BARR

Tamarack and Wilkinson Lakes In-Lake Treatment Feasibility Study

Prepared for
Vadnais Lake Area Water Management Organization (VLAWMO)
and Ramsey County Soil and Water Conservation Division

November, 2023

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CLEAN WATER LAND & LEGACY AMENDMENT

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1.0 Project Background and Purpose

Barr Engineering Company (Barr) was retained by Vadnais Lake Area Water Management Organization (VLAWMO) in 2023 to provide engineering services to build on past efforts by completing sediment monitoring (collected during spring 2023) and aluminum sulfate (alum) dosing for Tamarack and Wilkinson Lakes to improve lake water quality. This feasibility study includes sediment core collection/analysis, determination of an alum dosage plan, and compilation/consolidation of supporting information to implement in-lake management practices.

Figure 1-1 shows the watershed divides and drainage patterns for Tamarack and Wilkinson Lakes, including subcatchments and monitoring stations. Table 1-1 shows the lake morphology/depth and other watershed/water body characteristics for each basin (as determined in GIS or published by VLAWMO).

Table 1-1 Lake Morphology and Watershed Characteristics

Parameter	Tamarack Lake	Wilkinson Lake
Open Water Surface Area (acres)	13	100
Average Depth (feet)	5	3
Maximum Depth (feet)	10	5
Residence Time (years)	not estimated	0.2
Direct, Overall Drainage Area (acres)	130, 130	2973[1], 4555[2]

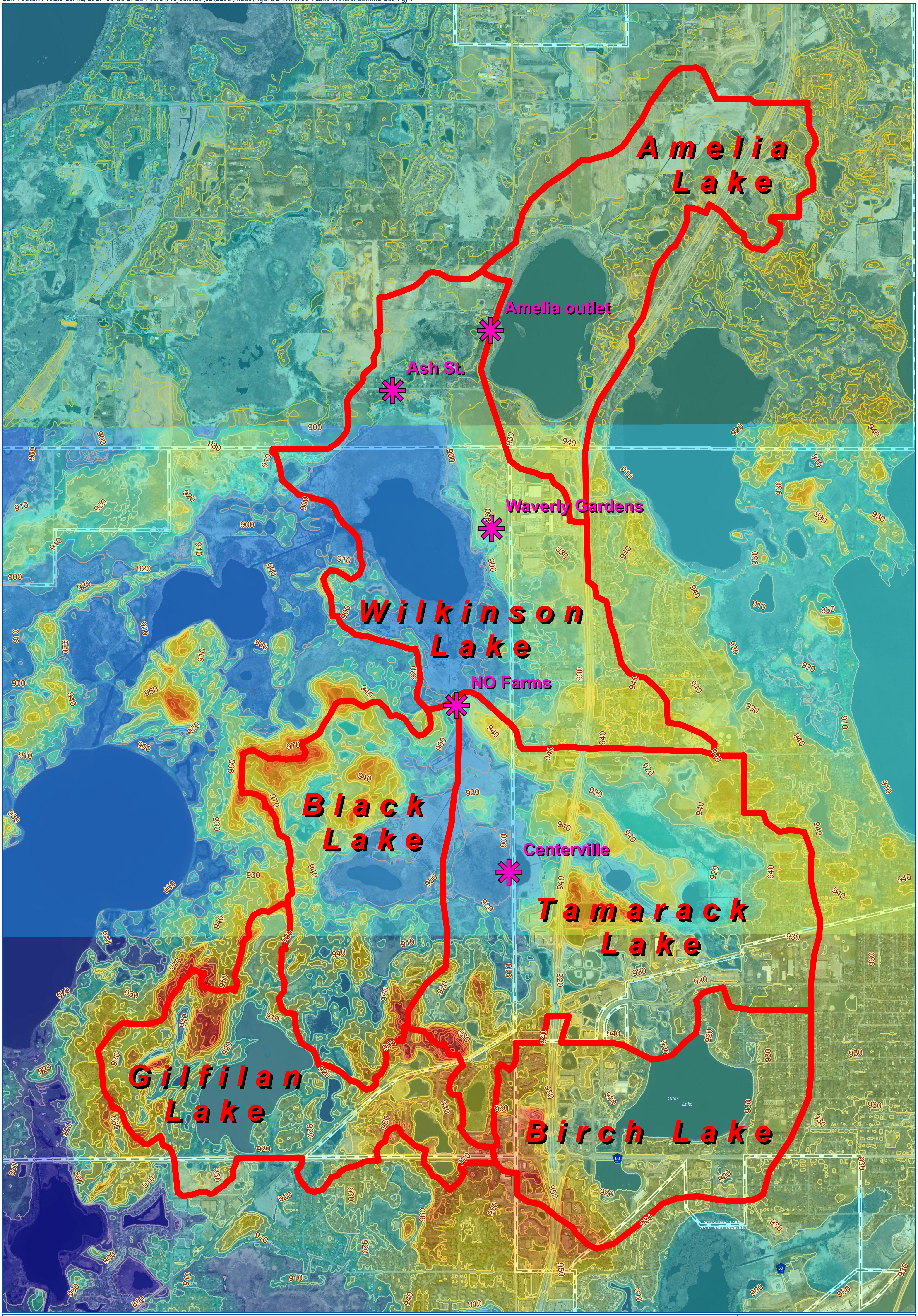
[1]Based on Subwatershed ID#2007904 in TMDL Report (excludes lake surface area)

[2]Based on Subwatershed ID#s 2007901, 2007903, and 2007904 in TMDL Report

1.1 Summary of Lake TMDL Report and Past Studies

Barr systematically reviewed reports and data collected on Tamarack Lake and Wilkinson Lake, including the total maximum daily load (TMDL) report and implementation plan (2013 & 2014), sustainable lake management plans/reports (2011, and 2017 and 2023 updates), storm sewer and treatment practice plans, proposed redevelopment plans and retrofit report (2012), BMP feasibility studies (2017 & 2020), fish (2012 & 2017) and aquatic plant survey reports (2010 & 2014), sediment (2008) and bathymetric/macrophyte/ vegetation biovolume/bottom composition surveys (2017 & 2022).

While Tamarack Lake has been listed as impaired for excess nutrients, it was not previously addressed in the TMDL report.



BARR

- Wilkinson Watershed Sampling Sites
- Wilkinson Lake Subcatchments
- 10-Foot Elevation Contour
- Municipal Boundary

0 1,000 2,000
Feet

WILKINSON LAKE WATERSHED
Vadnais Lake Area Watershed Management Organization

FIGURE 1-1

The TMDL report (Wenck, 2014a) and implementation plan (VLAWMO, 2014) estimated internal and watershed loading and called for 63% total phosphorus load reductions for Wilkinson Lake, which corresponded with a 76% reduction of stormwater runoff, after accounting for an explicit margin of safety.

The high percentage of watershed loading on Wilkinson Lake focused the direction on additional studies since the publishing of the TMDL report. This included increased monitoring and several feasibility studies, along with updated fish and vegetation studies. VLAWMO recently bid and initiated construction on a deep-water wetland restoration project that is expected to remove approximately 33 pounds of total phosphorus per year from the south tributary to Wilkinson Lake.

Lake and watershed modeling, along with the associated GIS mapping, from the TMDL study were obtained by Barr and reviewed for use in a recent feasibility analysis (Barr, 2017). Additional concerns with the TMDL modeling are discussed in Section 2.1, in which it was determined that the following data gaps and limitations of the past analyses would also need to be addressed to better evaluate the sources of phosphorus during the critical condition and potential improvement options for Wilkinson Lake:

- The P8 watershed modeling from the TMDL study did not simulate the existing watershed Best Management Practices (BMPs) and phosphorus assimilation by upstream lakes. As discussed in Section 2, this may have led to overestimated phosphorus loadings for each lake watershed in the TMDL study.
- The GIS mapping (and associated P8 watershed modeling) from the TMDL study included a significant landlocked area from Gilfillan Lake, as well as an area from Lake Amelia that is only connected infrequently (during wet years), in the Wilkinson Lake watershed. This may have also led to overestimated phosphorus loading for this watershed in the TMDL study.

Stormwater monitoring data collected in the Wilkinson Lake watershed since 2011 was obtained and evaluated to better distinguish priority phosphorus source areas that would not otherwise have been determined from the P8 modeling developed for the TMDL study.

1.2 Summary of Recent Water Quality Monitoring

Table 1-2 shows the ten-year summer average total phosphorus and chlorophyll-a concentrations observed for each lake, along with the average Secchi disc transparency, compared to MPCA’s shallow lake water quality criteria. Table 1-2 shows that, despite recent water quality improvements in Wilkinson Lake, both lakes do not currently meet MPCA’s shallow lakes criteria.

Table 1-2 Average Summer Water Quality (2013-22) and Shallow Lake Criteria Comparison

Water Body	Total Phosphorus Concentration (µg/L)	Chlorophyll-a Concentration (µg/L)	Secchi Disc Transparency (meters)
Tamarack Lake	167	121	0.38
Wilkinson Lake	134	32	0.97
MPCA Shallow Lakes Criteria	**60**	**20**	**1.0**

Both water bodies will experience low dissolved oxygen in the bottom waters, periodically, during the summer months, and are subject to internal phosphorus loading.

Figures 1-2, 1-3 and 1-4 show how the last ten years of average summer total phosphorus, chlorophyll-a and Secchi disc transparency, respectively, have varied for each lake. The first four years of the records shown in each figure represent the data used for the TMDL analyses of Wilkinson Lake. The monitoring data shows that both lakes have not been meeting any of the three shallow lake criteria during the period of record.

Figure 1-2 shows that average summer total phosphorus concentrations were generally better for the lakes in 2011, significantly worse in 2015 and 2016, followed by a return to improved water quality in Wilkinson Lake between 2017 and 2021. As a result, 2011 became the focus of the updated lake and watershed modeling discussed in Section 2.

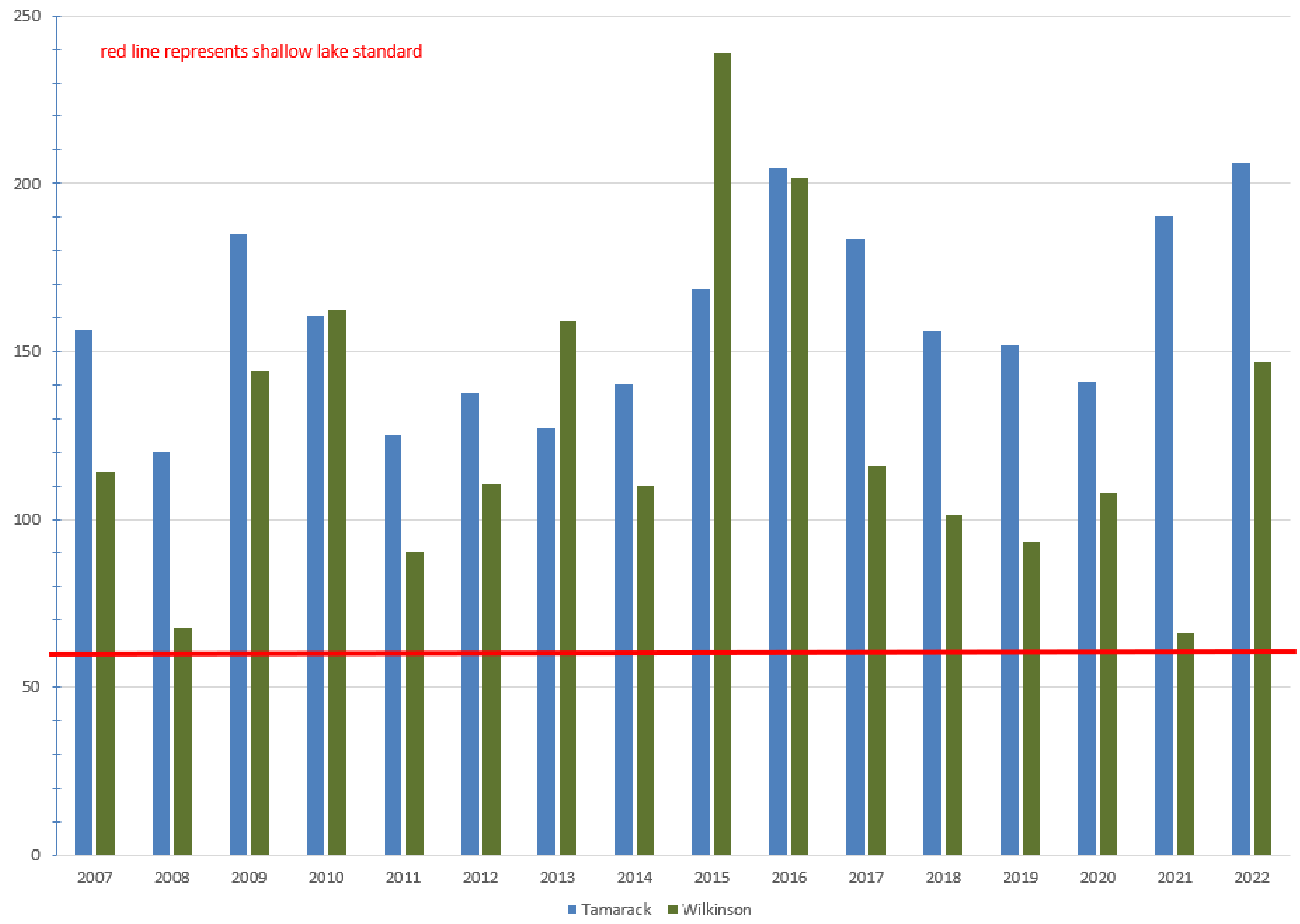


Figure 1-2 Summer Average (June-Sept.) Total Phosphorus Concentrations (µg/L) since 2007

Figure 1-3 shows that average summer chlorophyll-a concentrations were generally better for the lakes in 2011, significantly worse in 2015, followed by a return to improved water quality in Wilkinson Lake between 2016 and 2022. Chlorophyll-a concentrations in Wilkinson Lake met the MPCA criteria every year between 2017 and 2022.

Figure 1-3 shows that algae growth has remained high in Tamarack Lake since 2015. The highest chlorophyll-a concentrations on record in Tamarack Lake occurred during 2021 and 2022.

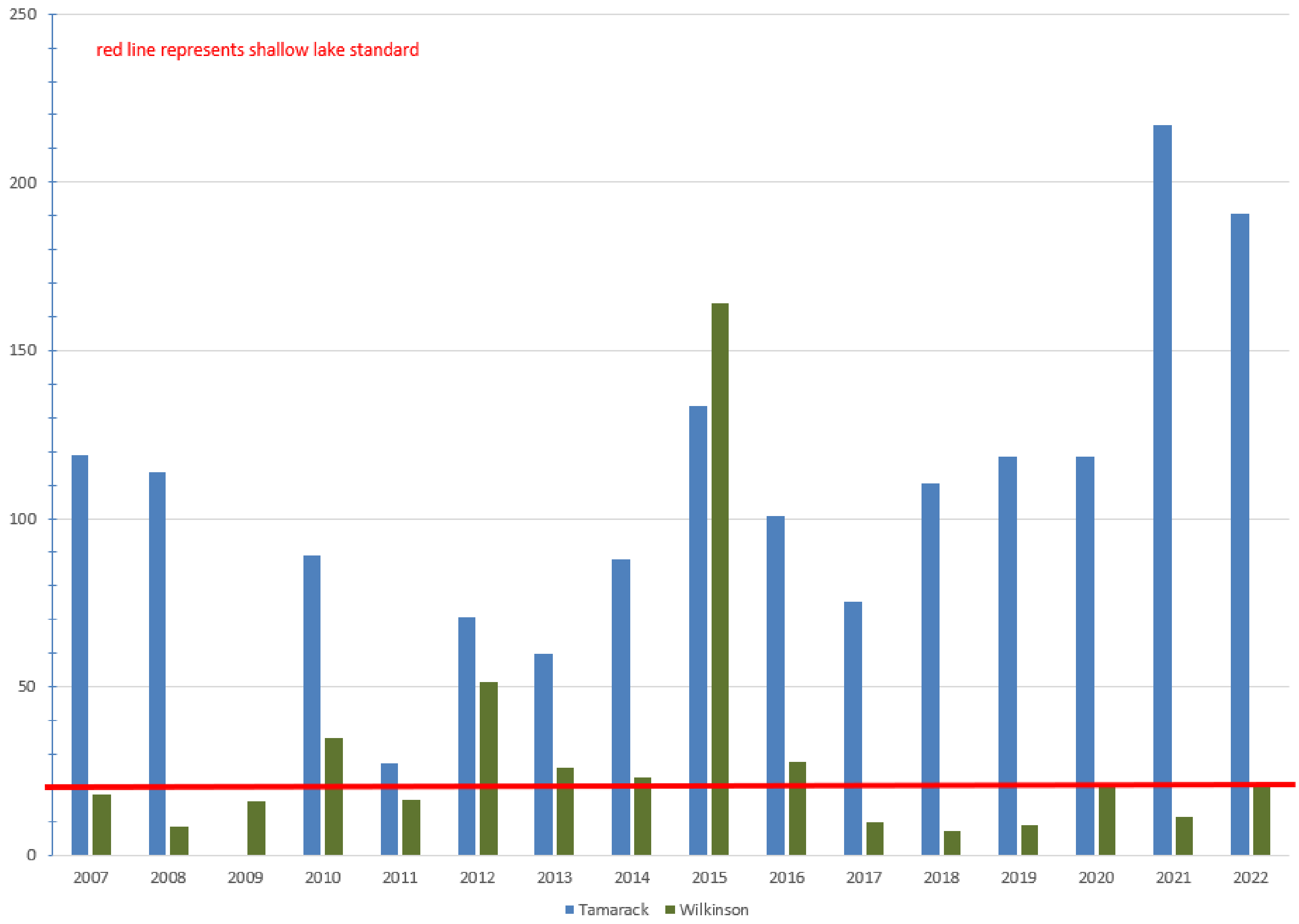


Figure 1-3 Summer Average (June-Sept.) Chlorophyll-a Concentrations (µg/L) since 2007

Figure 1-4 shows that average summer Secchi disc transparency measurements were significantly worse in 2015, followed by a return to improved water quality in Wilkinson Lake between 2016 and 2021. Secchi disc transparency in Wilkinson Lake met the MPCA criteria every year between 2017 and 2021, which explains why the long-term average shown in Table 1-2 very nearly met the MPCA threshold.

While Tamarack Lake experienced its highest transparency in 2022, it remains 0.4 meters lower than MPCA threshold (see Figure 1-4) due to high algae growth and high phosphorus concentrations.

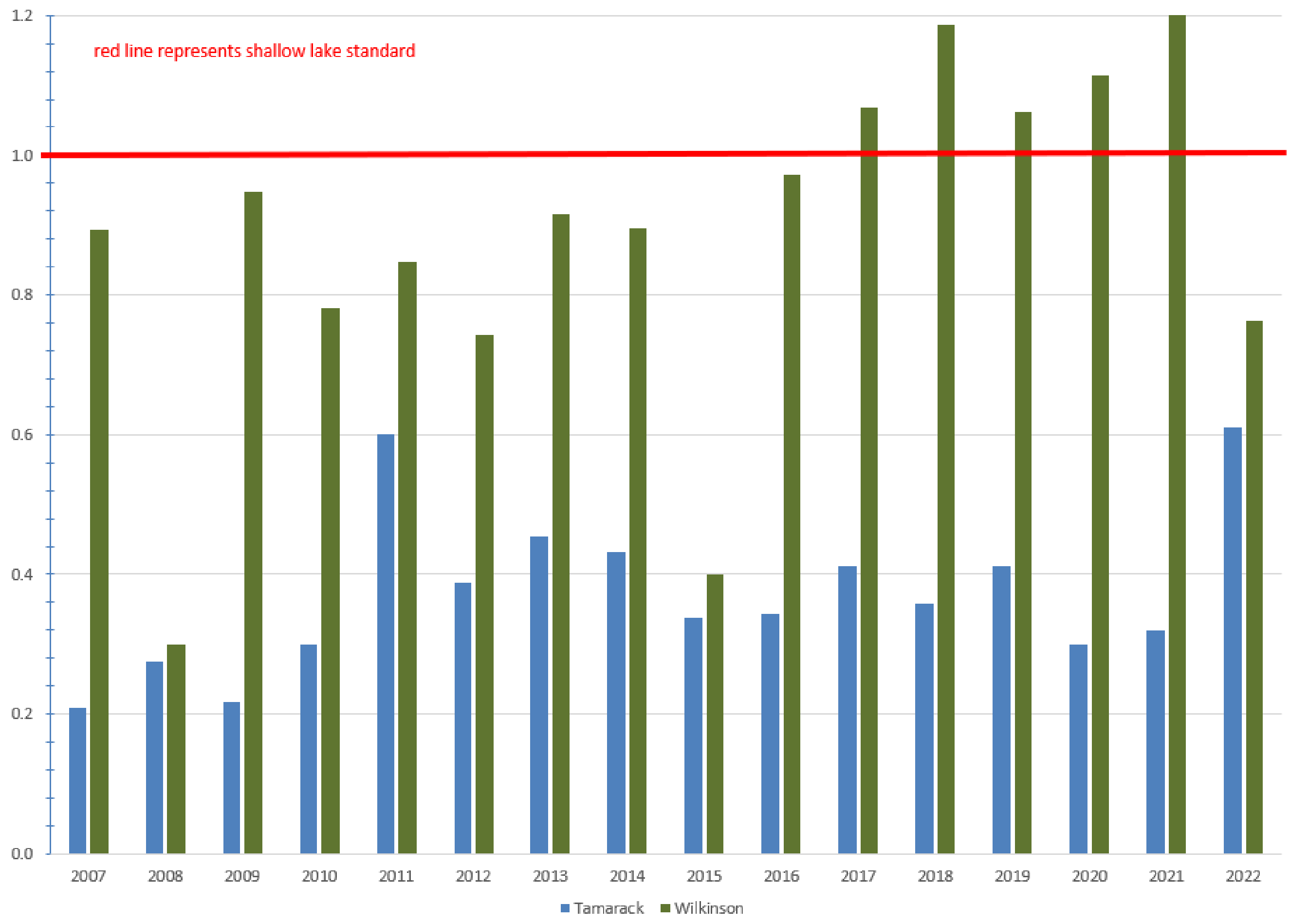


Figure 1-4 Summer Average (June-Sept.) Secchi Disc Transparency (meters) since 2007

1.3 Current Analysis of Lake Sediment Cores

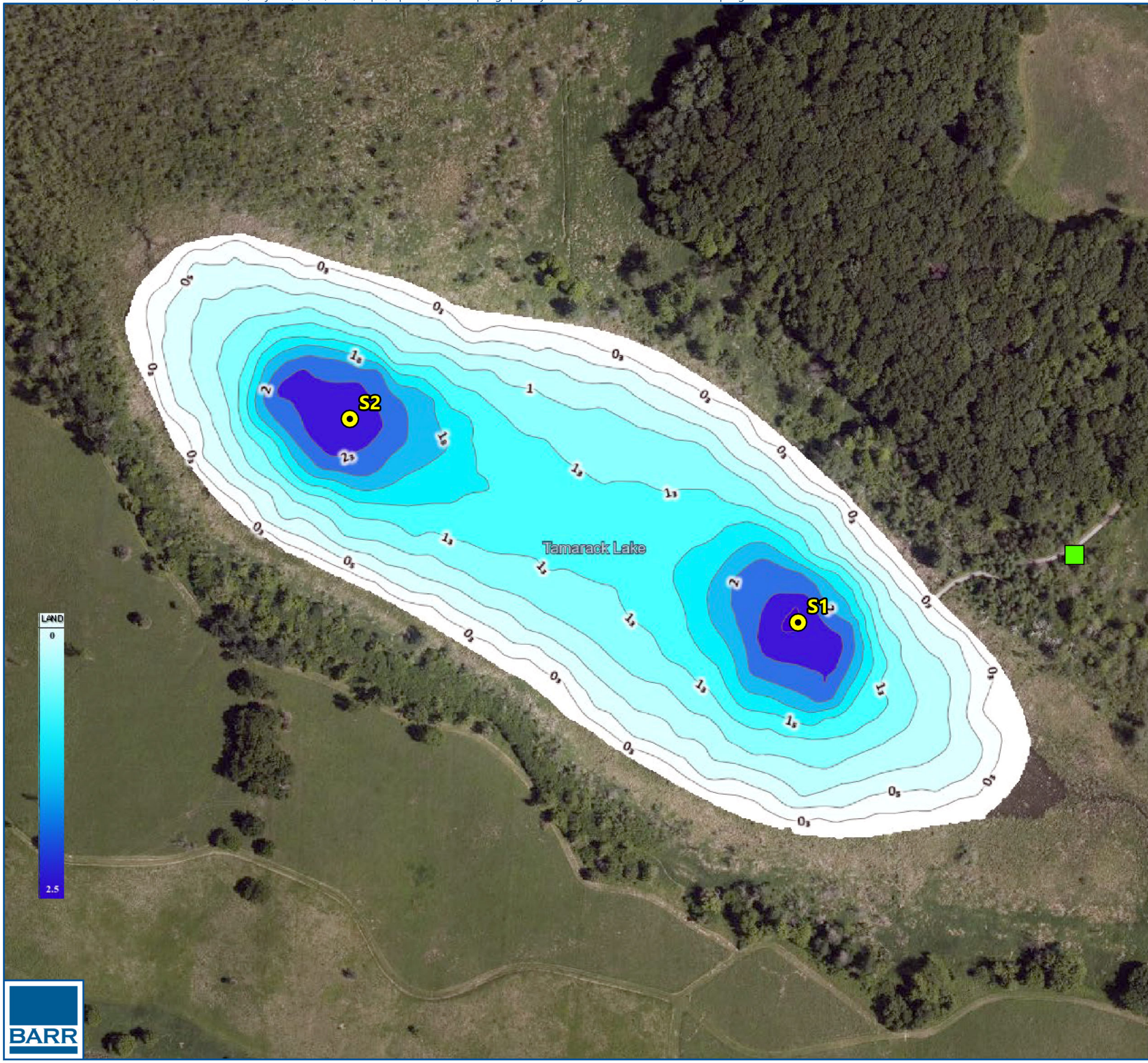
Phosphorus from stormwater over time accumulates in the bottom sediments of lakes and ponds. During the spring and fall, this phosphorus is largely tied-up in the sediments, but during the warm summer months the phosphorus can be released from bottom sediments and move upward into the water column. This can lead to summer and sometimes early fall algal blooms. During the winter, lake stratification can also lead to phosphorus release from anoxic bottom sediments. Not all the phosphorus that is incorporated into bottom sediments releases into the water column. Phosphorus in sediment is typically attached to something and can be found in the following forms (often referred to as "fractions"): calcium bound phosphorus (Ca-P), aluminum bound phosphorus (Al-P), iron bound phosphorus (Fe-P), and organically bound P (Org-P). Ca-P and Al-P are largely inert and are immobilized in the bottom sediment. Org-P decays over time and release phosphorus into the water column over the course of several years. Fe-P is the mobile phosphorus form that readily releases into the water column during warm summer months as oxygen is depleted in the sediment.

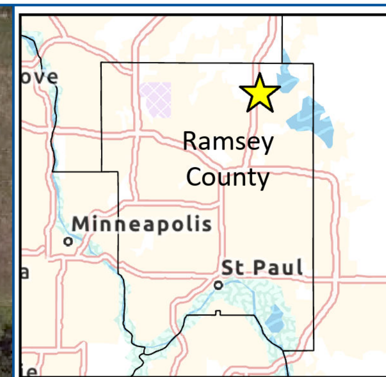
The primary purposes of collecting sediment cores are to quantify the amount of Fe-P (mobile phosphorus) and Org-P in sediment. The more Fe-P and Org-P in sediment the more alum will need to be applied to immobilize these phosphorus fractions. In general, aluminum treatment (either as alum or sodium aluminate, for example), forces the Fe-P to bind to aluminum and form Al-P (the inert form of aluminum). In most cases, alum treatments are designed to also provide excess aluminum in sediment which can then bind phosphorus years after the treatment. When aluminum in the form of alum or other solutions is added to a lake, it forms an aluminum hydroxide floc that settles to the lake bottom. The aluminum floc will mix into the top few to several inches of sediment over time and becomes diluted. The sediment phosphorus data collected at different depths was used to help determine the expected sediment mixing depth for each lake.

The total mass of mobile and Org-P in the actively mixed layers of sediment were determined for each lake. Alum doses were then calculated for each lake by determining an appropriate Al:Al-P ratio to immobilize the phosphorus that contributes to the internal load.

Sediment cores were collected between June 2 and June 6, 2023, in Tamarack Lake (2 cores) and Wilkinson Lake (4 cores) (see Figures 1-5 and 1-6, respectively). Each sediment core was sliced into 2-cm sediment samples down to a depth of 10 cm, and 5 cm intervals were collected down to 20 cm or deeper. Sediment samples were returned to the Barr Engineering laboratory and analyzed for the phosphorus fractions identified previously.

In general, mobile phosphorus concentrations in the sediment of Tamarack and Wilkinson Lakes were slightly lower than the organic-P fraction, as shown in Figure 1-7, but sediment phosphorus levels were generally higher in the core section at the sediment-water interface. Phosphorus concentrations and physical characteristics were relatively similar among both cores taken from Tamarack Lake, which were elevated above the mobile phosphorus concentrations measured in the Wilkinson Lake cores. Sediment cores S1 and S2 in Wilkinson Lake were like one another, with lower mobile phosphorus concentrations (see Figure 1-7), while sediment cores S3 and S4 in Wilkinson Lake had significantly higher mobile phosphorus concentrations. Figure 1-6 shows that the locations of sediment cores S3 and S4 correspond with the slightly deeper water in Wilkinson Lake and the flow path from the south tributary to the lake outlet.





Sediment Sampling Location

Alum Staging Area

0.3-m contours with depth in meters, take on August 2, 2022.

Source: Macrophyte, Contour, Biovolume and Bottom Composition Survey, 8/2/22. Data collected and prepared by Ramsey County Parks & Recreation, Soil and Water Conservation Division for Vadnais Lakes Watershed Management Organization.

N

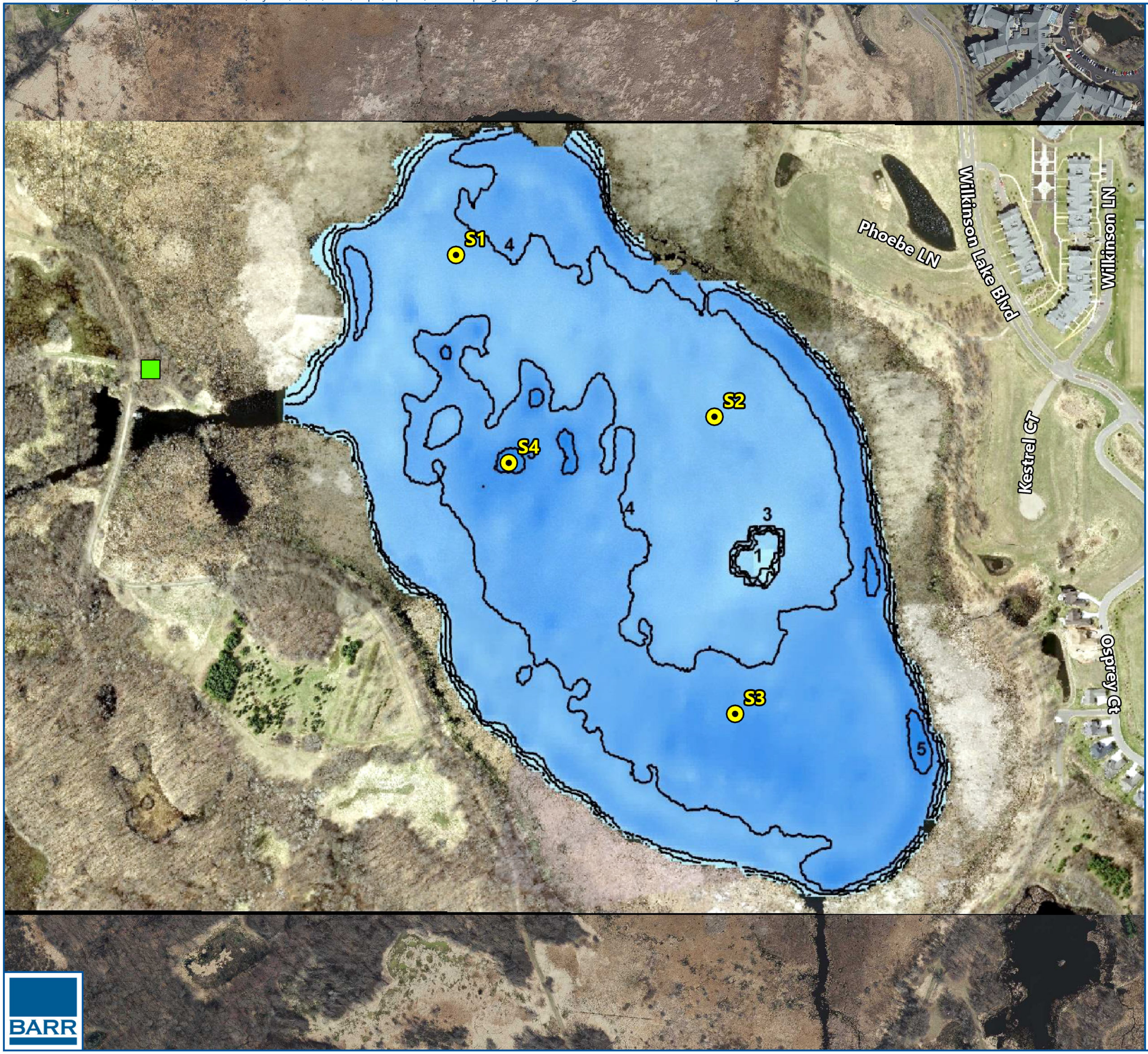
0 100 200

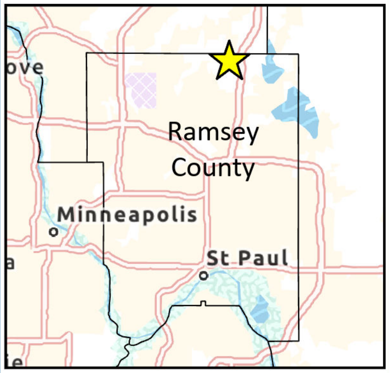
Feet

SEDIMENT SAMPLING LOCATIONS

Tamarack Lake

FIGURE 1-5





Sediment Sampling Location

Alum Staging Area

Source: Contour Survey 4/05/17. Data collected and prepared by Ramsey County Conservation District for Vadnais Lakes Watershed Management Organization.

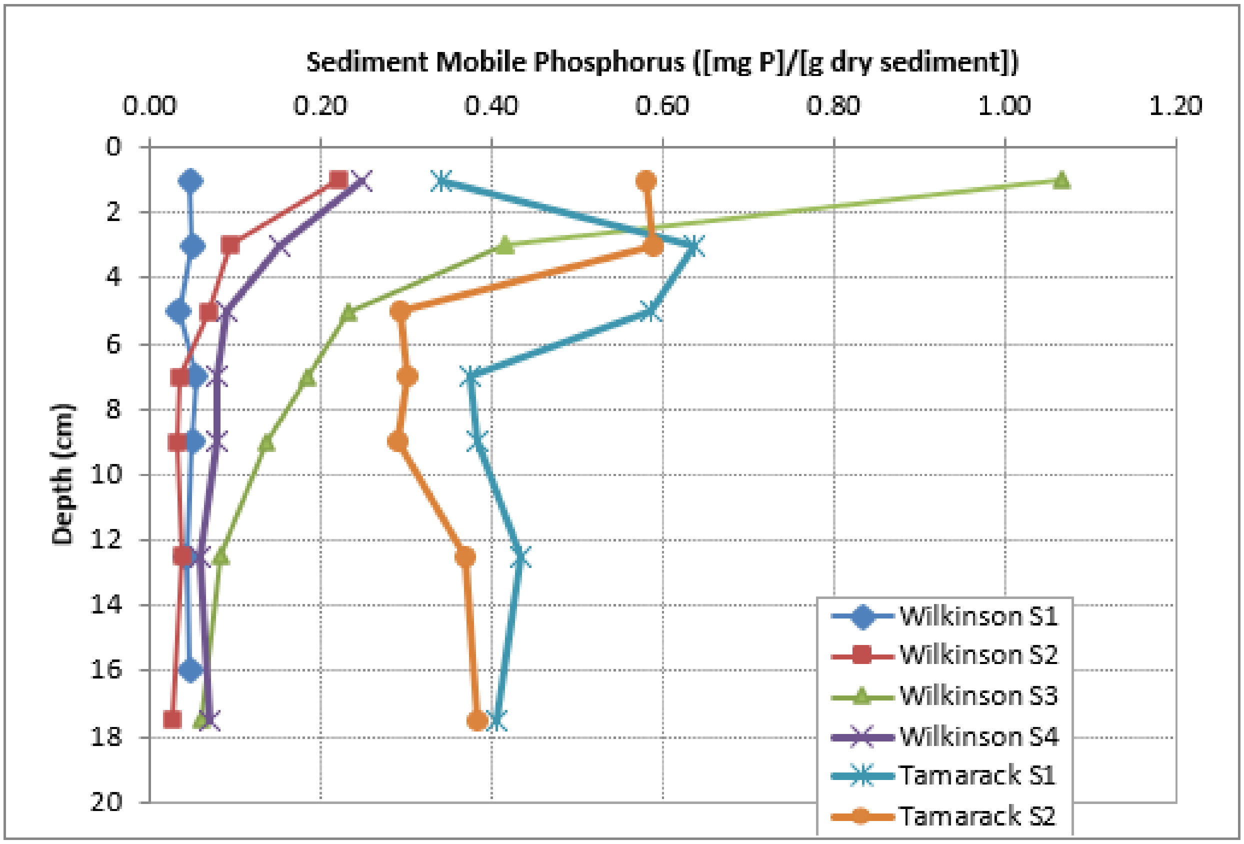
0 250 500

Feet

SEDIMENT SAMPLING LOCATIONS

Wilkinson Lake

FIGURE 1-6



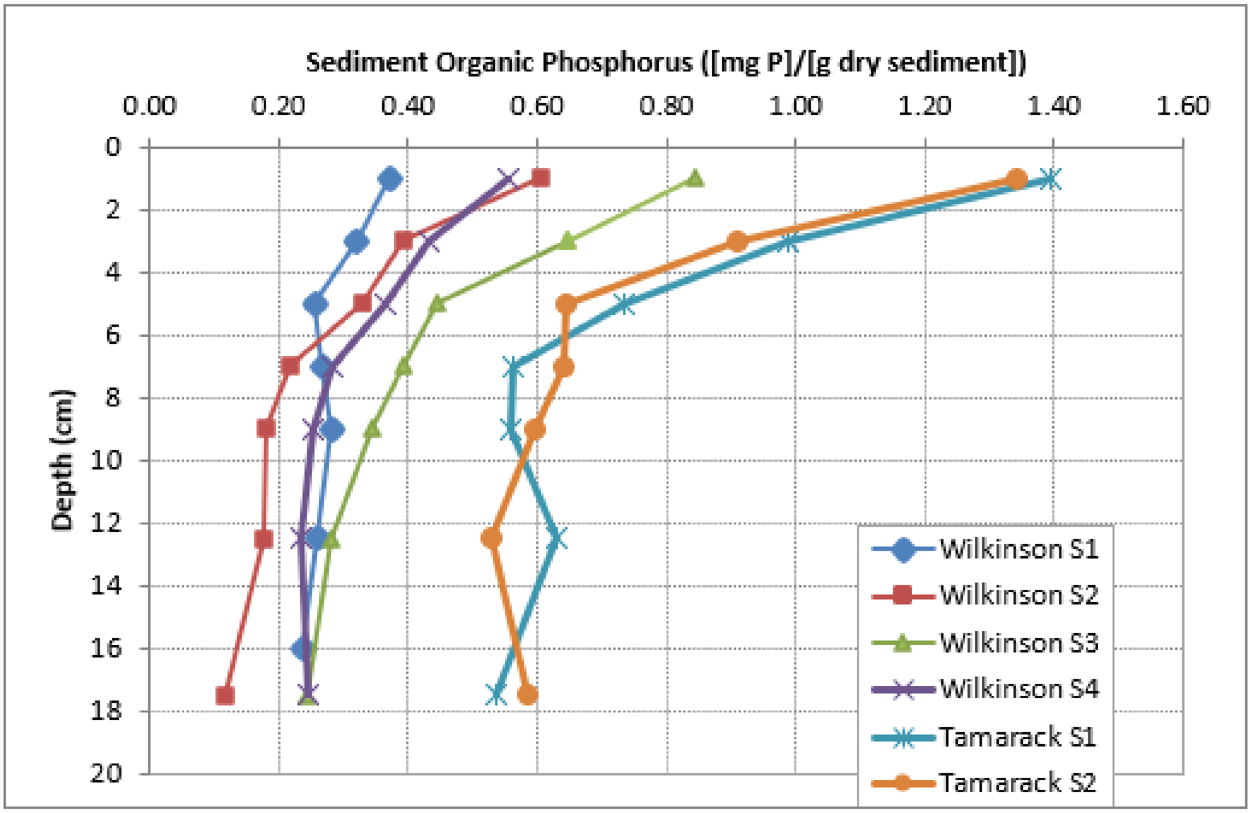


Figure 1-7 Results of Sediment Phosphorus Fractionations

2.0 Water Quality Modeling and Analysis

A key component to performing diagnoses is selecting a rigorous approach to evaluating potential water quality benefits. The simplified lake and watershed modeling approach used in the 2014 TMDL project did not account for intra-annual variations in lake water quality, so it was not considered for use in the previous feasibility analysis (Barr, 2017) as it lumps parameters at an annual time scale, treats lakes as fully mixed in a steady-state with uniform residence time, and does not adequately distinguish internal phosphorus loading sources from watershed sources during the critical conditions for water quality impairment. Based on our review of the available monitoring data and understanding of the purpose of the feasibility study, an approach was developed for evaluating the primary drivers of water quality impairment in each lake that adds further clarity, because it is based on updated monitoring data and accounts for intra-annual variations and recent management actions. Differentiating the individual drivers of lake water quality is based on the observed dynamics of each lake to set realistic expectations for future management actions.

The approach for this analysis used existing monitoring data, professional judgment, and past modeling to identify the best approach to cost-effectively improve lake water quality. Relevant subtasks included:

- Review current and historic water chemistry and biological data. Evaluate long- and short-term water quality trends.
- Review sediment phosphorus and dissolved oxygen data and use those data to estimate the internal phosphorus loading potential.
- Using existing watershed modeling, develop an updated lake phosphorus balance that includes phosphorus loads from watershed and in-lake sources and evaluate results to better understand the effect of varying climatic and sensitivity to management changes.
- Analyze fish data to evaluate potential impacts of rough fish on lake water quality and to determine the impact of water quality dynamics on the fish community.
- Integrate data analyses from above to diagnose causes of lake water quality problems, including feedback loops and dynamics between biological measurements and lake water quality observations.
- Evaluate existing and proposed water quality improvement options to identify feasible and cost-effective water quality improvement options for each lake basin.
- Complete an evaluation of feasible water quality improvement options to estimate expected lake water quality changes that could be attained.

2.1 Existing Management Practices

2.1.1 Watershed Best Management Practices (BMPs)

Since watershed mapping did not delineate the direct drainage areas tributary to existing BMPs and the BMP characteristics were not available, the updated P8 watershed modeling did not account for treatment for these BMPs in the feasibility study (Barr, 2017). Management actions were evaluated for the 2011 conditions in Wilkinson Lake, as the lake water quality modeling indicated that it represented a typical summer season that experienced both internal and external phosphorus loading impacts (see Section 2.2).

2.1.2 Past In-Lake Treatment Measures and Aquatic Invasive Species Control

An updated fish survey (Blue Water Science, 2017) indicates that natural winterkill conditions and an outlet carp barrier have successfully minimized rough fish populations and no other fish management is currently needed.

VLAWMO staff identified coontail and water lilies as the only two plant species in Wilkinson Lake when it was surveyed for the TMDL study (Wenck, 2014a). None of the plants were present in nuisance proportions and the vegetation in the surrounding wetland area consisted mostly of cattail and arrowhead. An updated vegetation survey was completed in 2017 by Ramsey County SWCD (then named RCD), which indicated the following:

> Aquatic macrophytes were found at all 60 points surveyed. Canada Waterweed (*Elodea canadensis)* and White Water Lily *(Nymphaea odorata)* were the most prominent species present, found at most of the survey points. Flat-stem pondweed (*Potamogeton zosteriformis*), Filamentous Algae *(Spirogyra/Cladophora sp.)*, and Coontail *(Ceratophyllum demersum)* were the next most common species. Found in fewer than 15% of the survey points were the following species: Curly Leaf Pondweed (*Potamogeton crispus*); Greater Duckweed (*Spirodela polyriza);* Sago Pondweed *(Potamogeton pectinatus)*; Yellow Water Lily (*Nuphar lutea*), Slender Waternymph (*Najas gracillima*); Muskgrass (*Chara spp.)* and Stonewort (*Nitella sp.*). Although the specific species of stonewort was not determined, there was no indication that the plant detected was the invasive starry stonewort – no white bulbils were seen. The secchi disk reading was 0.9m (2.95 ft).

2.2 Wilkinson Lake

Updated lake and watershed modeling was developed for this study and optimized to reproduce the observed water quality for each lake during the summer periods of interest. Figure 2-1 shows how the predicted and measured total phosphorus concentrations compare during the summer of 2011 for Wilkinson Lake without BMP implementation. Approximately 200 pounds of the overall phosphorus load was attributed to sediment phosphorus release during this time. The in-lake water quality modeling was used to show how implementation of the deep-water wetland restoration project (that is expected to remove 32.5 pounds of total phosphorus per year from the south tributary to Wilkinson Lake) and in-lake alum treatment would improve water quality during 2011. Figure 2-1 shows that the predicted phosphorus concentration in Wilkinson Lake would respond well to the implementation of the watershed BMP and an 80 percent reduction in internal load (like what would be expected following an in-lake alum treatment), or approximately 160 pounds per year of phosphorus.

The modeled summer average TP following BMP implementation shown in Figure 2-1 is 67 ug/L, but it should be noted that the results of these analyses are based on the same starting phosphorus concentration at the beginning of the summer. Over time, following full-scale BMP implementation or in-lake alum treatment, it is expected that the starting concentrations would be lower than what is shown at the beginning of each summer season. Based on the results shown in Figure 2-1, this in turn, should ensure that an in-lake alum treatment combined with implementation of the deep-water wetland restoration project would maintain lake water quality at levels that are very close to the shallow lake standards.

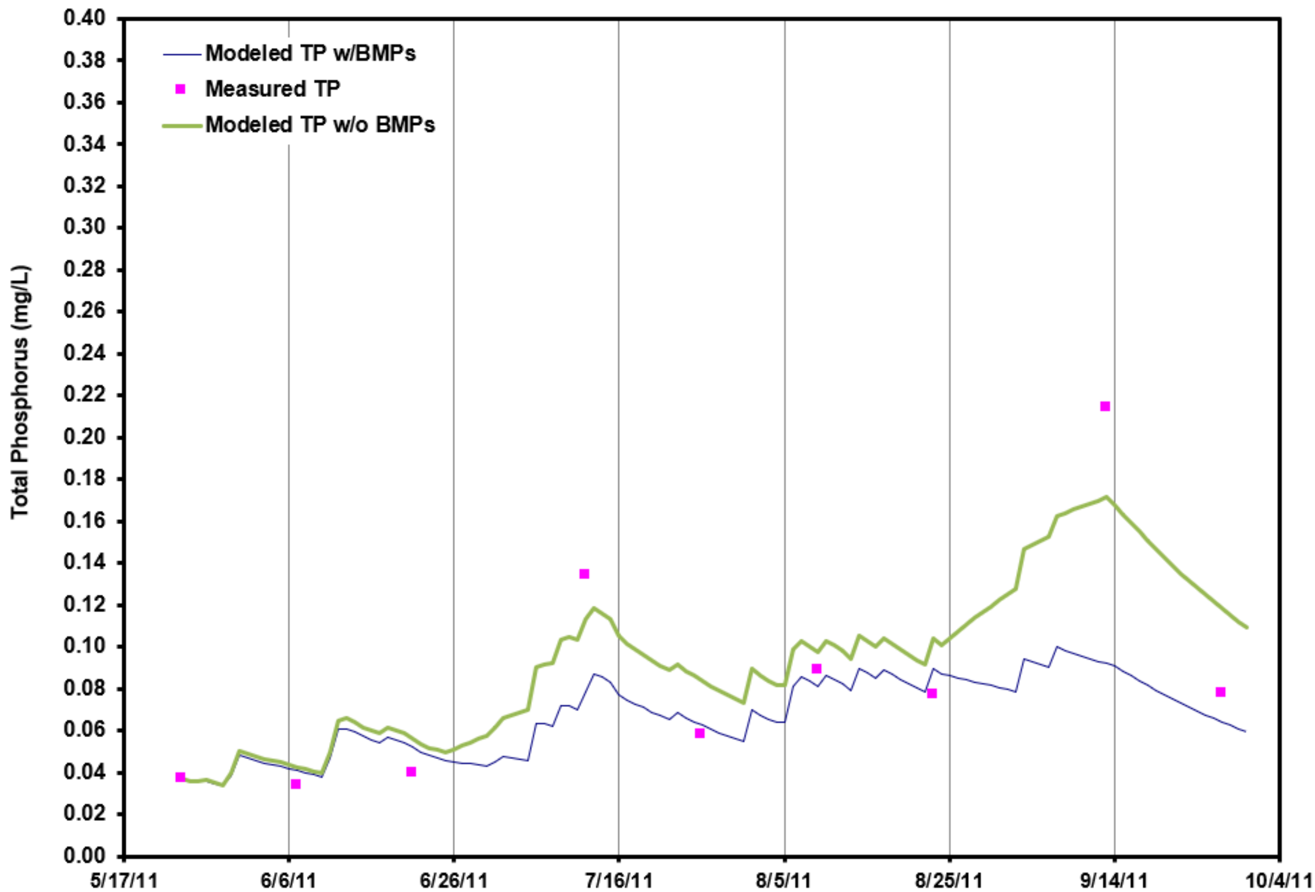


Figure 2-1 2011 Water Quality Modeling Results for Wilkinson Lake

2.3 Tamarack Lake

Since watershed and in-lake water quality modeling was not specifically available for Tamarack Lake, Barr reviewed the 2021 and 2022 lake water quality monitoring data to develop a mass balance estimate of how much the increasing summer total phosphorus concentrations could be associated with internal load. Measured total phosphorus concentrations increased by 166 and 200 µg/L during the respective summers of 2021 and 2022 for Tamarack Lake. On average, approximately 32 pounds of internal phosphorus load can be attributed to sediment phosphorus release during these two years. As a result, an in-lake alum treatment is also recommended for Tamarack Lake as the monitoring results indicate that it would be needed to ensure that the water quality goals/standards are met on a consistent basis. Over time, following an estimated 26 pounds per year of phosphorus load reduced (80 percent) from an in-lake alum treatment (and to a lesser extent, small-scale watershed BMP implementation), it is expected that the concentrations would be maintained closer to the shallow lake standard throughout the summer season.

3.0 Social Implications of In-Lake Management

Understanding the inner working and prescribing management strategies of lake systems requires use of complex mathematical watershed and lake models. However, the resultant management strategies, although technically supported, are often difficult to convey to the public. To address the issue, a stakeholder engagement process was incorporated into the 2017 feasibility study (Barr, 2017). The goal of the stakeholder engagement process was to involve the public, regulatory agencies and VLAWMO staff in the process of identifying and vetting management solutions for each lake. This stakeholder process was completed previously for Wilkinson Lake, and it's recommended for VLAWMO to convey some of the same output with key stakeholders to implement future projects for both lakes, and assist with getting alum treatment permitting from MPCA.

The 2016 Stakeholder Charrette was attended by members of the public, non-governmental organizations (including the North Oaks Homeowners Association), municipal agencies (Cities of North Oaks and White Bear Lake and Ramsey Conservation District), state government (Minnesota Department of Natural Resources and Minnesota Pollution Control Agency) and VLAWMO staff. The attendees convened for a state of the lake presentation for each lake followed by collaborative group discussions.

When group attendees were asked about what role fish and aquatic plants play, they were interested in discerning the difference between invasive and non-invasive plants. Also, there was concern about the lack of species diversity and how that would affect the ecological functions of the lakes. They were also interested in conducting a fish study in Wilkinson Lake (which was subsequently conducted in 2017).

In addition, group attendees wondered why Wilkinson Lake is considered a shallow lake and not a wetland. The group discussions generated questions for regulatory agencies to address and VLAWMO staff to consider. The MPCA detailed their role as the agency responsible for assessing a lake's quality and its ability to meet designated standards. Modifying the classification to assign a shallow lake or wetland designation to the public water/wetland through the MPCA is a relatively straightforward process requiring data (maximum depth, littoral area, shoreline vegetation, uses, etc.) supporting the change. After considerable discussion and a qualitative review of the available data on Wilkinson Lake, it was concluded that maintaining the shallow lake classification is best for this system. Wilkinson Lake is in the upper watershed and discharge from it must be relatively clean so as not to adversely affect the water quality of downstream lakes that ultimately feed the water supply.

Vegetation changes may need to be considered for an alum treatment. Both lakes do not have recreational use and native vegetation would be expected to experience increased growth. Curlyleaf pondweed is not currently present in Tamarack Lake, although ongoing monitoring is recommended. In Wilkinson Lake, curlyleaf pondweed monitoring and consideration for management is also recommended following an alum treatment.

4.0 Recommendations

4.1 Alum Treatment for Tamarack and Wilkinson Lakes

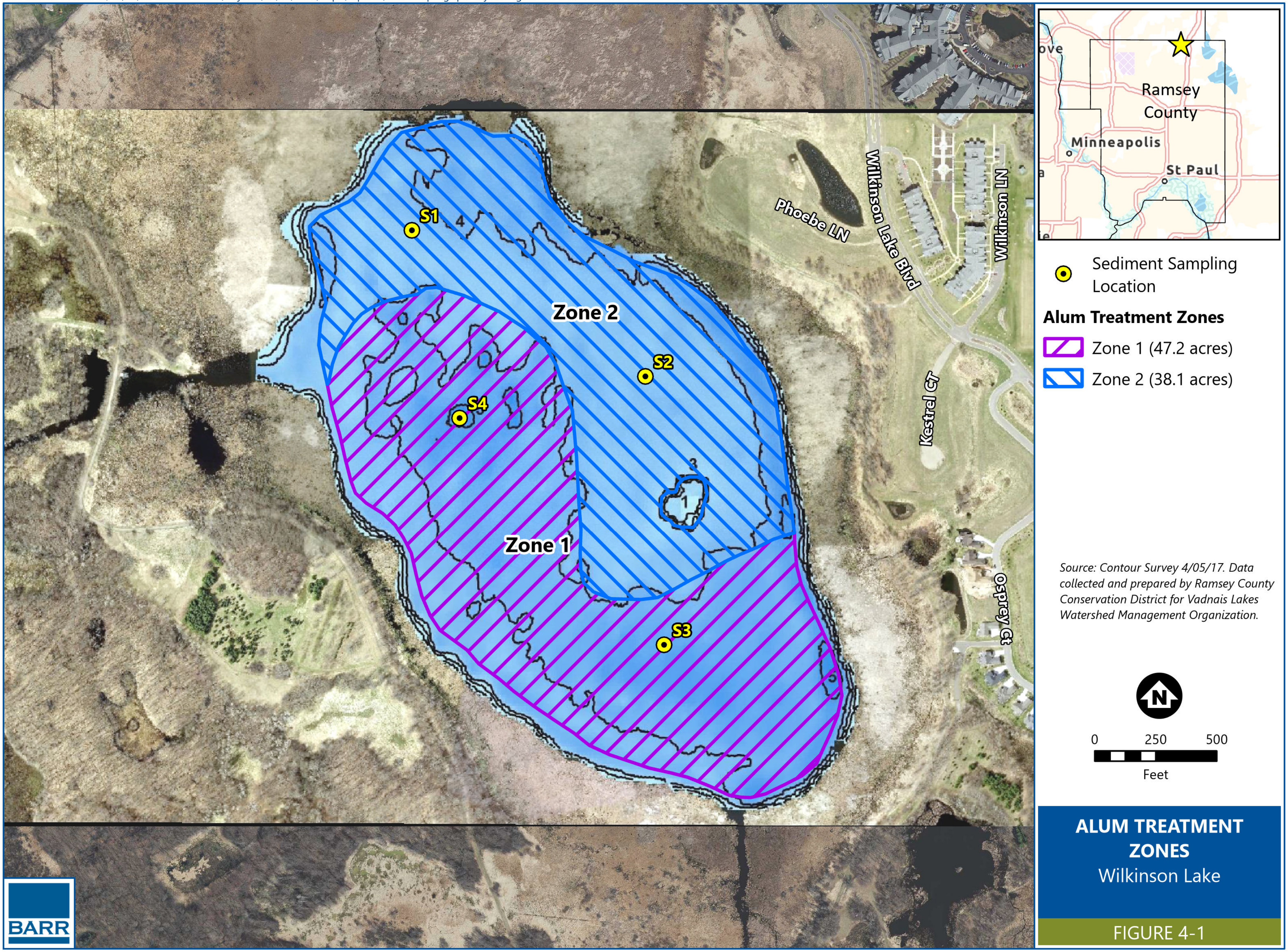
Alum treatment is recommended for both Tamarack and Wilkinson Lakes to reset the sediment phosphorus release rates to levels that are consistent with natural background conditions. The application of aluminum has two expected mechanisms: (1) aluminum binds with iron-bound phosphorus in the sediment, thereby forming Al-P, and (2) a residual amount of unbound aluminum remains in the sediment and is available to bind phosphorus that is released from the decay of Org-P. For most lake systems alum dosing is designed to provide some amount of "excess" aluminum to bind phosphorus released from decayed Org-P. However, the aluminum added to the sediment will age over time and be less effective at capturing more phosphorus. Due to the high amount of Org-P in Tamarack and Wilkinson Lake sediment, it is recommended that the alum treatments of Tamarack and Wilkinson Lakes be split into two applications. By splitting the alum treatment into two applications separated by two or more years, more of the decomposing Org-P can be captured by the alum. The second application would occur two or more years after the first application and could be completed as soon as lake monitoring data indicates that internal phosphorus loading is beginning to reoccur.

Two forms of aluminum are typically applied to lakes: alum and sodium aluminate. When alum is added to a lake, it will lower the pH (make it more acidic), while sodium aluminate will raise the pH (more basic). Therefore, these two chemicals are often added in combination to neutralize the pH effects during treatment. At lower doses, alum-only applications can be conducted without adversely affecting the pH (i.e. pH stays above 6). Alum is typically less expensive and easier to work with than sodium aluminate, and an alum-only treatment may be preferable when it will not cause an unacceptable change in pH.

Since Wilkinson Lake sediment cores S1 and S2 had lower mobile phosphorus concentrations than sediment cores S3 and S4, and since the locations of sediment cores S3 and S4 correspond with the slightly deeper water and the flow path from the south tributary to the lake outlet, the Wilkinson Lake dosages were split into two treatment zones as shown in Figure 4-1. Table 4-1 shows the recommended alum and sodium aluminate dosages prescribed for each lake with split applications, including a breakdown of the treatment zone dosages for Wilkinson Lake.

Table 4-1 Recommended Alum Dosing for Split Applications

Lake	First Application		Second Application		Lake Total	
	gallons alum	gallons sodium aluminate	gallons alum	gallons sodium aluminate	gallons alum	gallons sodium aluminate
Tamarack	3,770	1,885	3,770	1,885	7,540	3,770
Wilkinson Zone 1	19,070	9,535	19,070	9,535	60,830	30,415
Wilkinson Zone 2	11,345	5,673	11,345	5,672		
				Treatment Total	**68,370**	**34,185**



ALUM TREATMENT ZONES
Wilkinson Lake

FIGURE 4-1

The pH in the waterbody must be closely monitored during alum applications, and if the pH reaches the critical value of 6.0, the treatment should be stopped until the pH can recover. If pH and alkalinity conditions are different at the time of treatment and show a greater potential to lower pH below 6.0 during treatment, the treatment plan could be altered to replace a portion of the alum with a higher quantity of sodium aluminate to buffer the pH.

Typically, in-lake alum treatments are effective for 15 to 20 years, with shallow lakes experiencing shorter durations of effectiveness, depending on the extent of watershed treatment. However, it is expected that the split applications of alum, combined with the extent of stormwater treatment in each lake watershed, will ensure that the effective life of the alum treatment is greater than ten years and that alum would not need to be reapplied for 15 years. VLAWMO will be responsible for any future maintenance that will be needed to achieve the effective life of the project.

4.2 Estimated Implementation Costs

As discussed in Section 2.1, and shown in Figure 1-1, there are several existing/planned BMPs and upstream lakes and wetlands in the Wilkinson Lake watershed and the Tamarack Lake watershed that do not contribute excess phosphorus loading.

Splitting the alum treatment into multiple applications would also allow for adjustments to the final alum dose, based on observations of water quality and/or sediment chemistry following the first application. the total estimated costs (including engineering, treatment oversight and a 25% contingency is recommended) for the recommended split treatment for each lake are shown in Table 4-2. Phase 1 is recommended for the fall of 2024. The treatment costs are based on the prescribed dosages of alum and sodium aluminate shown in Table 4-1 and assumed unit costs of $3 per gallon for alum and $7.50 per gallon for sodium aluminate.

Table 4-2 Summary of Alum Treatment Costs

Description	Tamarack Lake		Wilkinson Lake	
	Phase 1	Phase 2	Phase 1	Phase 2
Chemical treatment contract	$26,000	$26,000	$205,000	$205,000
Engineering and treatment contracting support	$4,000	$4,000	$10,000	$10,000
Contingency (25%)	$7,500	$7,500	$53,750	$53,750
Totals	**$37,500**	**$37,500**	**$268,750**	**$268,750**
	$75,000		**$537,500**	

The alum treatment costs shown in Table 4-2 assume that both basins are treated at the same time to minimize mobilization costs for the treatment contractor. Treatment support includes pH monitoring of each lake each time that chemicals are applied to assure that the project's permit requirements are met. Figures 1-5 and 1-6 show the recommended locations for a contractor's alum staging area, including path access and locations for temporary tanks adjacent to Tamarack Lake and Wilkinson Lake, respectively.

It is expected that wider-scale implementation of additional site-scale BMPs throughout the watershed would also be cost-effective as the watershed experiences development and redevelopment but may not always be feasible and would likely need to be implemented as a part of street reconstruction projects to realize significant cost savings. Other than winterkill, which along with the outlet carp barrier, has controlled the rough fish densities (Blue Water Science, 2017), no other in-lake treatment alternatives were considered cost-effective and/or adequate to meet the water quality goals for the lakes. Herbicide treatments may be warranted in Wilkinson Lake after alum treatment to ensure that curlyleaf pondweed and/or other invasives do not supplant native plants. Curlyleaf pondweed has not been documented in Tamarack Lake, so herbicide treatment should not be needed.

5.0 References

Barr Engineering Company. 2017. East Goose, West Goose and Wilkinson Lakes Feasibility Study. Prepared for Vadnais Lake Area Water Management Organization (VLAWMO) in partnership with Young Environmental Consulting Group.

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Wenck. 2013. Vadnais Lake Area WMO Total Maximum Daily Load (TMDL) and Protection Study. Prepared for VLAWMO.