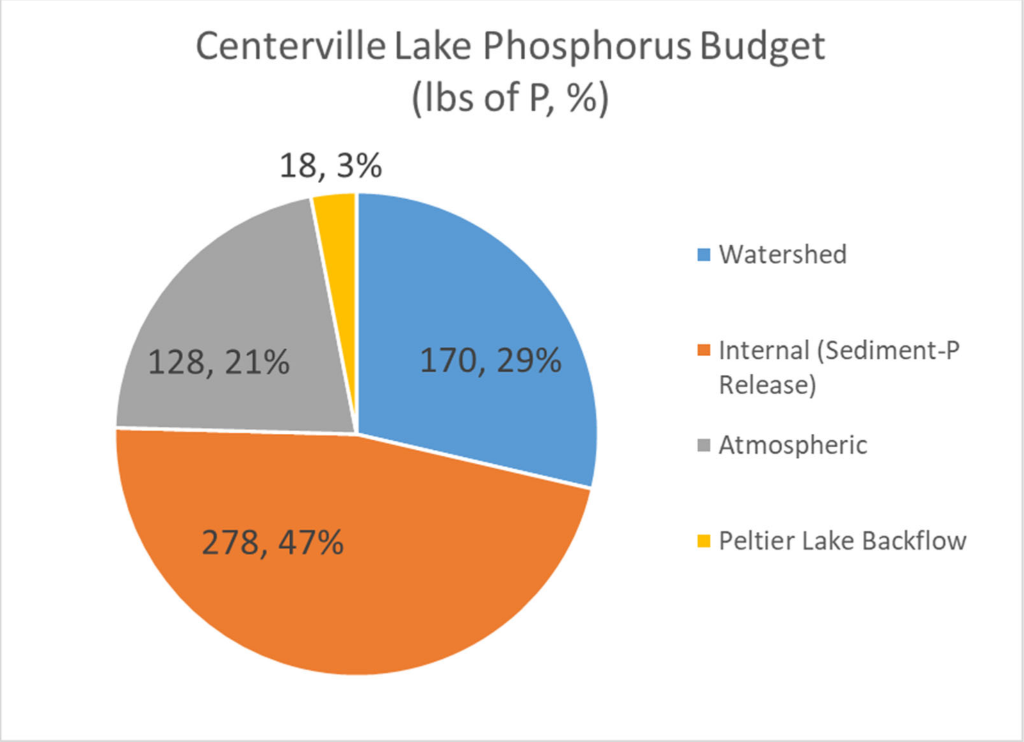

Figure 2. Annual phosphorus budget for Centerville Lake.

Summary

Algae blooms in Centerville Lake are frequent and severe, and state water quality standards are exceeded by 1.5-2 times. Recently completed diagnostic studies suggest that internal phosphorus loading – specifically from sediment-P release – is the primary driver of poor water quality. Mitigating sediment-P release (for example, with chemical inactivators, like aluminum sulfate) will be necessary to improve water quality on Centerville Lake and achieve state standards.