Stantec

Memo

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Project/File:	Diagnostic Feasibility Study on Briggs, Rush, and Julia Lakes	Date:	January 6, 2025

Reference: 227706313

Overview

Stantec Consulting Inc (Stantec) recently completed the phosphorus diagnostic feasibility study for Briggs, Julia, and Rush Lakes. The objective of the study was to determine the magnitude of internal and external phosphorus loading, assess load reduction and management goals, evaluate the feasibility of an alum treatment to reduce internal loading, and conduct common carp (carp) population assessment and determine population size and assess effects on water quality. This technical memorandum describes the methods, results, conclusions and recommendations from the study

Stantec's approach relied on the following datasets:

- In-lake water quality sample data for each lake, both historical and contemporary
- Tributary water quality data for Julia Creek, Briggs Creek, and the Briggs Lake Bayou
- Measured phosphorus release rates from collected sediment cores (2023)
- Regional watershed model results
- Prior watershed assessment publications relative to the lakes and watershed
- Carp sampling results for each lake (2024)

After thorough review, these datasets were characterized for input into a lake response model for each lake. The lake response model provides a vetted method for numerical evaluation of sources of phosphorus to each lake. The results of the lake response model demonstrate the relative magnitude of each contributing source to the lake, namely external sources (i.e., runoff), sediment release (i.e., internal), bioturbation (i.e., carp), and natural deposition (i.e., atmospheric). Other common phosphorus sources to lakes, such as failing septic systems and point sources, were not estimated due to incomplete records and therefore challenges with accurately characterizing their contributions. What follows is a detailed explanation of Stantec's development of the lake response models and a discussion of the results.

Water Quality Sampling Results

Lake Data

Briggs, Julia, and Rush each have unique lake morphometries and total phosphorous (TP) loading sources. Table 1 below summarizes the basic attributes of each lake. Briggs Lake, the largest lake of the group by area and volume, is considered a thermally stratified lake based on 2023 temperature profile data. Meaning, for extended periods of the year the lake profile forms a distinct, colder, hypolimnion layer in the bottom layer of the lake. During these periods the lake often exhibits anoxia in the hypolimnion, when dissolved oxygen (DO) concentrations persist below 2 mg/L. This is contrary to what was described by MPCA's 2012 report, which describes Briggs as predominantly mixed based on limited 2008 data[1]. This difference in interpretation may be attributed to a non-representative sample dataset evaluated in the MPCA's report or may indicate that thermal stratification can change over time. Rush and Julia Lakes, however, thermally mix and stratify more intermittently throughout the year (i.e., polymictic lakes). This episodic mixing is associated with anoxic conditions near the lake bottom that are less frequent and have shorter durations than anoxic conditions in Briggs Lake, which maintains stable thermal stratification in summer. Attachment A includes lake profile plots of DO and temperature depth, which help illustrate the variability in thermal stratification and DO among all three lakes.

Table 1. Lake attributes summary.

Lake Name	Attribute	Value	Units
Briggs	Area	404.4	acres
	Max Depth	25	feet
	Mean Depth	11.7	feet
	Volume	4,731	acre-feet
	Watershed: Lake Area Ratio	23:1	unitless
Julia	Area	154.5	acres
	Max Depth	15	feet
	Mean Depth	8.2	feet
	Volume	1,267	acre-feet
	Watershed: Lake Area Ratio	14:1	unitless
Rush	Area	160.9	acres
	Max Depth	11	feet
	Mean Depth	6.7	feet
	Volume	1,078	acre-feet
	Watershed: Lake Area Ratio	63:1	unitless

Lake morphometry and temperature/DO profiles data provides fundamental information about lake dynamics that helps guide inferences from in-lake TP concentrations. TP concentrations across time (both seasonally and annually), across depth (surface vs. bottom), and across all three lakes were used to

[1] MPCA. 2012. Water Quality Assessments of Select Lakes within the Mississippi River (St. Cloud) Watershed. Document number wq-ws3-07010203.

develop assumptions for lake response modeling and to explain mechanistic lake processes that may not be adequately captured by the lake response model.

Multiple data sources were used to evaluate in-lake TP concentrations, namely tributary data collected by Sherburne Soil and Water Conservation District (SWCD), data collected by the Briggs Lake Chain Association (BLCA) volunteers (2006-2023), and historical sample data available from Minnesota Pollution Control Agency's (MPCA) EQuIS database. Table 2 summarizes the temporal record for each dataset that was used in lake model development.

Table 2. Summary of in-lake phosphorus data sources used for this study.

Data Source	Temporal Coverage
Sherburne SWCD	2023
BLCA	2006-2023
MPCA EQuIS Database	1985-2023

Figures 1 through 3 below illustrate 2023 TP grab sample results collected by lake association members for each lake. Each sampling event included a surface sample (epilimnion) and a bottom sample (hypolimnion) for evaluation of TP concentrations across the vertical lake profile. The collection of both surface and bottom samples in tandem facilitates better understanding of phosphorus sources and dynamics within the lake. In general, each lake exhibits a gradual increase in surface TP concentrations throughout the season. Bottom TP concentrations generally spike in mid-summer in each of the three lakes without a noticeable increase in surface concentration. The increase in bottom TP concentrations is most pronounced in Briggs, where bottom concentrations increase an order of magnitude from June to July, and the period of elevated bottom concentrations is consistently high during that period.

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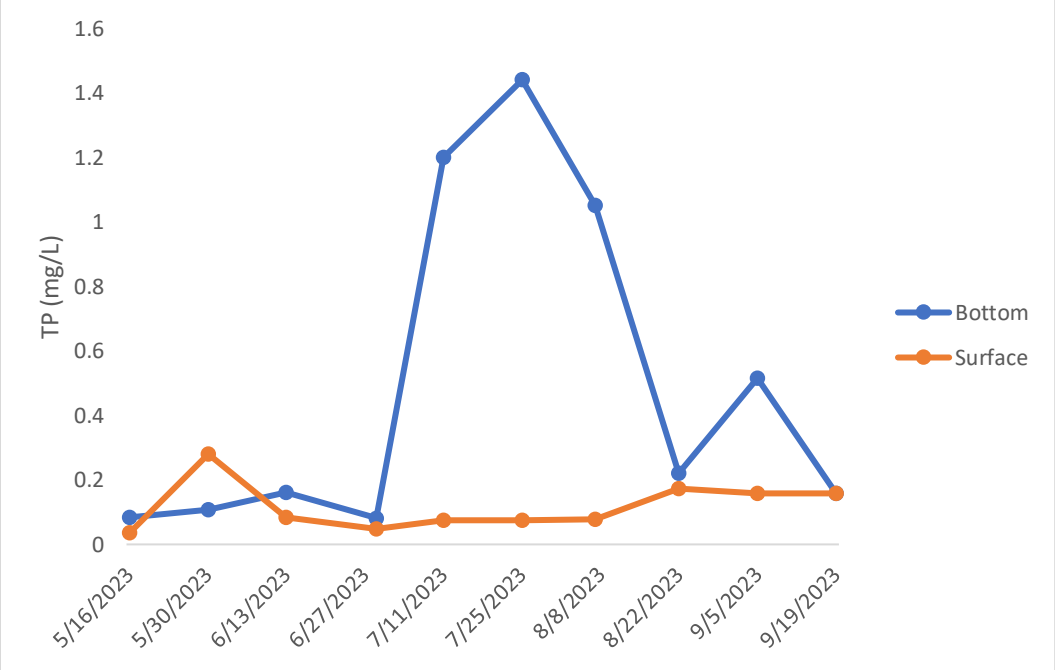

Figure 1. Briggs Lake summer 2023 total phosphorus (TP) concentrations, surface and bottom.

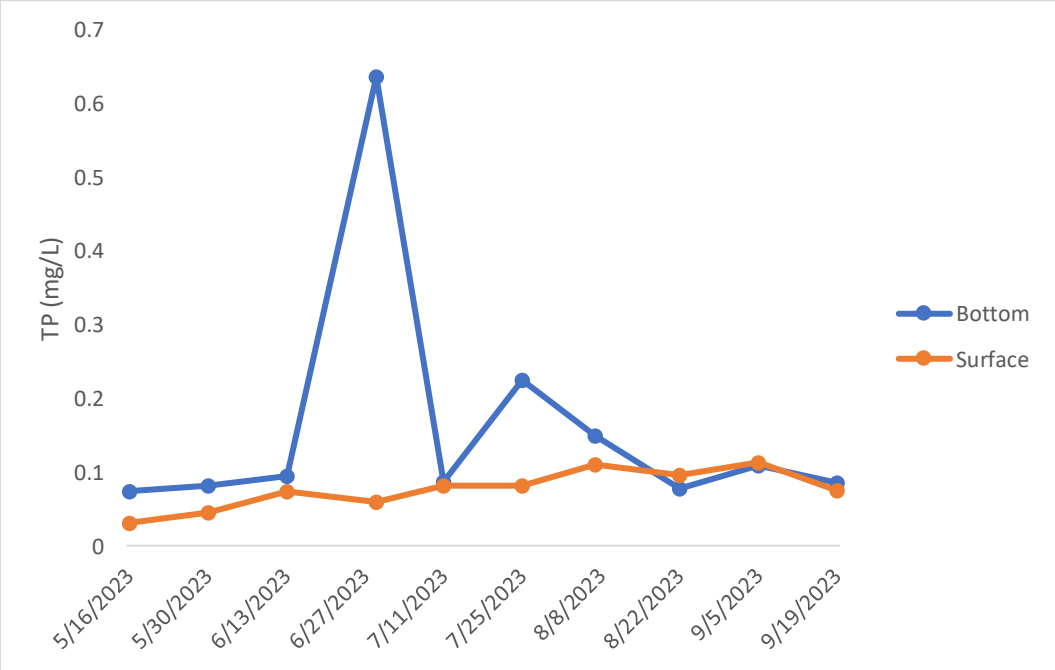

Figure 2. Julia Lake summer 2023 total phosphorus (TP) concentrations, surface and bottom.

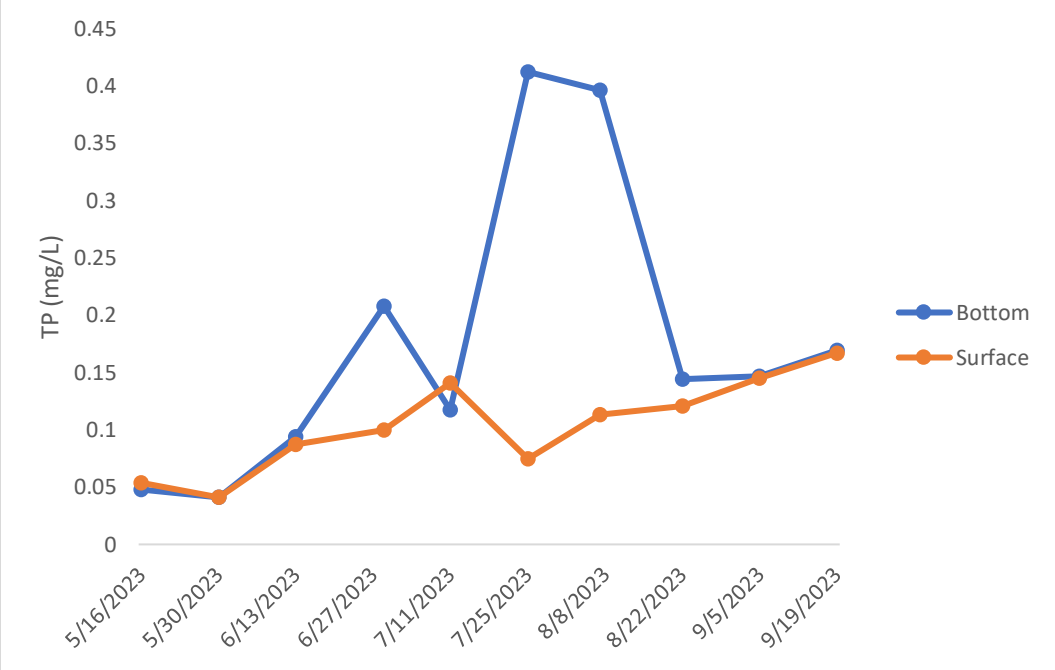

Figure 3. Rush Lake summer 2023 total phosphorus (TP) concentrations, surface and bottom.

The surface water TP concentration in summer generally reflects the net effect of external P loading and algal uptake. In contrast, increasing phosphorus concentration in the bottoms can be indicative of internal P loading from the sediments. This trend is similar among all three lakes and will be discussed further as it relates to the release of phosphorus from lake bottom sediment in the following section.

As part of Stantec's review, trends in Chlorophyll a (Chl-a) and Secchi depth were evaluated using the record of available data. Boxplots for each lake are included in Attachment B. Chl-a and Secchi disk depth (a measure of water clarity) demonstrate high interannual variability and are characterized by low clarity and high algal productivity on average.

Tributary Data

Sherburne County SWCD provided summer TP sample data for the outlets of Briggs Creek and Julia Creek that were measured in 2023. Average values for each sample location are summarized in Table 3. Because there were only three sampling events, and the region experienced drought conditions in 2023, these values were compared with historical sample data at those same locations from 2006, 2007, and 2015 to establish that 2023 sample concentrations were representative. The Briggs Creek sample data provided a baseline snapshot characterization of current tributary loading conditions to Briggs Lake (inclusive of watershed contributions), whereas the Julia Creek sample data provided that same information for tributary loading conditions to Julia Lake. Estimated annual loads for 2006, 2007, 2015, and 2023 from these datasets are summarized in Table 3. In addition, estimates from a 2006 water balance/phosphorus budget analysis performed by the SWCD and 2019 sampling data were included for the Briggs Bayou, which intermittently drains to Briggs Lake during high precipitation periods when the Elk River overtops the

watershed boundary and generates outflow from the Bayou to the lake. The Briggs Bayou was a negligible source of discharge and TP during the 2007 and 2023 sample periods, but a potentially a large contributor of phosphorus during the 2019 monitoring period.

The regional Hydrological Simulation Program Fortran (HSPF) model was used to validate these results, due to the intermittent nature of tributary sampling and uncertainty about representation of annual average conditions due to drought conditions in 2023. Average annual TP loading rates and discharge rates were identified from the Mississippi – St. Cloud (Clearwater-Elk) Hydrologic Unit Code 8 – scale HSPF model, developed as part of Minnesota Pollution Control Agency's (MPCA) Watershed Restoration and Protection Strategy (WRAPS) effort, for the subwatersheds draining to the Briggs Creek and Julia Creek tributary sample locations.

Approximated average tributary annual P loads from the HSPF model are summarized with the grab sample data-based loads in Table 3 for comparison. Note that 2019 was an exceptionally high flow year, and values for Briggs Bayou for that year are coarse estimates. The HSPF model results for Julia Creek are approximately three times higher in terms of total discharge volume and five times higher in terms total annual TP load when compared with the 2023 tributary monitoring results. This discrepancy is likely due to the following factors:

- Longer simulation period of the HSPF model, which simulated average annual condition from 1995-2015
- The absence of regional calibration data at the scale of the Briggs Lake Chain watersheds
- The HSPF model estimates loading for the entire calendar year versus the summer sampling season provided by the tributary data.

The HSPF model subwatersheds, drainage network, and tributary sample locations illustrated in Attachment C for reference.

Table 3. Summary of tributary annual discharge and annual total phosphorus (TP) estimates by data source.

Tributary	Annual Discharge (acre-ft/year)						Annual TP Load (lbs/year)					
	2006 Data	2007 Data	2015 Data	2019 Data*	2023 Data	HSPF	2006 Data	2007 Data	2015 Data	2019 Data*	2023 Data	HSPF
Briggs Creek	3,245	2,998	2,990	-	4,271	2,995	396	474	512	-	634	782
Julia Creek	215	316	188	-	282	913	34	53	28	-	51	257
Bayou	2,423	-	-	123,799	-	-	634	-	-	14,576	-	-

**2019 Bayou data was averaged for a 120-day period, and likely overestimates annual discharge and annual TP load to Briggs Lake.*

Sediment Core Results & Internal Load Calculation

Sediment cores were taken at a single, targeted, locations for all three lakes (Figure 4). Cores were taken from the deepest location of each lake to best represent release rates in areas experiencing anoxic summertime conditions. Sediment cores were also collected to quantify the mobile and non-mobile pools of phosphorus (P) from Julia and Rush Lakes. Four cores were collected from Briggs Lake, and three sediment cores each from Rush and Julia Lakes. Each core was sectioned into two depth intervals (0-5 and 5-10 cm depth intervals) for P fractionation analysis (Table 4), sediment characteristics (i.e., moisture content, bulk density, and percent organic matter), total phosphorus, total iron and total aluminum. The purpose of this analysis is to quantify the pools of P that are subject to diffusion from the sediments and characterize the areal extent of potential internal P loads to determine the feasibility of an alum treatment to suppress internal P loads.

Table 4. Operational grouping and recycling potential of phosphorus fractions.

Operational Grouping	P Fraction	Recycling Potential
Mobile P pool	Iron-bound P	Biologically-labile and may be recycling through biogeochemical and geochemical reactions
	Loosely-bound P	
	Labile organic P	
Non-mobile P pool	Aluminum-bound P	Biologically-refractory and subject to burial; not readily available for biological uptake.
	Calcium-bound P	
	Refractory P	

Reference: 227706313

After collection, the cores were incubated and analyzed by the University of Wisconsin-Stout laboratory. Two core samples were taken at each lake location to control for variability in release rate and field collection error, and the average of the two samples was used to represent anoxic release rates for each lake. Measured release rates are summarized in Table 5.

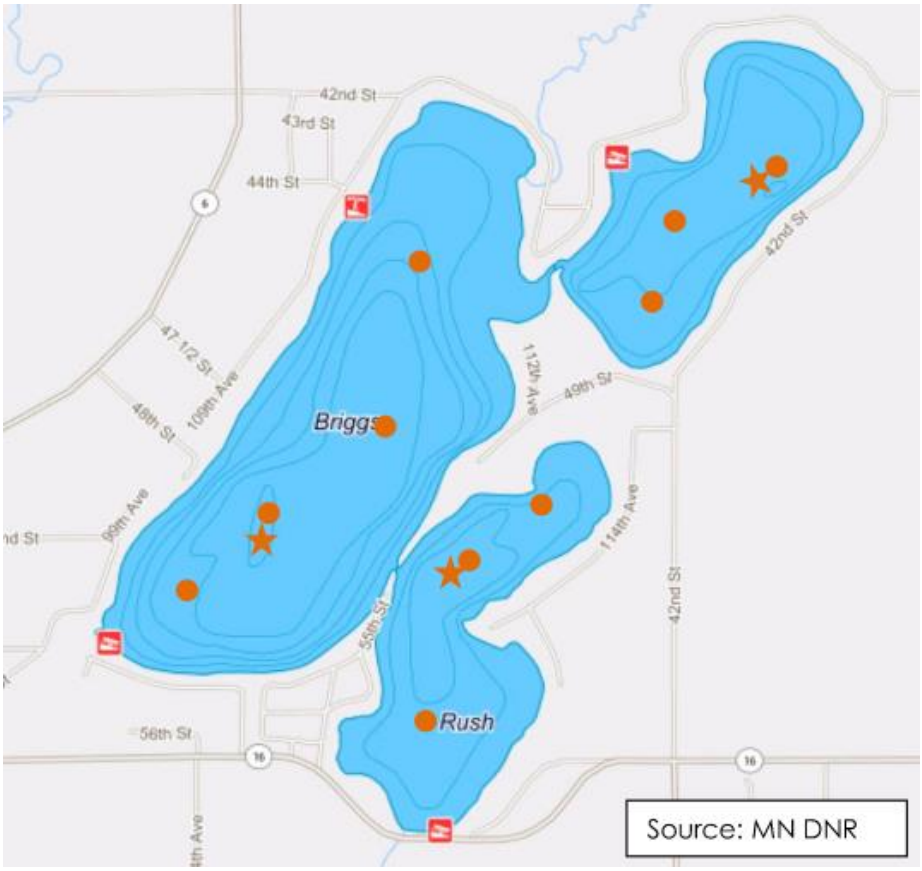

Figure 4. Approximate sediment coring locations in Briggs, Julia and Rush Lakes. Orange stars represent core locations for sediment P release rates. Orange circles represent locations where sediments were collected for quantification of the various pools of phosphorus (P fractionation).

Table 5. Measured anoxic release rates for each lake. Average release rate is the average of duplicate sediment core lab results.

Lake Name	Release Rate (mg/mg^2-day)		
	Sample 1	Sample 2	Average
Briggs	8.23	11.19	9.7
Julia	3.93	5.26	4.6
Rush	2.02	1.99	2.0

The pools of phosphorus most likely to diffuse from the sediments under anoxic conditions include the loosely-bound P and iron-bound P (see Table 4). Collectively, loosely-bound P and iron-bound P are referred to as redox-P, which is typically the primary basis for an aluminum sulfate (alum) treatment that functions to reduce internal sediment P release. We evaluated the lateral and vertical spatial variability in redox-P along with the P release rates and modeling results to assess the feasibility of an alum treatment to reduce internal load. This data is also used to determine the alum treatment area and application strategy (discussed further in the Management Recommendations section and Attachment G).

In general, the mass of phosphorus in the deeper Briggs Lake sediments was nearly double the mass found in the two shallow regions. This observation is expected as settling material tends to accumulate in the deeper regions of a lake just due to physics and hydrodynamic focusing. The deeper areas in Briggs Lake showed redox-P concentrations that were roughly twice as high as in Julia and Rush Lakes (Figure 5). Combined with the measured phosphorus release rates, these data indicate that internal phosphorus loading under anoxic conditions is a bigger problem in Briggs Lake than in Julia or Rush (Figure 6 & Figure 7).

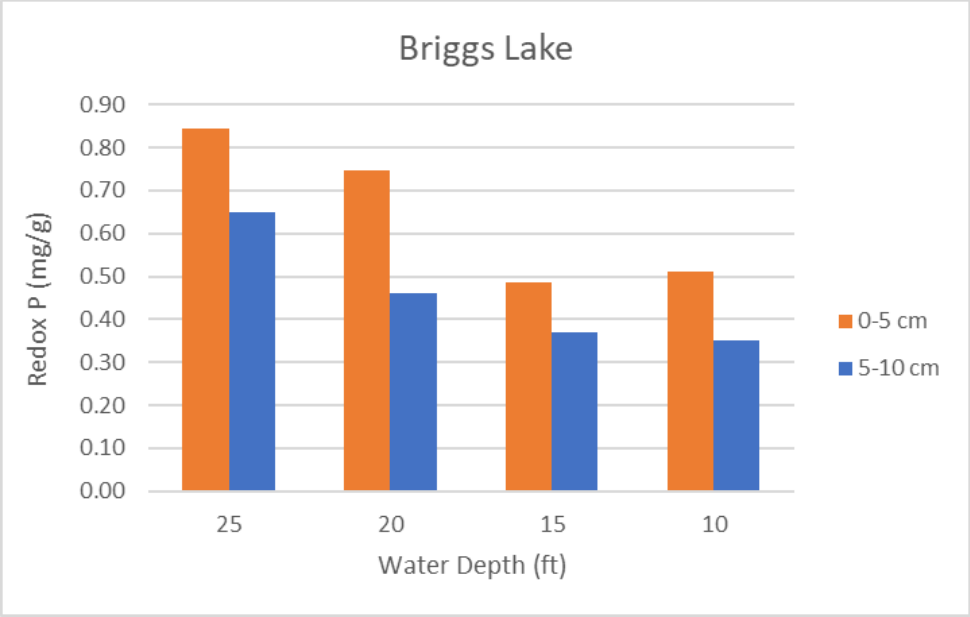

Figure 5. Redox-P concentrations in the upper 0-5 cm and 5-10 cm vertical sediment depth intervals in Briggs Lake across four water depths.

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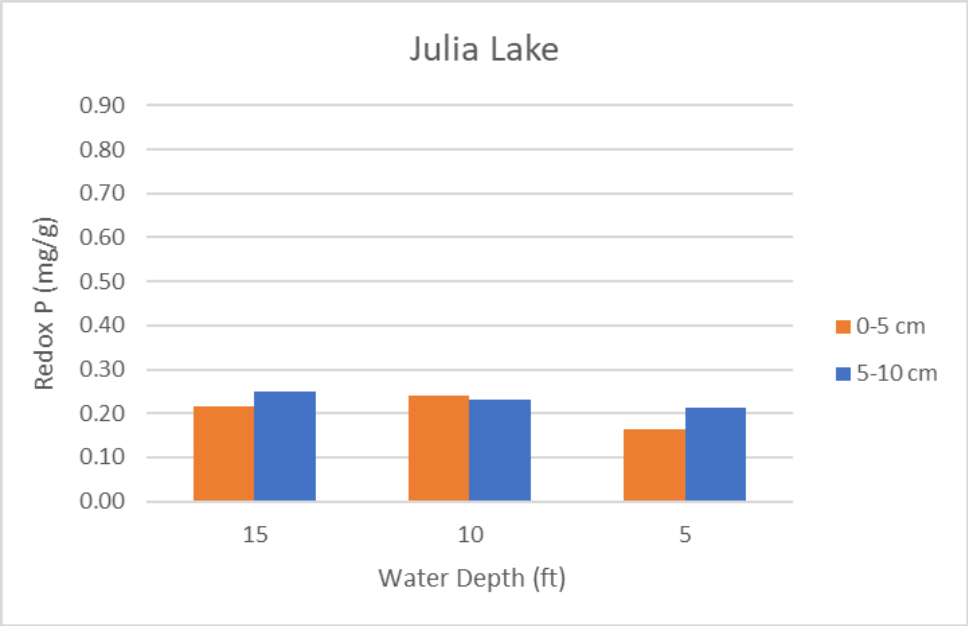

Figure 6. Redox-P concentrations in the upper 0-5 cm and 5-10 cm vertical sediment depth intervals in Julia Lake across three water depths.

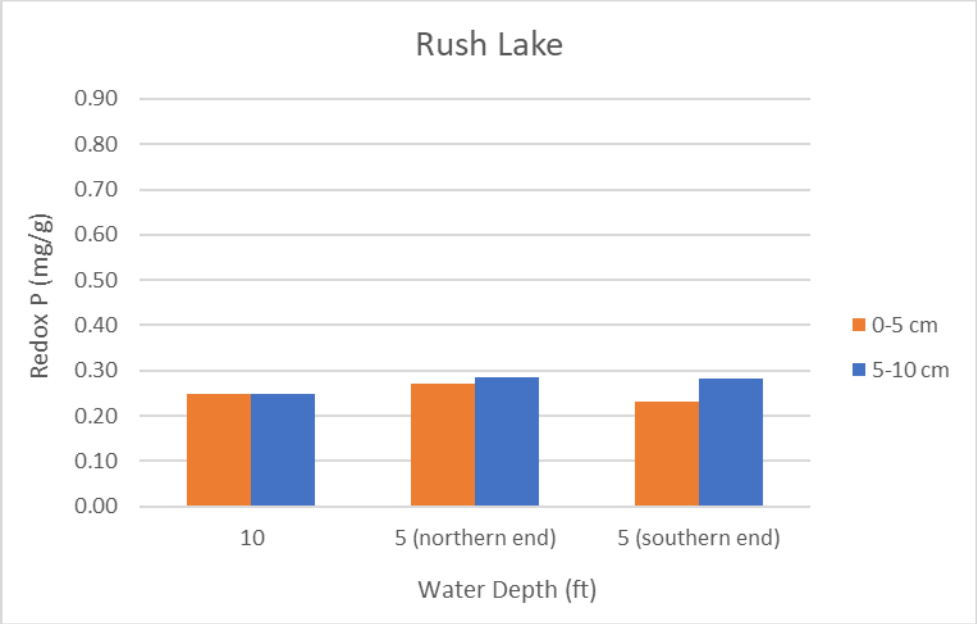

Figure 7. Redox-P concentrations in the upper 0-5 cm and 5-10 cm vertical sediment depth intervals in Rush Lake across three water depths.

Other Model Inputs & Assumptions

Phosphorus loads originating from sources external to the lake were estimated for landscape processes/direct runoff and atmospheric deposition using a combination of empirically derived values and previously modeled results[2]. Internal loads were estimated by pairing the lab measured phosphorus release rates outlined above, and the number of anoxic days in the hypolimnion, which was calculated using an empirically derived equation developed by Nurnberg (2005)[3]. Anoxic days were estimated for Julia and Rush using the Nurnberg (2005) equation for polymictic lakes, whereas Briggs was estimated using the equation for stratified lakes. Each phosphorus source and its corresponding source dataset are summarized in Table 6 below.

Table 6. Summary of dataset sources for phosphorus loading estimates used for lake response model development.

Phosphorus Source	Dataset
Landscape/runoff	2023 tributary data; HSPF results; 2006, 2007, 2015, and 2019 tributary data were used to validate annual average conditions were well approximated by the 2023 tributary data
Atmospheric	Atmospheric loading rate estimates from Barr (2004)[4]
Internal	(1) Measured sediment core release rates and (2) Empirically derived equation for estimating number of days of anoxia

COMMON CARP

Carp can exacerbate sediment phosphorus release through their nesting and foraging behaviors. When carp population densities exceed 100 kg/ha they are likely to cause significant impacts to aquatic vegetation in shallow lakes and densities above 200 kg/ha tend to negatively impact water quality[5]. Given the potential abundance of carp in these lakes, it is important to estimate the potential contribution of phosphorus from carp relative to the total load. Two carp surveys were conducted in August and September of 2024 to determine the estimated population size in each lake. These population estimates were used to calculate phosphorus loads from carp density based on literature values, which is discussed in the following section. Details on the carp surveys and population estimation can be found in **Attachment D.**

Table 7 shows the estimated TP loads based on carp survey data, and the percentage of the estimated TP load due to carp relative to the total TP load estimated in each lake response model. These estimates were based on values cited in Ramsey-Washington Metro Watershed District's *Phalen Chain of Lakes Carp Population Study*[6]*;* carp sediment P release was estimated between 1.07 mg P/m^2/day to 2.18 P/m^2/day for

[2] HSPF Model for St-Cloud-Mississippi
[3] Nürnberg, G. K. 2005. Quantification of internal phosphorus loading in polymictic lakes. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 29(2), 623-626.
[4] Barr Engineering. 2004. (Updated 2007). Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for the Minnesota Pollution Control Agency, St. Paul, MN.
[5] Bajer, P., G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632(1):235-245.
[6] Ramsey-Washington Metro Watershed District (RWMWD). November 2006. Phalen Chain of Lakes Carp Population Study.

carp populations of 200 kg/ha. The TP load estimates in Table 7 are based on the high load estimates from Ramsey-Washington carp study (2.18 P/m^2/d) and were only applied to the littoral zone area of each lake, which are areas where carp are most likely to inhabit.

Table 7. Estimated annual total phosphorus contributions from carp, by lake. The right-most column of the table demonstrates the estimated carp TP load relative to the total load estimated from the lake modeling exercise. Note that current carp densities are coarse estimates based on typical carp densities for similar lakes. Densities will be updated when carp sampling is completed in summer 2024.

Lake Name	Lake Area (acres)	Littoral Area (acres)	Carp Density (kg/ha)	Annual Carp TP Load (lbs)	Carp TP (% of total)
Briggs	404.4	170	584	554	25%
Julia	154.5	154.5	460	503	64%
Rush	160.9	160.9	601	524	40%

Additionally, the following assumptions were made regarding TP sources and their datasets:

- Stantec used TP loads from HSPF to estimate runoff for each model. As a validation step, these results were compared with TP loads estimated from tributary data collected in 2006, 2007, 2015, and 2023. Generally, the HSPF results were consistent with prior estimates on a *concentration* basis. However, the HSPF model may have overestimated TP loads and runoff based on our evaluation of available tributary data.
- In the absence of groundwater TP data, groundwater TP contributions were assumed to be negligible for all three lakes.
- In the absence of groundwater inflow data, groundwater inflow was assumed to be negligible for all three lakes.
- Assumed dry conditions for atmospheric loading rate. This is consistent with prior lake modeling efforts in this system.
- Assumed that the flushing rate (i.e., inverse of residence time) is equal to the total annual inflow to the lake divided by the lake volume. This is consistent with prior lake modeling efforts for this system.
- Annual loading estimates cannot accurately estimate Bayou contributions without more robust modeling approaches due to the intermittent nature of Bayou hydrology.

Lake Response Model Setup

Lake response models were set up for each lake using a series of Excel-based spreadsheets to employ the Canfield-Bachman equation for natural lakes. The Canfield-Bachman equation “models” in-lake TP concentrations based on an empirically-based regression analysis of lake data for natural lakes in North

America. More details on the Canfield-Bachman equation can be found in the Wisconsin Lake Modeling Suite (WiLMS) documentation[7]. The equation is summarized below:

$$P = \frac{L}{z(.162(L/z)^{0.458} + p)}$$

Each of the model (equation) variables are listed in Table 8 below. The resulting value, *P*, is used for comparison with the observed in-lake mean concentration. The fit of observed versus simulated concentration is used as a performance benchmark for verifying the accuracy and completeness of model inputs. Values for the primary model inputs, characterized in detail by source, are summarized in Attachment E.

Table 8. Canfield Bachman equation variables for natural lakes.

Variable Name	Variable Description
P	Predicted mixed layer TP concentration (µg/L)
L	Areal TP load (mg/m^2-yr)
Z	Mean lake depth (m)
p	Flushing rate (yr^{-1})

All three lakes met the conditional model constraints of applying the Canfield Bachman equation for natural lakes, which are as follows:

- 4 < P < 2600 mg/m^3
- 30 < L < 7600 mg/m^2 -yr
- 0.2 < z < 307 m
- 0.001 < p < 183/yr

Lake Response Model Results

Surface TP concentration estimated by each model, and their corresponding observed average surface TP concentration are summarized in Table 9 below.

[7] Wisconsin DNR. (2003). Wisconsin Lake Modeling Suite Program Documentation and User's Manual Version 3.3 for Windows.

Table 9. Comparison of lake response model estimated TP concentrations and observed TP concentrations.

Model	Average Surface TP Concentration (µg/L)	
	Estimated	Observed
Briggs Lake	115.7	114
Julia Lake	73.7	79
Rush Lake	118.3	106

The results indicate that the models are adequately characterizing TP loading to all three lakes on an annual basis. The concentration estimated by each model is uncalibrated, meaning no adjustments were made to TP loads estimated for each source. For example, typical practice is to increase or decrease estimated loading sources based on disagreement between estimated and observed (i.e., measured) concentrations, where informed adjustments are made based on knowledge of data limitations, uncharacterized sources, or processes not captured by the models. The close match of estimated and observed concentrations, across all three lakes, suggests that the models' inputs are characterized well.

One of the primary objectives of this study was to determine the relative magnitude of the sediment P release rates under anoxic conditions as it relates to other external sources of phosphorus to the lakes. The lake response model results suggest that internal loading is the predominant source of TP in Briggs Lake, on an annual basis (approximately 50% of the total load).

The results suggest that sediment phosphorus release does not play a large role in the phosphorus budget for Julia Lake (~ 19% of total load) or in Rush Lake (approximately 7% of the total load). Upstream contributions from Briggs Lake, and carp, are larger contributors of TP in Julia and Rush Lakes.

Figure 8 through Figure 10 below characterize pollutant sources by their relative contribution, for each lake.

Reference: 227706313

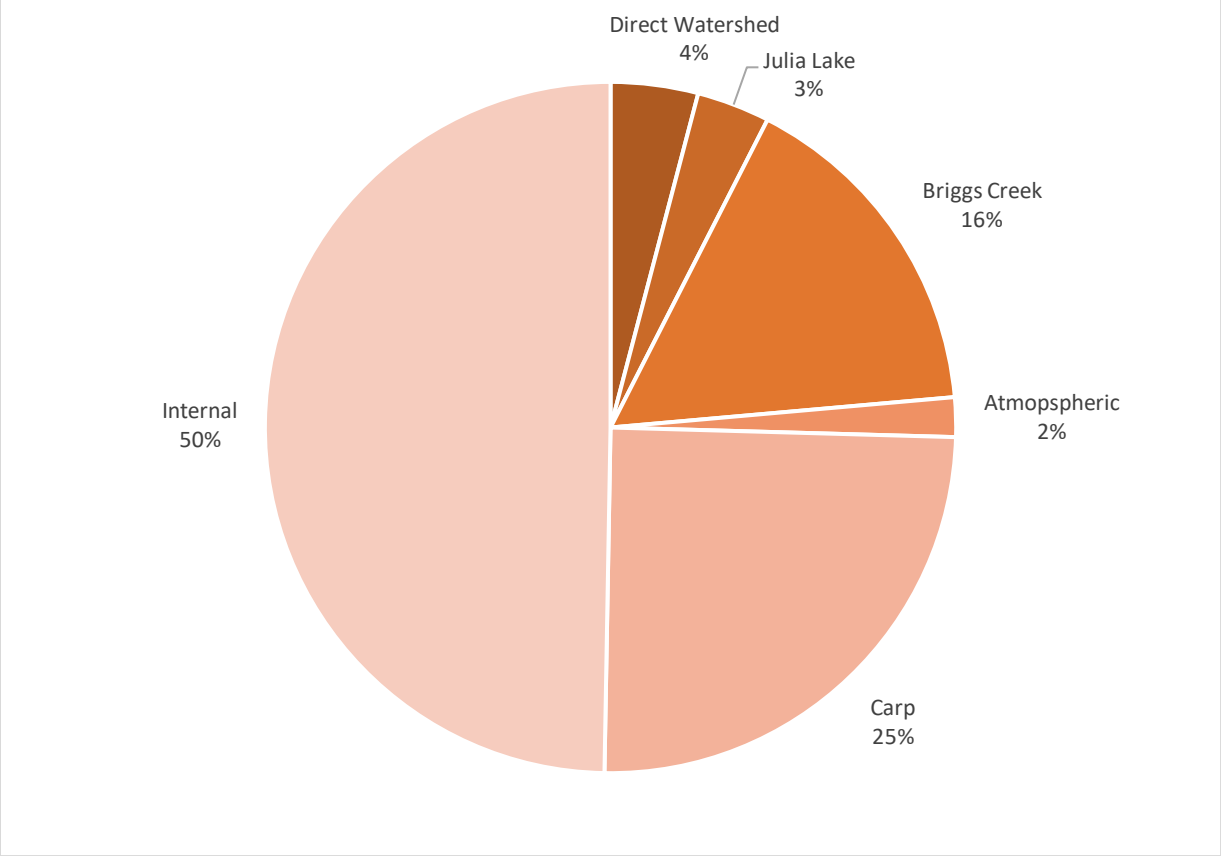

Figure 8. Briggs Lake total phosphorus budget. Annual percent contribution by source as estimated by lake response model.

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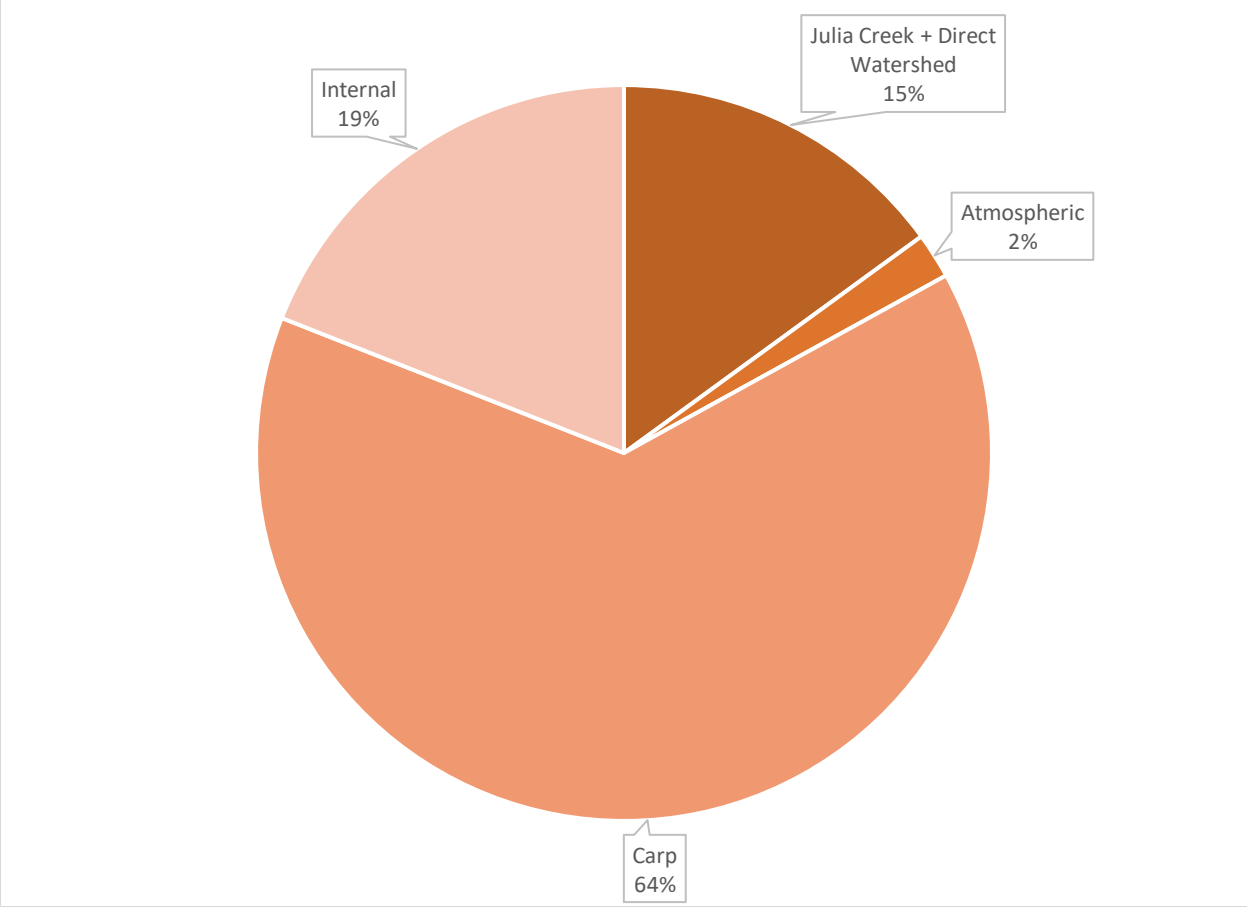

Figure 9. Julia Lake total phosphorus budget. Annual percent contribution by source as estimated by lake response model.

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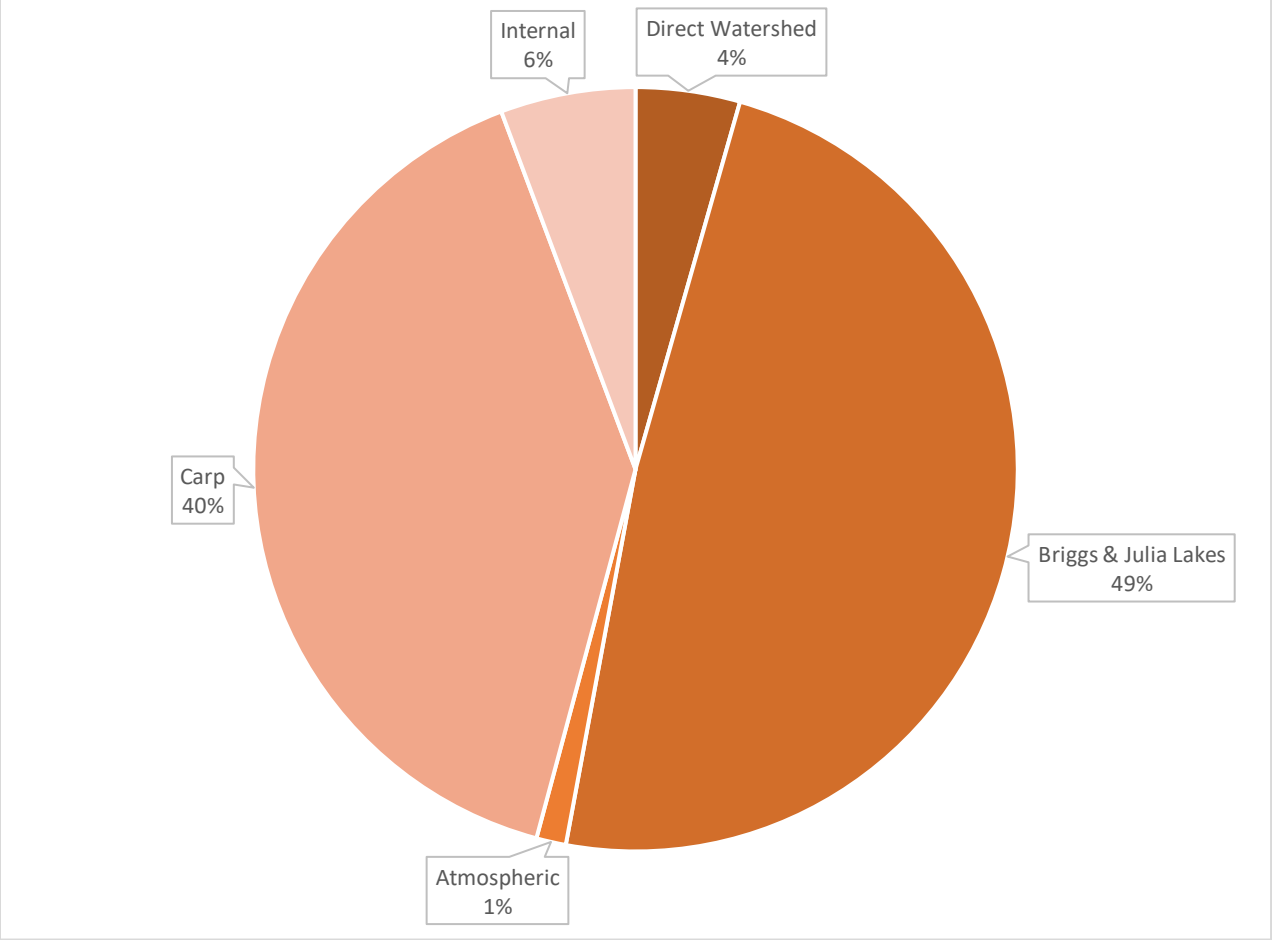


Figure 10. Rush Lake total phosphorus budget. Annual percent contribution by source as estimated by lake response model.

Model Summary

The lake response modeling exercise suggests that Briggs Lake has significant internal loading due to sediment phosphorus release, which is summarized in Table 10 below. While Julia has what is considered a high sediment phosphorus release rate (4.7 mg/m^2/year), the annual internal load from sediment release it is not as large of a phosphorus source as the other source estimates. For example, the Briggs Lake internal phosphorus load from sediment release is estimated to be upwards of 50% of the total annual TP load, followed by Julia at 19% and Rush at 6%. The lake with the lowest internal load from sediment release, as a percentage of total annual TP load, is Rush Lake (6% of the total load).

Table 10. Summary of internal phosphorus loads compared with the total estimated load for each lake.

Lake	Lake Area (acres)	Estimated Internal TP Load (lbs/year)	Estimated Total TP Load (lbs/year)	% of Internal P Load to Total TP Load
Briggs	404.4	2,416	4,860	50%
Julia	154.5	326	1,714	19%
Rush	160.9	163	2,847	6%

Using the model results, the assimilative capacity was calculated for each lake. The assimilative capacity is defined as the greatest contribution of TP, on an annual basis, that each lake can receive while still meeting state water quality standards. The results of this analysis are summarized in Table 11.

Table 11. Summary of assimilative capacity for Briggs, Julia, and Rush Lakes based on 2024 lake response models.

Lake (TP Criteria)	Estimated Annual TP Load	Estimated Annual TP Load to meet standard	Estimated Percent Reduction to meet standard
Briggs (40 µg/L)	4,860	1,040	78.6%
Julia (60 µg/L)	1,714	1,310	23.6%
Rush (60 µg/L)	2,847	1,230	56.8%

Management Recommendations

The results of this study indicate the need for the in-lake management recommendations which are summarized in Table 12. Notably, phosphorus loading to the lakes from external sources needs to be reduced, so Stantec recommends continued efforts to reduce watershed nutrient loading which will benefit all three lakes. From an internal lake management perspective, carp removal in Julia and Rush Lakes is recommended because carp density in both lakes exceed the water quality threshold, which indicate that carp are exacerbating poor water quality in these two lakes. Given the hydrologic connectivity between Briggs, Julia and Rush Lakes, carp management needs to be considered for the entire lake chain. This approach may include radio telemetry and tracking of carp movement to determine primary spawning areas with future management actions including installation of fish barriers to limit migration into spawning areas and subsequent removal of carp biomass.

Table 12. Recommended management actions to reduce phosphorus loads in the Briggs Chain of Lakes.

Lake	Management Recommendations
Briggs	• Alum treatment • Continue watershed reduction actions
Julia	• Carp removal/management • Continued watershed reduction actions
Rush	• Carp removal/management • Continued watershed reduction actions

Reduced phosphorus loads leaving Briggs Lake will benefit Rush Lakes. As internal loading in Briggs Lake was approximately half of the total load, we recommend an aluminum sulfate (alum) treatment to reduce sediment phosphorus release.

The recommended dose, treatment area and estimated costs are shown in Table 13. Attachment G contains a summary of the alum dosing scenario analysis and cost-benefit comparison among different treatment scenarios. A single application is recommended for Briggs Lake given the high proportion of phosphorus derived from internal sources (i.e. sediment release from diffusive flux and via carp disturbance). The alum treatments presented in Attachment G assume a horizontal treatment area that varies as shown but the treatment depth is 5 cm for all three scenarios. We estimated the longevity of a single alum application by approximating the length of time for phosphorus sedimentation to bury the alum dose under 5 cm of accumulation sedimented material. Based on the current assumed external P loading rate, the alum layer would remain in the upper 5 cm of sediment for approximately 6-7 years. At that time, a second alum application may be needed to mitigate diffusive flux of sediment P release, depending upon the continued extent of external P loading and carp management efforts. There is not a lot of information in the literature regarding the ideal sequencing or parallel management of carp and implementation of alum treatments, which really depends on site-specific conditions. Carp will disturb the sediments in more shallow areas whereas in Briggs, the alum is recommended for water depths over 20 ft, which are not likely to experience abundant grazing and sediment disturbance by carp. As long as there are active binding sites on the applied alum, phosphorus will bind with alum regardless of temporal and intermittent sediment resuspension induced by carp activity.

Based on recent unit prices for similar treatment in Minnesota, the material costs for the recommended treatment scenario for Briggs Lake is approximately $915,362, which does not include contractor fees for the application. Typically, contractor fees for a 122-acre application would be approximately $30,000 depending on the selected contractor and not assuming any inflation from now until 2025 or 2026 when the application might occur. Table 14 shows the additional expenses needed for an alum treatment includes development of bidding documents with technical specifications for the applicator, bid support including solicitation and management, application oversight reviewing delivery logs and monitoring pH in the lake, and applicator mobilization and demobilization fees.

Reference: 227706313

Table 13. Alum dose, treatment area and estimated material costs for Briggs Lake.

			Volume of Material		Estimated Cost*		
Treatment Area	Treatment area (acres)	Alum Dose (g Al/m^2)	Alum (gal)	Buffer (gal)	Alum ($)	Buffer ($)	Alum + Buffer ($)
≥ 20 ft	122	127	125,737	62,868	313,084	602,278	915,362

**Cost assumes $2.50/gal of aluminum sulfate (alum) and $9.58/gal of sodium aluminate (buffer). Material prices fluctuate with market prices and are subject to change.*

Table 14. Estimated Full-Cycle Cost for Alum Treatment to Briggs Lake. Cost estimate includes fees for consultant support on bidding and RFP management as well as alum applicator mobilization and demobilization fees.

Item	Estimated Cost
Development of Bid Documents, Technical Specifications	$3,500
Develop and Manage RFP and Contractor Bids	$2,000
Application Oversight including pH monitoring	$3,000
Alum Contractor Mobilization and Demobilization	$30,000
Estimated Alum Material Costs	$915,362
Total Estimated Cost for Single Alum Treatment to Briggs Lake	$953,862

Reference: 227706313

Attachment A – Lake Profiles

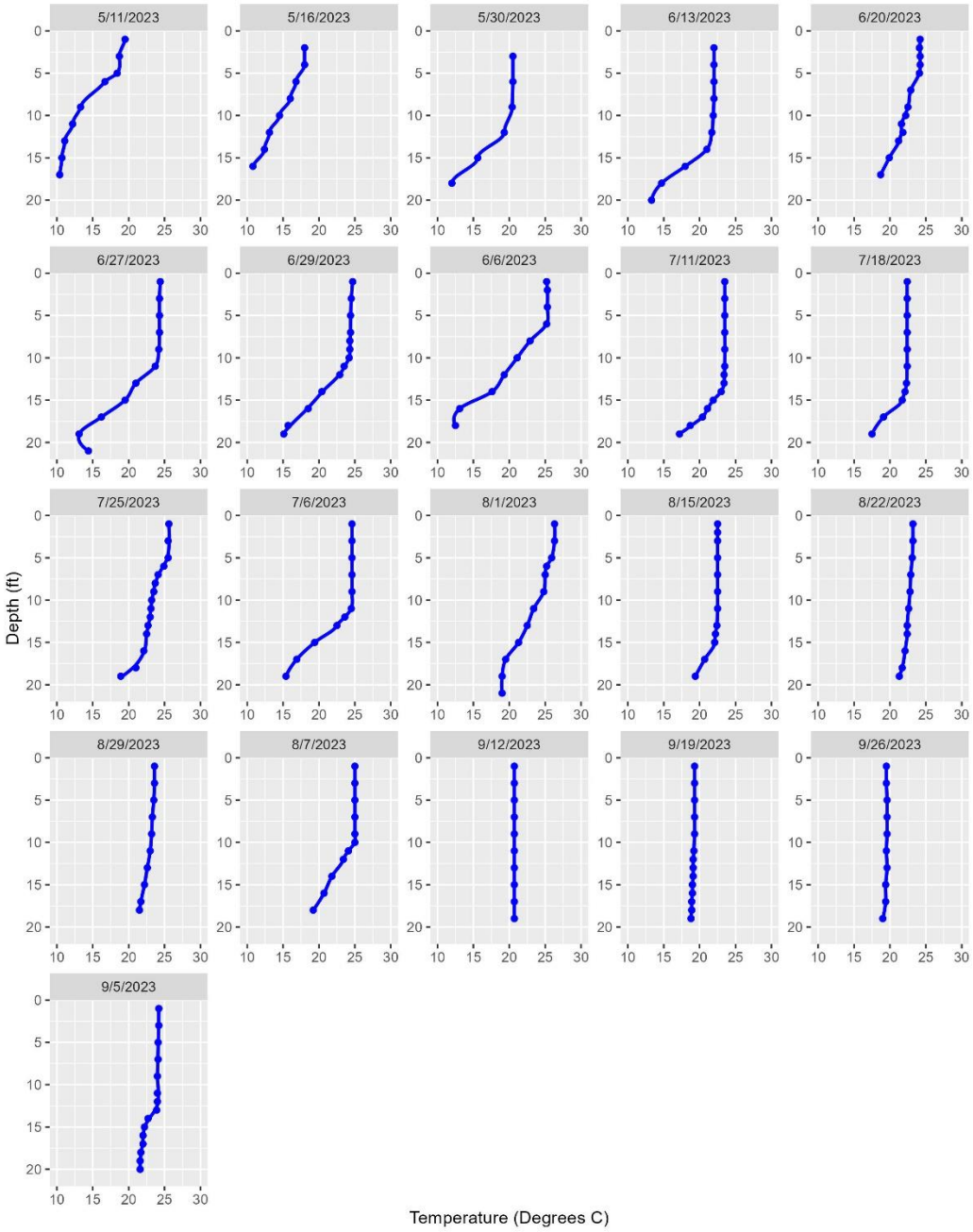


Figure 11. Briggs Lake temperature profiles, 2023.

Reference: 227706313

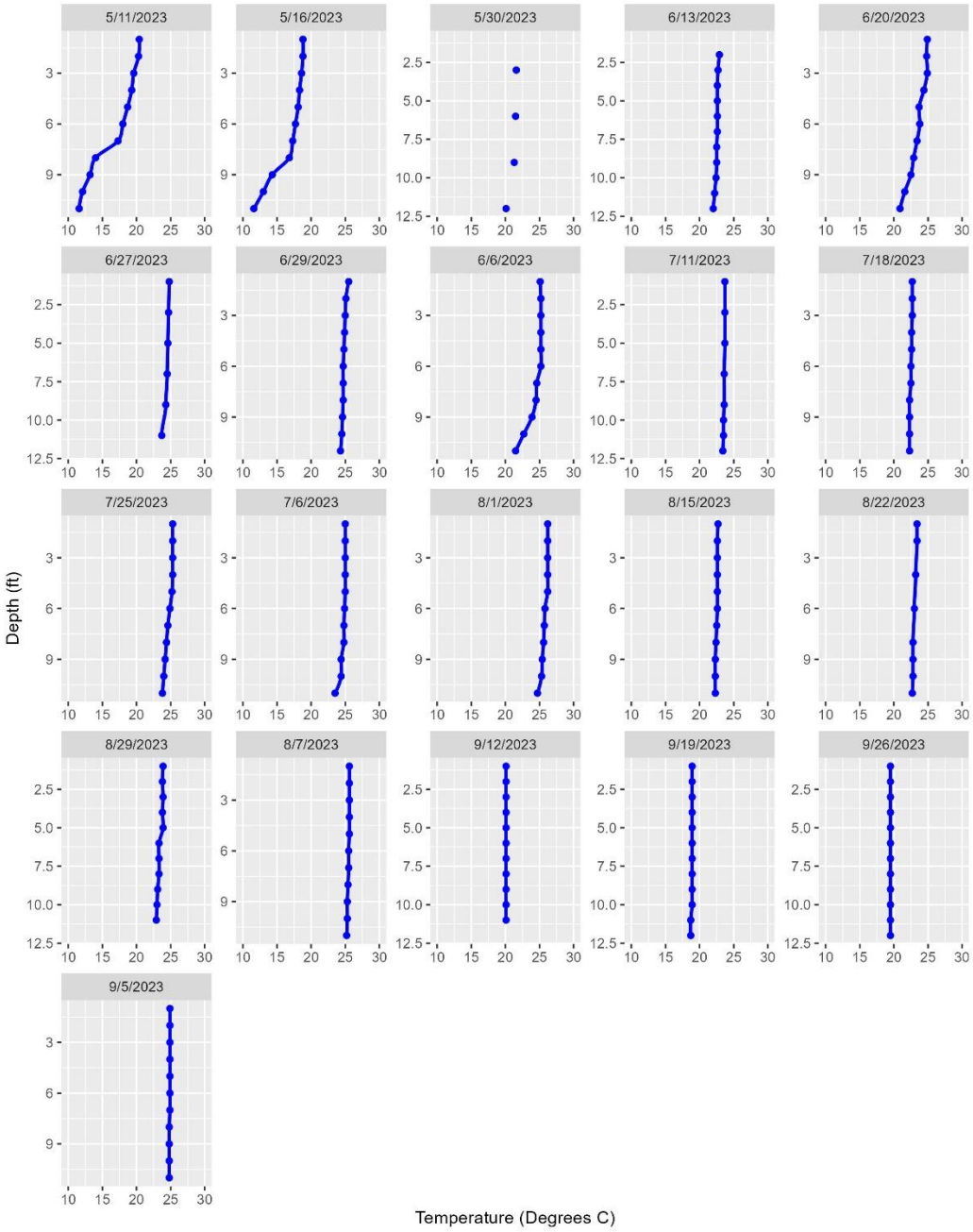


Figure 12. Julia Lake temperature profiles, 2023.

Reference: 227706313

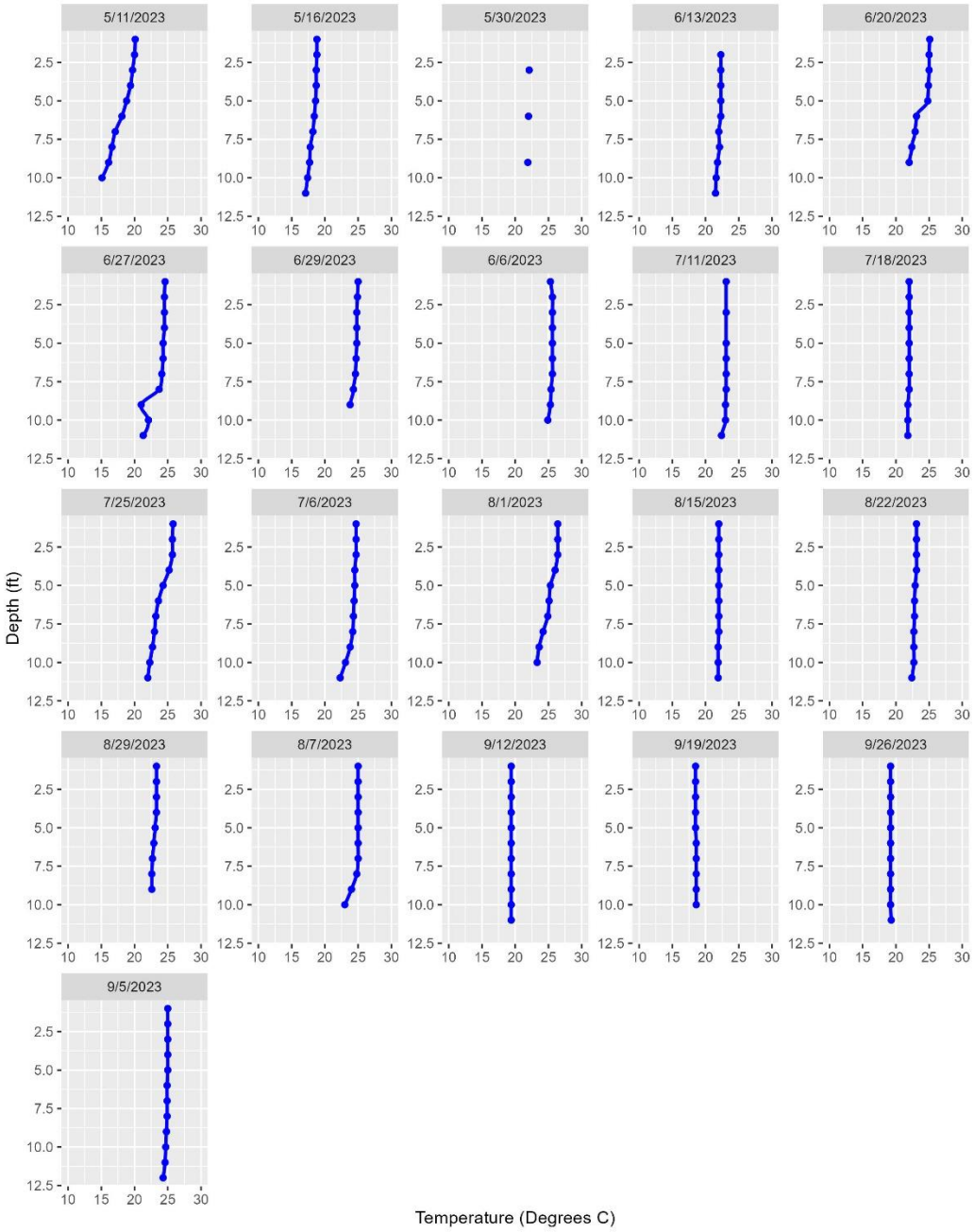


Figure 13. Rush Lake temperature profiles, 2023.

Reference: 227706313

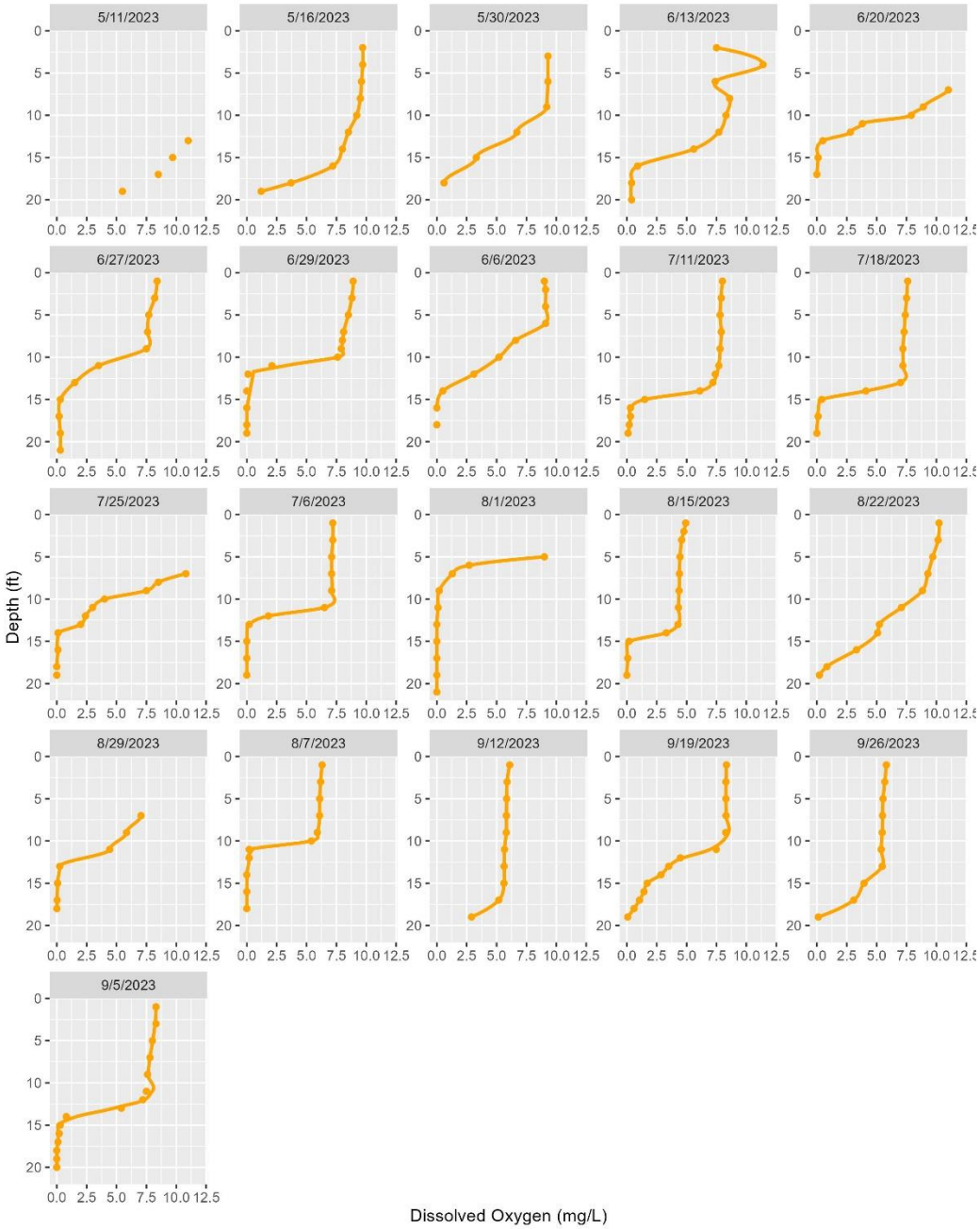


Figure 14. Briggs Lake DO profiles, 2023.

Reference: 227706313

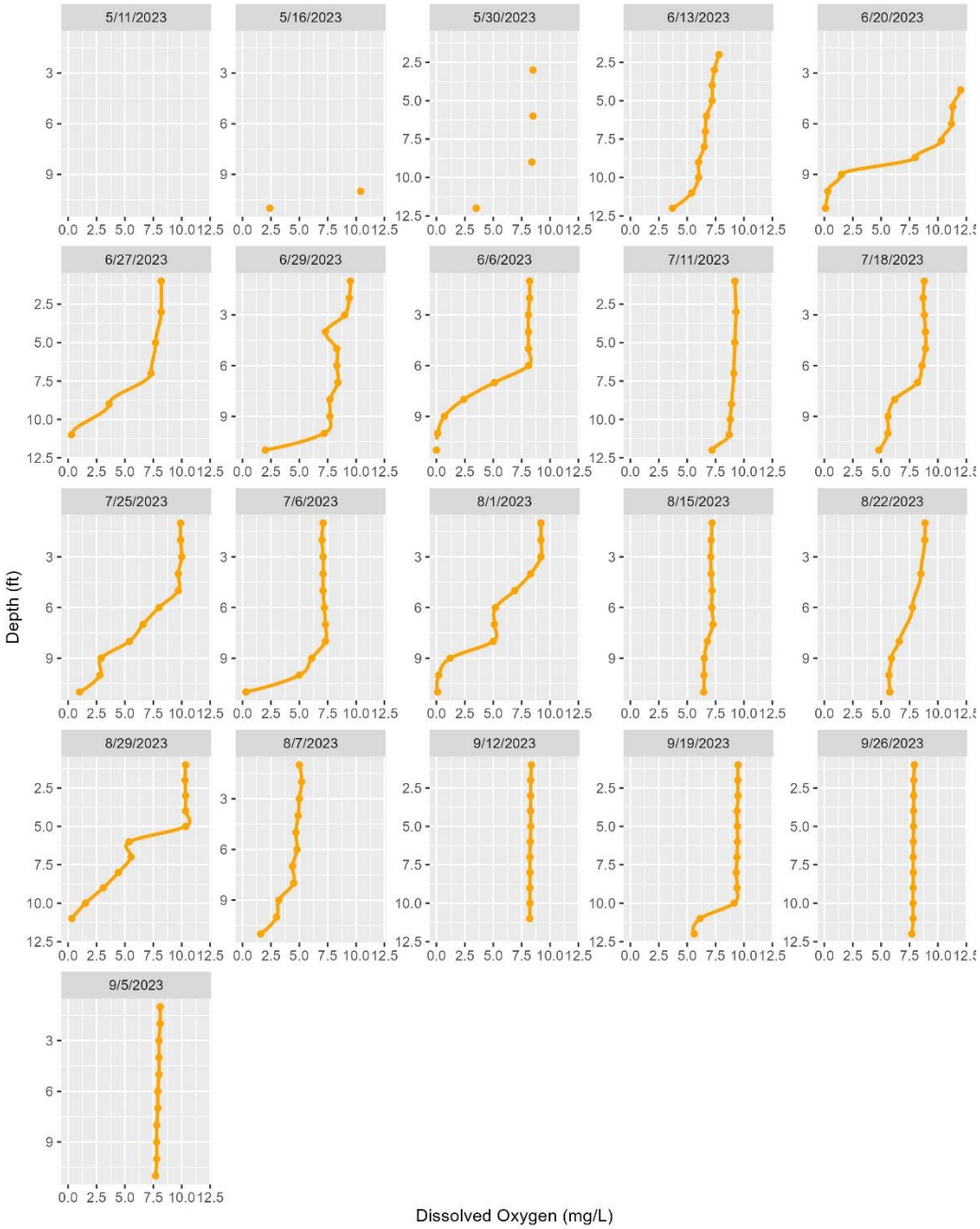


Figure 15. Julia Lake DO profiles, 2023.

Reference: 227706313

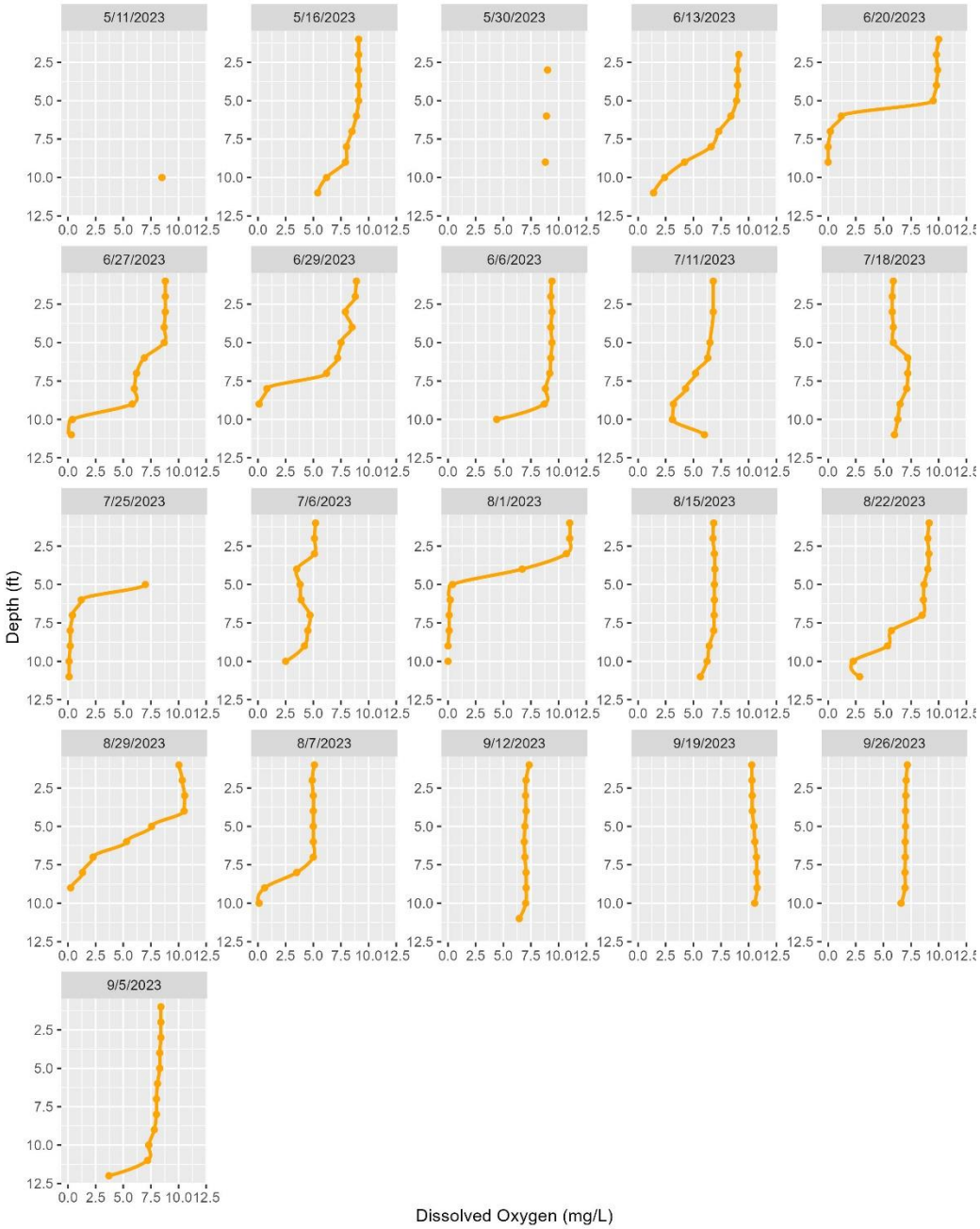


Figure 16. Rush Lake DO profiles, 2023.

Reference: 227706313

Attachment B – Ancillary Lake Water Quality Data

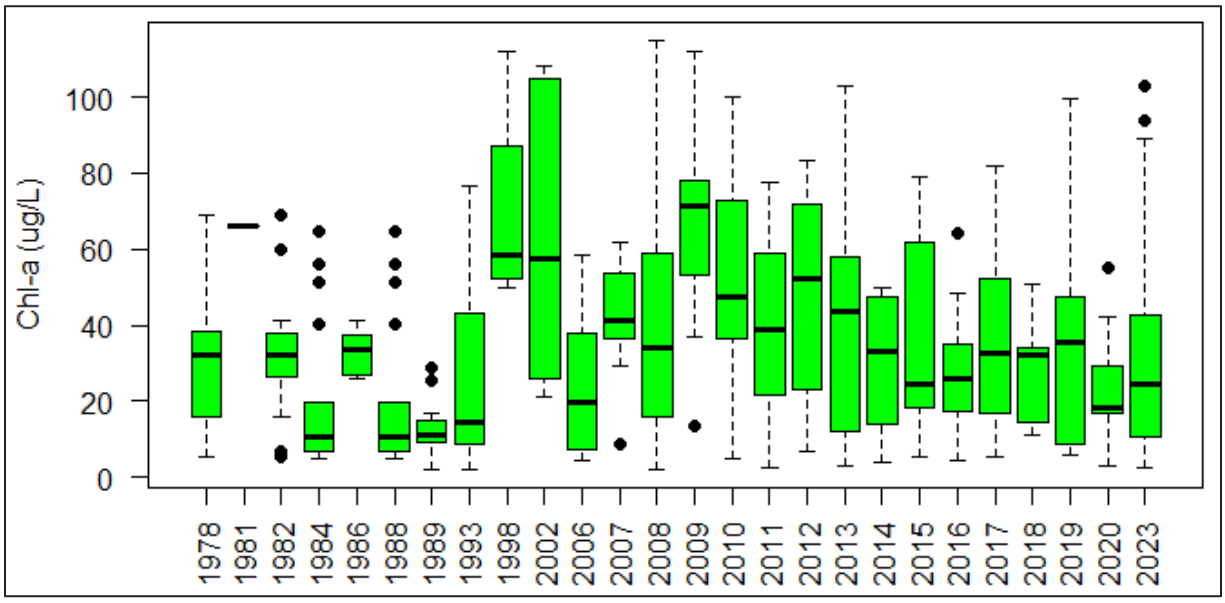


Figure 17. Briggs Lake Chlorophyll a concentration, 1978-2023.

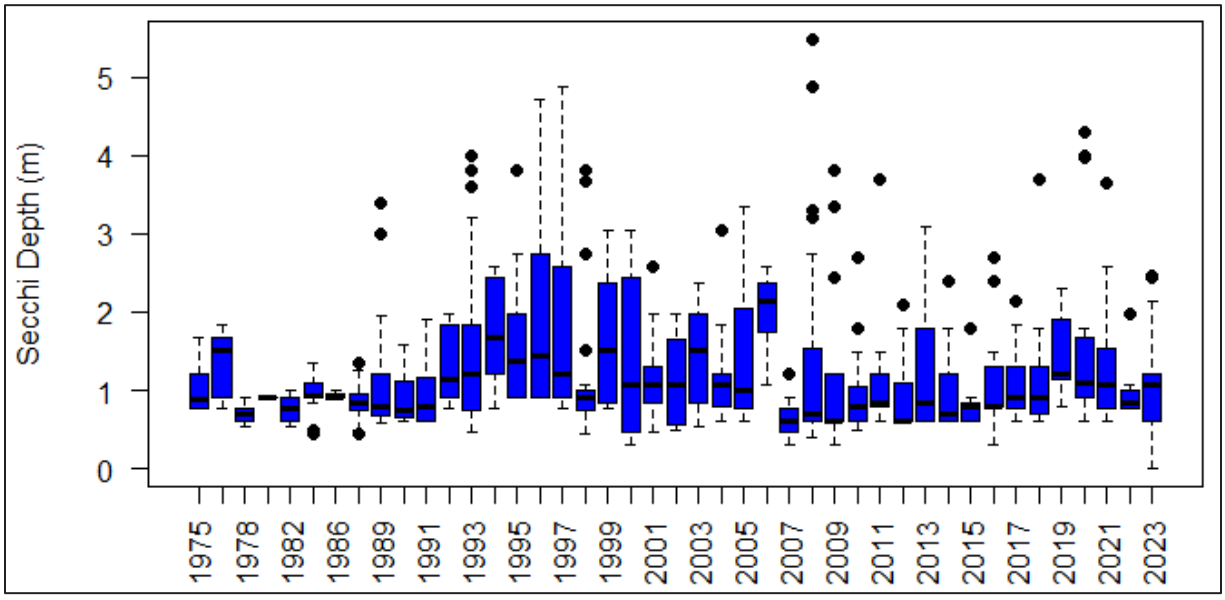


Figure 18. Briggs Lake Secchi depth results, 1975-2023.

Reference: 227706313

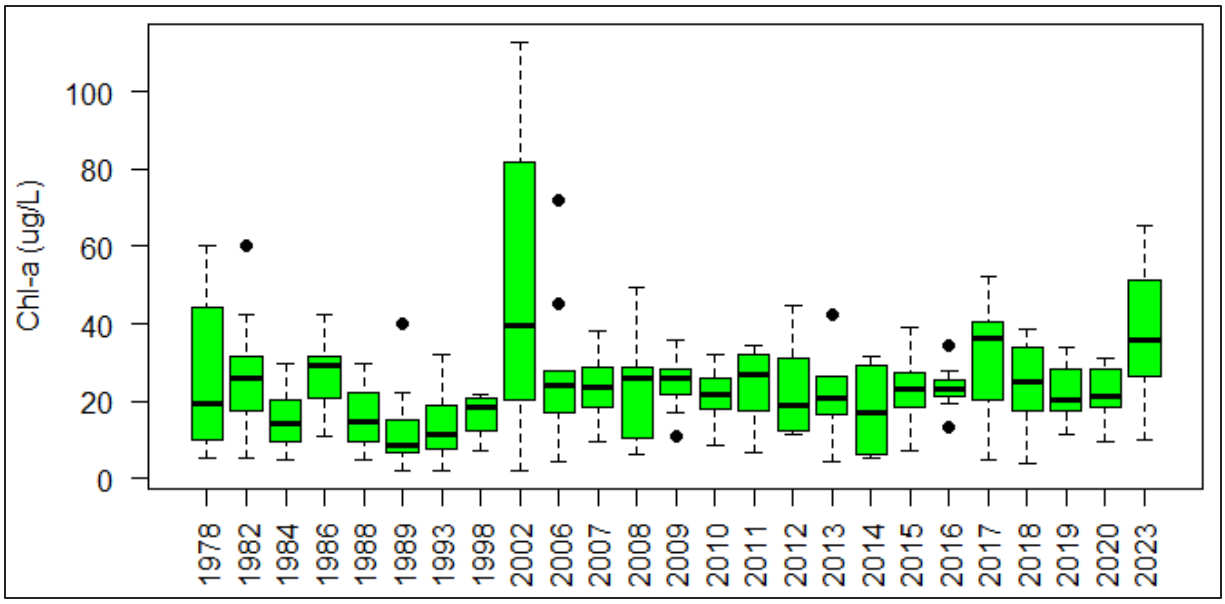


Figure 19. Julia Lake Chlorophyll a concentration, 1978-2023.

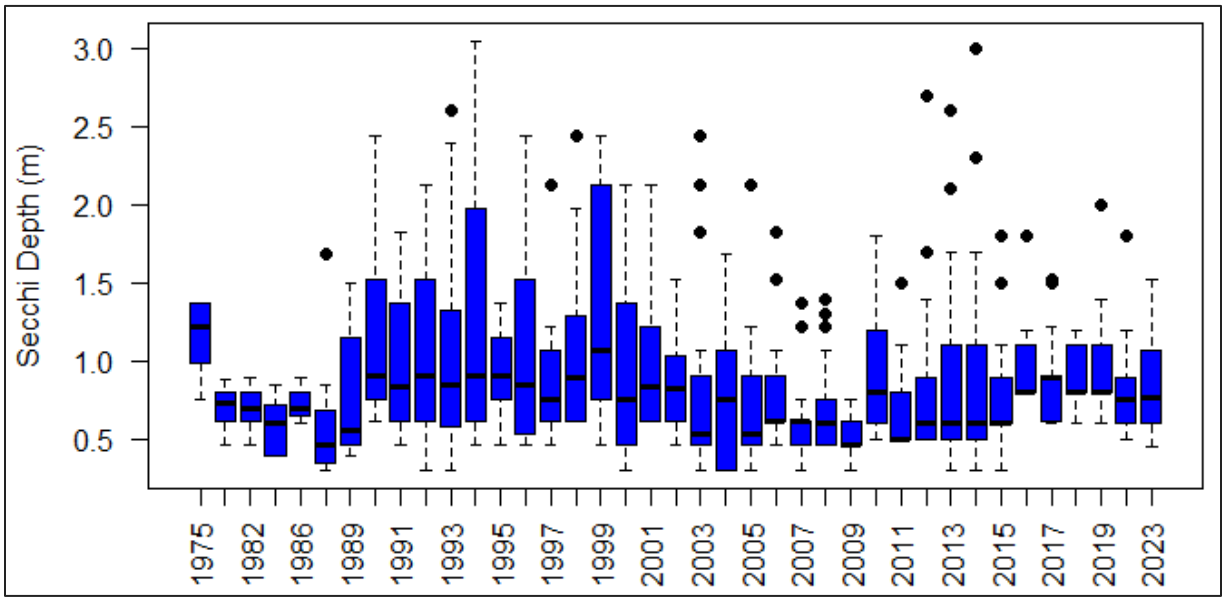


Figure 20. Julia Lake Secchi depth results, 1975-2023.

Reference: 227706313

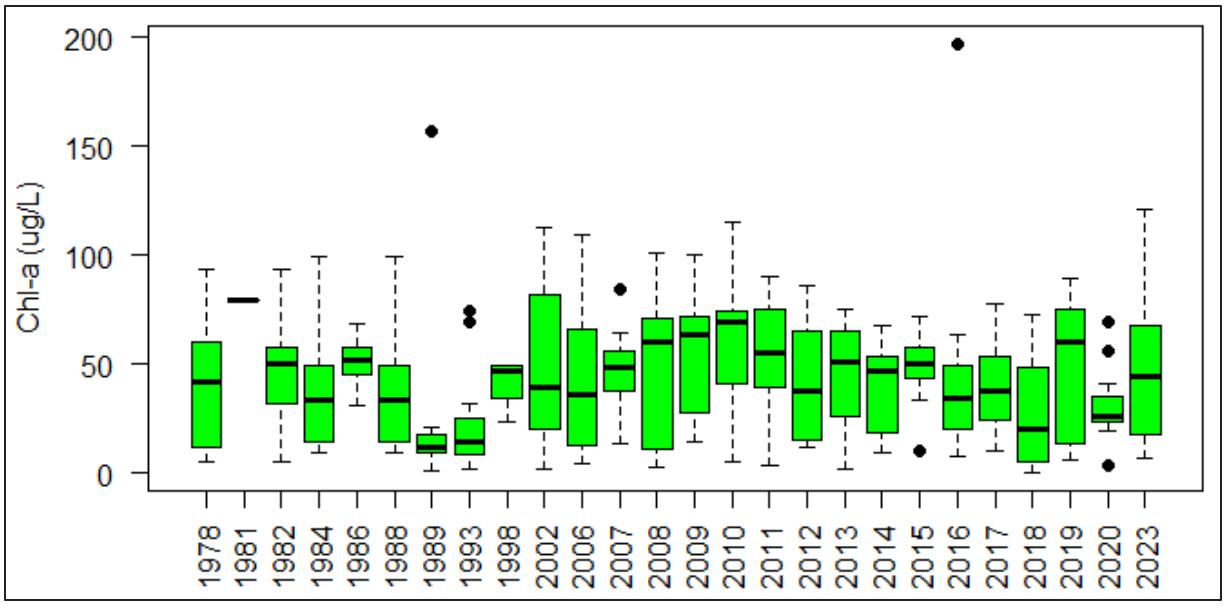


Figure 21. Rush Lake Chlorophyll a concentration, 1978-2023.

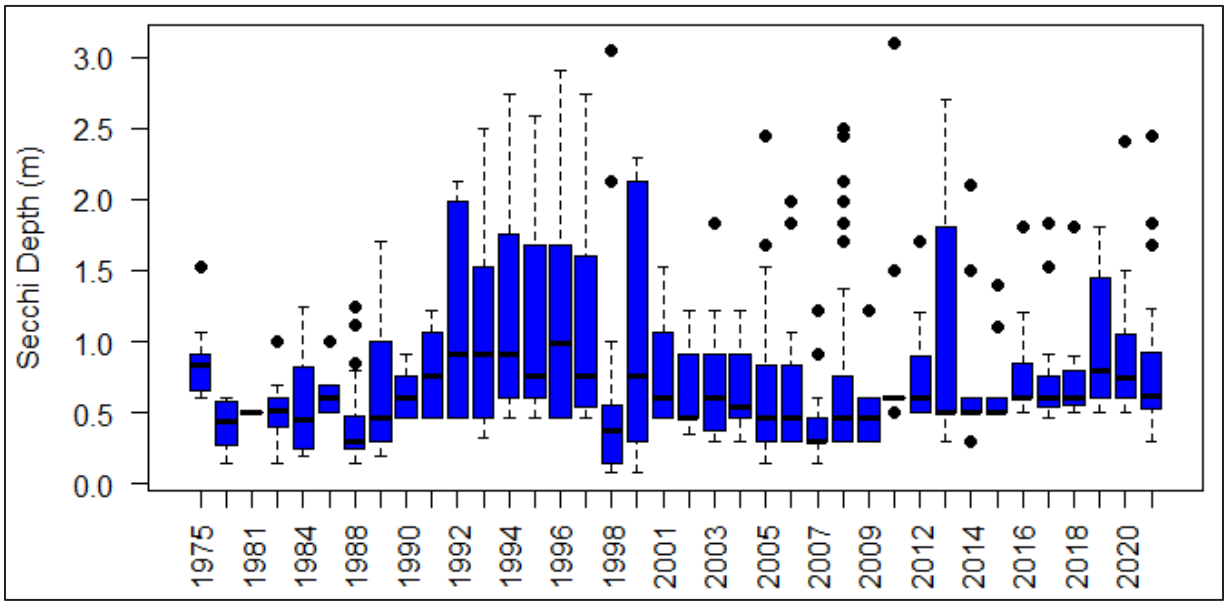
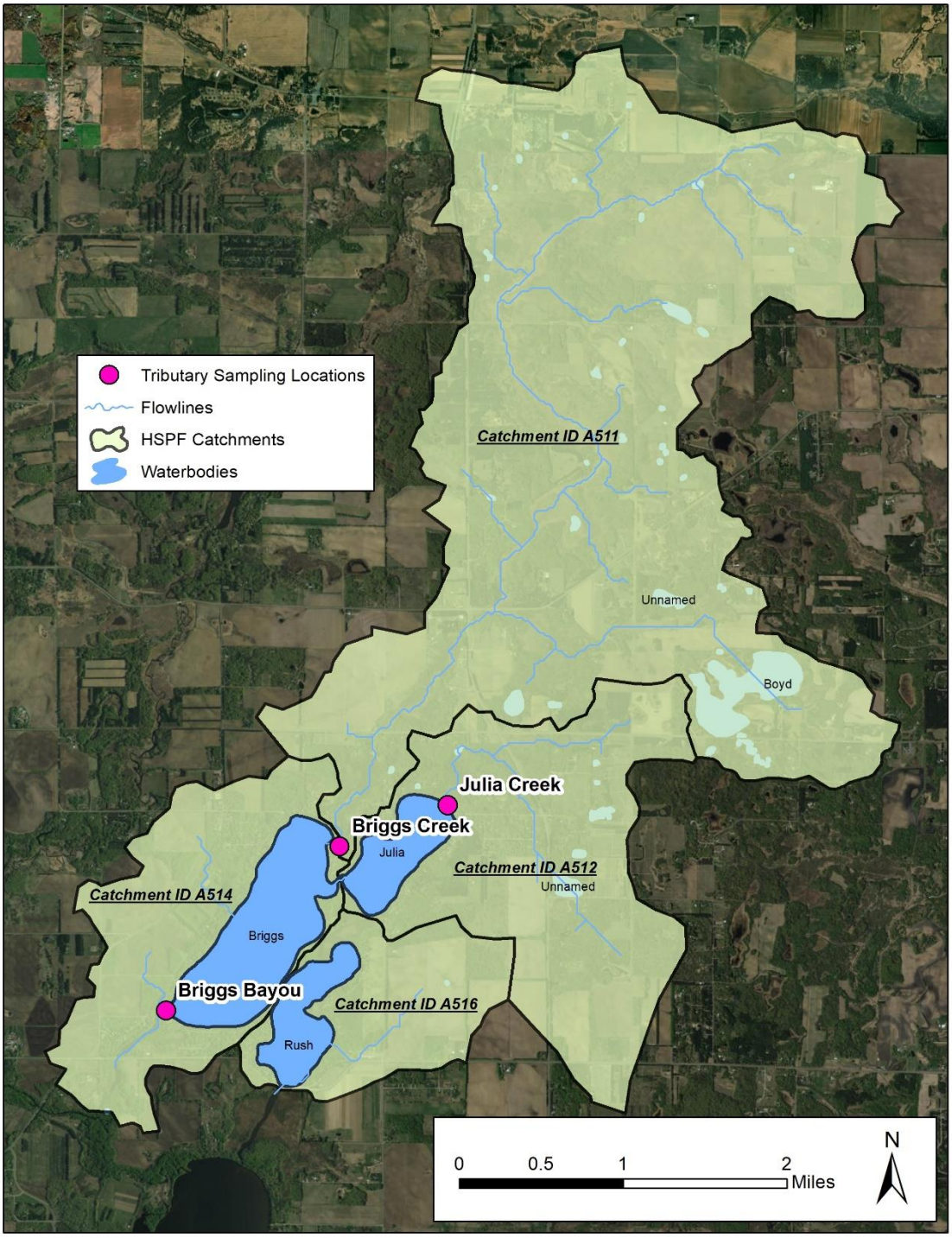


Figure 22. Rush Lake Secchi depth results, 1975-2023.

Reference: **227706313**

Attachment C – Watershed Map



Reference: 227706313

Attachment D – Carp Surveys and Population Estimates

Introduction

Common carp (*Cyprinus carpio*) are one of the most widely distributed invasive species in North America and can cause ecological and water quality problems in shallow lakes (Chumchal et al. 2005, Bajer et al. 2009). During foraging carp disturb the substrate and uproot aquatic vegetation causing increases in turbidity and nutrients.

Field Methods

Two common carp (carp) surveys were conducted on August 15th, 16th, September 19th, and September 20th, 2024, using an electrofishing boat delivering 15-20 amps of pulsed direct current (25% Duty Cycle, 64Hz Rate) with an industry standard control box (ETS, Madison WI). Three transects along the shoreline of Briggs Lake and two transects on Julia and Rush Lakes were completed during each survey event. Each transect consisted of 20 minutes of electrofishing 'on time' when electrical current was being delivered while driving slowly along the shoreline. One netter positioned at the front of the boat netted all stunned carp, and fish were held in livewell tanks and allowed to recover until the transect was complete. All carp were measured, weighed, and released. Surveys were completed under Minnesota DNR Fisheries Research permit number 36229.

Carp Population Estimates

A total of 112 common carp were sampled in all three lakes during the 2024 surveys. The average length of carp was 25.8 inches (655.9 mm) and ranged from 15 to 32 inches (385-810mm). The average weight of carp was 10.1lbs (4.6 kg) and ranged from 2.2lbs to 22.9lbs (1kg-10.4kg).

The catch per unit effort (CPUE) was used to calculate carp density with the linear regression equation developed by Bajer and Sorensen (2012).

$$\text{Carp density per hectare} = 4.71 * \text{CPUE} + 3.04$$

A population estimate and biomass density was calculated for each lake individually and for all three lakes combined due to the hydrologic connection between the 3 lakes allowing carp to easily travel among the three lakes (Table 1).

Table 1. Carp population and biomass estimates for Briggs, Julia and Rush Lakes.

Lake	Population Estimate (# individuals)	Population 95% confidence limits	Biomass Density (lbs/acre)	Biomass Density 95% confidence limits (lbs/acre)
Briggs	19,364	16,097 - 22,631	521	433 - 609
Julia	7,014	2,655 - 11,373	411	156 - 666
Rush	8,377	8,073 – 8,680	537	517 - 556
All Lakes Combined	34,833	27,367 – 42,299	491	386 - 597

Conclusion

Bajer et al. (2009) proposed an ecological threshold of common carp densities of 100 kg/ha (89 lbs/acre). Common carp populations above this threshold may cause declines in vegetation and water quality. The population of common carp in the chain of lakes is well above the 89 lbs/acre ecological threshold proposed by Bajer et al. and well above what is considered 'high' density > 200 kg/ha (>178 lbs/acre) for common carp.

The method used to calculate the PE by using boat electrofishing CPUE was developed by Bajer and Sorenson (2012) in shallow midwestern lakes. They concluded a linear relationship existed between CPUE and carp densities. However, in 2022 new research was published that examined the use of boat electrofishing CPUE as a common carp population estimator among populations with different densities. Simonson et al. (2022) found common carp populations may exhibit hyperstability where catch rates remain high even as populations decline. They found that at high population densities (>178 lbs/acre) the relationship between CPUE and PE is not linear. At high densities CPUE is not expected to change unless the population density changes substantially. The current population of carp in the chain of lakes is high and large removals of common carp would be needed in order to detect changes in the carp population.

References

Bajer, P., G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. *Hydrobiologia* 632(1):235-245.

Reference: 227706313

Bajer P.G. and P.W. Sorensen. 2012. Using boat electrofishing to estimate the abundance of invasive common carp in small midwestern lakes. *North American Journal of Fisheries Management* 32: 817-822.

Chumchal, M.M., W.H. Nowlin and R.W. Drenner. 2005. Biomass-dependent effects of common carp on water quality in shallow ponds. *Hydrobiologia* 545:271-277.

Simonson, M. A., M. J. Weber, and A. McCombs. 2022. Hyperstability in electrofishing catch rates of common carp and bigmouth buffalo. North American Journal of Fisheries Management 42:425-437.

Reference: 227706313

Attachment E – Lake Model Inputs & Results

Table 15. Briggs Lake model inputs and results.

Category	Parameter	Value	Unit
Watershed Load	Direct TP Load	199	lbs/year
Watershed Load	Direct Surface Discharge	558	acre-feet/year
Upstream Lakes	Julia Lake TP Load	166	lbs/year
Upstream Lakes	Julia Lake Discharge	280	acre-feet/year
Upstream Lakes	Briggs Creek TP Load	782	lbs/year
Upstream Lakes	Briggs Creek Discharge	2,995	acre-feet/year
Carp Load	Carp generated TP Load	1,207	lbs/year
Atmospheric Load	Inflow	0.0	acre-feet/year
Atmospheric Load	TP Load	89.8	lbs/year
Internal Load	TP Load	2,416	lbs/year
Total Load	TP Load	4,860	lbs/year
Model Equation	L*	1,347	mg/m^2
Model Equation	p*	0.81	yr^{-1}
Model Equation	z*	3.6	m
Model Equation	P*	115.7	µg/L
Observed Data	In-lake mean surface concentration	114.0	µg/L

Table 16. Julia Lake model inputs and results.

Category	Parameter	Value	Unit
Watershed Load	Julia Creek TP Load	257	lbs/year
Watershed Load	Julia Creek Surface Discharge	913	acre-feet/year
Carp Load	Carp generated TP Load	1,097	lbs/year
Atmospheric Load	Inflow	0.0	acre-feet/year
Atmospheric Load	TP Load	34	lbs/year
Internal Load	TP Load	331	lbs/year
Total Load	TP Load	1,714	lbs/year
Model Equation	L*	1,244	mg/m^2
Model Equation	p*	2.36	yr^{-1}
Model Equation	z*	3.6	m
Model Equation	P*	73.7	µg/L
Observed Data	In-lake mean surface concentration	79.0	µg/L

Reference: 227706313

Table 17. Rush Lake model inputs and results.

Category	Parameter	Value	Unit
Watershed Load	Direct TP Load	126	lbs/year
Watershed Load	Direct Surface Discharge	315	acre-feet/year
Upstream Lakes	Briggs/Julia TP Load	1,381	lbs/year
Upstream Lakes	Briggs/Julia Discharge	4,456	acre-feet/year
Carp Load	Carp generated TP Load	1,142	lbs/year
Atmospheric Load	Inflow	0	acre-feet/year
Atmospheric Load	TP Load	36	lbs/year
Internal Load	TP Load	163	lbs/year
Total Load	TP Load	2,847	lbs/year
Model Equation	L*	1,983	mg/m^2
Model Equation	p*	4.43	yr^{-1}
Model Equation	z*	2.0	m
Model Equation	P*	118.3	µg/L
Observed Data	In-lake mean surface concentration	106.0	µg/L

Reference: 227706313

Attachment F – Nurnburg Anoxic Factor Equations for Polymictic and Stratified Lakes

One key determinant in the estimation of internal phosphorus loads is the assumption on the temporal and spatial extent of anoxia. The spatial extent of anoxia in lakes can be estimated during from a robust set of dissolved oxygen profiles at high frequency to evaluate anoxic extent. In the absence of the high frequency dissolved oxygen data, regression equations to estimate the spatial extent of anoxia in thermally stratified and polymictic lakes have been developed (Nurnberg 2005[8]; Nurnberg 2009[9]) to facilitate estimation of an "anoxic factor", which represents the number of days where the anoxic sediment area is equal to the lake surface area. These equations help facilitate calculation of whole-lake internal phosphorus loading estimates. Below are the two equations that Stantec used in the water quality modeling.

Polymictic Lakes

$AF_{pred} = -36.2 + 50.2 \log(TP_{summer}) + 0.762\ z/A_0^{0.5}$

Where:

- AF_{pred} = predicted anoxic factor
- TP = summer average total phosphorus
- $z/A_0^{0.5}$ = morphometric factor (with z, mean depth in meters and A_0, lake surface area in km^2)

Thermally Stratified Lakes

$AF_{pred} = -35.4 + 44.2 \log(TP) + 0.95\ z/A_0^{0.5}$

Where:

- AF_{pred} = predicted anoxic factor
- TP = annual average total phosphorus
- $z/A_0^{0.5}$ = morphometric factor (with z, mean depth in meters and A_0, lake surface area in km^2)

[8] Nurnberg, GK. 2005. Quantification of internal phosphorus loading in polymictic lakes. *Verh. Internat. Verein. Limnol.* 29: 623-626.
[9] Nurnberg, GK. 2009. Assessing internal phosphorus load – problems to be solved. *Lake and Reservoir Mgmt* 25: 419-432.

Reference: 227706313

Attachment G – Alum Dosing Scenarios for Briggs Lake

Overview

Three main factors are considered when determining whether to treat a lake with alum:

1) the rate at which phosphorus is releasing from the sediment under anoxic conditions;

2) the water depth and assumed area of lake experiencing anoxia; and

3) the concentration of mobile-P in the sediments.

As described in the memo, Briggs Lake is the only lake in the chain that exhibited high internal P loading rates that could be mitigated with an aluminum sulfate (alum) treatment. The following sections describe our assessment of the treatment area, strategy, recommended dose and estimated costs.

Alum Treatment Scenario Evaluation

Stantec calculated alum doses based on the mass of mobile-P (redox-P plus 30% of the labile organic-P) across various depth contours estimated to be releasing dissolved P under anoxic sediment conditions. A buffered alum treatment allows for a high dose of alum to be applied without adverse impacts on lake pH.

We performed a cost-benefit assessment of three buffered alum treatment scenarios. The objective of the analysis was to identify an optimal treatment extent based on the measured phosphorus in sediments, assumptions on the areal extent of within a reasonable return on investment.

Three scenarios were evaluated for Briggs Lake, which are summarized in Table 1 below.

Table 1. Summary of alum treatment scenarios evaluated along with the estimated cost per scenario.

				Volume of Material		Estimated Cost*		
Scenario #	Treatment Area	Treatment area (acres)	Alum Dose (g Al/m^2)	Alum (gal)	Buffer (gal)	Alum ($)	Buffer ($)	Alum + Buffer ($)
1	≥ 15 ft	185	120	179,255	89,628	446,346	858,634	1,304,980
2	≥ 20 ft	122	127	125,737	62,868	313,084	602,278	915,362
3	≥ 25 ft	5	125.6	4,738	2,369	11,798	22,696	34,494

These scenarios were evaluated based on the mass of phosphorus measured in the sediment at different depth contours (see Figure 5 in main body of memo). The highest mass of phosphorus that could potentially diffuse from the sediments (i.e. redox-P) was higher in the 20 ft and 25 ft depth contours when compared to the 15 ft and 10 ft depth contours. Therefore, we evaluated various scenarios that would include areas of higher phosphorus mass.

Reference: 227706313

Treating only the areas 25 ft and greater is too small of a treatment would not justify the return on investment due to mobilization fees and the presence of high phosphorus in the area covering 20 ft water depths.

For comparison and assessment of the estimated cost, we also calculated an alum dose that would include the 15 ft depth intervals. The cost of treatment to include the 15 ft depth interval would not provide a return on investment due to the high cost and lower mass of redox-P in those areas (see Figure 5). In consideration for future applications, dissolved oxygen profiles could be collected at the 15 ft water depth to determine the relative extent of anoxia along with sediment cores to determine the rate of P flux under anoxic conditions from these sediments. If determined to exhibit sustained anoxic conditions and high P release rates, then the 15 ft depth interval could be included in a future application, if needed. We have estimated the longevity of an alum application to Briggs Lake based on the P sedimentation function in the lake response model (discussed further below).

In summary, we recommend Scenario 2 for Briggs Lake where a buffered alum treatment would apply approximately 125,737 gallons of aluminum sulfate (alum) and 62,868 gallons of sodium aluminate (buffer) over a 122-acre treatment area. We recommend a single treatment dose at this prescribed rate.

Post-treatment monitoring should include continued collection of surface and hypolimnetic TP and orthophosphate to adequately capture the lake's response to treatment. Likewise, collection of sediment cores to evaluate post-treatment phosphorus release rates would be recommended in order to quantify the direct effectiveness of the alum treatment.

Longevity of an alum treatment is challenging to accurately predict due to the external factors that control treatment success and longevity. The longevity of an alum treatment depends on the treatment area, alum dose, and continued loading from other sources. Phosphorus that deposits onto the sediment after an alum treatment will not physically come into contact with the aluminum and therefore will not be subject to mitigation, which is a major factor in the longevity of treatment.

Stantec estimated longevity as the length of time to bury the alum treatment with 5 cm of phosphorus sedimentation, in which the goal is to assess how long it will take to bury the alum layer after the alum application. The sediment depth of the calculated alum dose was 5 cm which is why that depth was selected for the longevity analysis. A critical factor in this approach, is the determination of phosphorus sedimentation occurring in the lake. To that end, Stantec isolated the phosphorus sedimentation term from the Canfield-Bachmann equation for natural lakes to estimate how long it would take to replace inactivated phosphorus in the top 5 cm of sediment:

Reference: 227706313

$$P_{sed} = C_P * C_{CB} * \left(\frac{W}{V}\right) * [TP] * V$$

Where,

P_{sed} = Phosphorus sedimentation rate
C_P = Equation constant
C_{CB} = Equation constant
W = External annual TP load
TP = Near-surface growing season TP concentration
V = Lake volume

The analysis assumes that the external TP load to the lake remains constant at an annual rate of 1,654 lbs/year to Briggs Lake (Table 2). The TP variable, or in-lake phosphorus concentration, was estimated using the average observed concentration from 2022 and 2023 for each lake, given that the future near-surface TP concentration post-treatment is difficult to predict. The results of the phosphorus sedimentation-based analysis indicate that the estimated treatment longevity in Briggs Lake is approximately 7 years.

Table 2. Estimated Duration Until Phosphorus Sedimentation Covers Alum Treatment Area

Parameter	Value	Units
Lake Area	404	acres
Lake Area	1.63	km^2
Total P	1.58	mg/g DW
Dry Bulk Density	0.088	g/cm^3
Total P	0.13904	mg/cm^3
Total P	139040	mg/m^3
Total P	0.13904	kg/m^3
Total sediment surface area	1,634,931	m^2
P Sedimentation Rate	1,658	kg/yr
Total P	227,321	kg/m
Total P	2,273	kg/cm
Total P (top 5 cm)	11,366	kg/5 cm
Years until 5 cm of P is deposited	**6.86**	**years**

The phosphorus sedimentation approach also has limitations. This approach does not estimate for a treatment objective or in-lake response. Rather, it is a generalized method for evaluating the anticipated period in which the alum treatment would be actively binding phosphorus. Some limitations of this estimation approach are that it does not account for the variability in treatment area, treatment volume, or treatment effectiveness on internal loading. It only approximates how long the alum layer will conceivably be within the upper 5-cm sediment later before being buried by sedimentation processes.

Reference: 227706313

Additional analysis was performed to further augment the understanding of alum treatment effects, and how those might translate to water quality outcomes. Using the Briggs Lake model, the internal loads were artificially reduced under two potential alum effectiveness regimes, 50% and 90% internal load reductions. The baseline model (i.e., current conditions) estimates a surface concentration of 0.116 mg/L. The lake response model estimates that a 50% reduction in internal load would result in a surface concentration of 0.096 mg/L and that a 90% reduction would result in a surface concentration of 0.078 mg/L. Meaning, a 90% reduction of the internal load would translate to a 33% reduction in surface level TP concentrations, as estimated by the model.