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Technical Memorandum

To: Minneapolis Park and Recreation Board
From: Barr Engineering Co.
Subject: Cyanobacteria Mitigation Feasibility Study - for Cedar Lake and Lake Nokomis
Date: October 19, 2022
Project: Lake Nokomis and Cedar Lake Blue-Green Algae Bloom Mitigation Strategies Project
c: Young Environmental

Using the conclusions of the cyanobacteria stressor analysis and the results of previous implementation efforts, new mitigation options were considered to address the in-lake and near-lake stressors that drive cyanobacteria blooms, including controlling nutrient delivery and cyanobacteria-specific treatments in each lake with an emphasis on strategies that MPRB could implement in the lake or on MPRB property. This memorandum reports on the feasibility assessment and makes recommendations for conceptual design of structural mitigation strategies that should be considered in the final phase of the project.

1.0 Results of Cyanobacteria Stressor Analysis

Barr developed a stressor identification study to assess the drivers of cyanobacteria dominance and blooms in Cedar Lake and Lake Nokomis.

For Cedar Lake the primary drivers include:

1. High nutrient concentrations in the hypolimnion because of shallow anoxia and sediment phosphorus (P) release
2. Strongly stratified conditions with high nutrient concentrations at the thermocline selecting for cyanobacteria that regulate buoyancy in the Summer and into the Fall
3. High phosphorus concentrations under winter ice because of high internal P loading resulting in conditions that favor cyanobacteria adapted to cold temperatures and low light conditions
4. Nitrogen limitation in late summer that favors nitrogen fixing cyanobacteria
5. Increased light availability during the winter as a result of snow plowing and removal to maintain local cross country ski trails.

For Lake Nokomis the primary drivers include:

1. Weakly stratified conditions with high nutrient concentrations near the lake bottom selecting for cyanobacteria that regulate buoyancy in the Summer and into the Fall
2. High nutrient concentrations in the hypolimnion because of large areas of anoxia and sediment P release
3. A large carp population that may be exacerbating internal phosphorus loading in the lake
4. While phosphorus concentrations under winter ice as result of internal P loading are moderate, conditions still favor cyanobacteria adapted to cold temperatures and low light conditions
5. Nitrogen limitation in late summer that favors nitrogen fixing cyanobacteria

6. Increased light availability during the winter because of snow plowing and removal to support local pond hockey activities.

2.0 Screening-Level Feasibility Assessment of Mitigation Strategies

2.1 Feasibility Assessment

To develop a high-level screening of potential mitigation options, each mitigation option was assessed for advantages, disadvantages, timing, risk, feasibility, and magnitude of costs (Table 1 and Table 2). Following is a brief description of each assessment factor.

Advantages/Disadvantages

The advantages and disadvantages for each potential mitigation option were summarized for each lake taking into consideration each lake's unique characteristics. Lake specific advantages/disadvantages were specifically called out for each lake. Otherwise, the advantages/disadvantages apply to the general practice.

Application/Timing Options and Implementation Timeline

Application and timing address the length of time it will take to implement the project (implementation start and then implementation period), frequency of implementation, and timing of implementation (season). For example, an alum treatment may be implemented in less than a year but take six years to be fully implemented. For algaecides, it may take less than one year to develop a treatment method and implement the process, but the frequency of implementation will be annually in Spring, Summer, Fall, and/or Winter.

Risk/Uncertainty

All of the projects carry risk of unintended outcomes, failure, or challenges in operation. Additionally, many options are relatively new and have minimal research to support their efficacy. The risk and uncertainty of each approach was summarized for consideration.

Feasibility

Project feasibility is an overall assessment of the project's viability given local conditions, lake characteristics, local infrastructure, and other factors. Feasibility was ranked as low, medium or high based on the potential for implementation, potential efficacy, number of potential side effects, and advantages/disadvantages of the approach. For example, copper-based algaecides were assigned a low feasibility score because of the potential to release cyanotoxins after killing the algae, the potential build-up of copper in the sediments with annual use, studies that suggest long term algaecide use can lead to high internal P loading, and the MPRB's and local residents' desire to avoid chemical treatments if possible.

Relative Cost

High level cost ranges were developed for each project based on implementation of other similar projects or professional experience. Costs were generally described in ranges to assign the general cost range of the project. For cost estimating, the expected life of each project is 20 years. Nonstructural BMP costs were estimated by assuming implementation over a 20-year period. For example, if algaecides were used annually, the total cost was estimated by multiplying the annual cost by 20. Costs for the 20-year period include capital costs, design, construction, and operations and maintenance. It should be noted it was not always possible to split these costs among those categories and the costs are expected ranges for comparison purposes. More detailed cost assessment will be completed on projects carried to conceptual design in the next phase of the project.

2.2 Reactive Mitigation Strategies

Short term reactive measures may be used to control harmful algal blooms while long term controls are designed and implemented. Short term measures include algae control methods that can be implemented in less than a year and react to an identified bloom occurrence or indications that a bloom may occur. However, since these strategies react to a bloom occurrence and do not address the root cause of the problem, they need to be implemented routinely, at a minimum every year.

Algaecides

Algaecides are the most commonly used reactive approach for mitigating cyanobacteria or harmful algae blooms. Some of the typical products for cyanobacteria were reviewed (Table 1). While there are numerous effective options, copper-based algaecides are the most used products. However, long term use of copper-based algaecides was demonstrated to have many potential negative side effects including dissolved oxygen depletion by decomposition of dead algae, accelerated phosphorus recycling from the lakebed and recovery of the algal population within 7 to 21 days, and occasional fish kills due to oxygen depletion or copper toxicity or both (1). Other products, such as hydrogen peroxide or peracetic acid, do not result in buildup of metals in the sediment but can result in other impacts, including oxygen depletion, and bloom recovery is likely to still occur. Finally, efficacy can be very species specific and may not have the desired results without careful product selection. Therefore, any use of algaecides should be considered short term until the cyanobacteria drivers can be addressed.

One promising area where algaecide use may be effective is winter use under the ice to reduce Spring cyanobacteria blooms and reduce reproductive akinetes that may be overwintering in the sediments. This approach may control impacts to dissolved oxygen and minimize blooms by reducing the seed population. However, winter applications of algaecides are still being researched and there is a high level of uncertainty in the efficacy of this approach.

Algaecides can also be used to suppress a cyanobacteria bloom if bloom formation can be predicted. In water supply reservoirs, many utilities use real time phycocyanin and chlorophyll-a data to determine when to treat to prevent bloom formation. Others simply apply at similar times a year based on past experience. However, these are typically deep reservoirs, many of which are nonrecreational, where copper settles to deep sediments away from potential impacts to biota. For recreational uses, this approach requires real time data, testing of toxins before and after application, and a detailed approach for application that needs to be designed using years of experience.

Physical Disturbance – Sonication (Ultrasonic Radiation)

Sonication (ultrasonic radiation) is a relatively new technology for mitigating cyanobacteria or harmful algae blooms. Sonication treatments emit high frequency ultrasound to target mechanical damage to algal cells. Specifically, the ultrasound frequencies are set to levels to damage and collapse cyanobacteria gas vacuoles responsible for regulating buoyancy. The damage to the vacuoles results in settling of the cyanobacteria cells to the sediment. Sonication can also inhibit cyanobacteria photosynthesis by damaging intracellular and extracellular complexes involved in photon uptake.

Sonication has been viewed as a selective mitigation option because of the reported heightened impacts to algae containing gas vacuoles (cyanobacteria) over other species lacking such gas vacuoles (green algae). If sonication results in the selective mitigation of cyanobacteria, as shown in laboratory studies and small pilot studies, sonication could be an environmentally safer strategy than algaecide treatments, which can be less selective and create toxic conditions for multiple algal species.

However, while lab studies and pilot studies have shown effective selective mitigation of cyanobacteria cells, field-scale findings are contradictory. Field-scale studies have found some of the following concerns (2):

- Knowledge gaps on optimization and scalability of equipment for larger waterbodies.
- The ultrasonic frequencies, radiation durations, and coverage areas must be adopted to address differences in gas vacuoles between cyanobacteria species. Since cyanobacteria species vary spatially and temporally in lakes, creating an effective, consistent sonication treatment may be difficult.
- Uncertainties related to the impact of ultrasonic frequencies on green algae, plants, zooplankton, and fish.
- Studies have shown that some cyanobacteria species may be able to rebuild their gas vacuoles, which would impact the efficacy of the ultrasonic equipment.

As a part of this study, Barr reached out to LG Sonic to assess the feasibility of installing MPC-Buoys in Cedar Lake and Lake Nokomis. The MPC-Buoy is a floating, solar-powered system that not only creates ultrasound to control cyanobacteria blooms, but can also provide real-time water quality monitoring (e.g., chlorophyll-a, phycocyanin, turbidity, dissolved oxygen, pH, temperature). A depiction of the MPC-Buoy is shown in Figure 1. LG Sonic states that each MPC-Buoy can control algae in areas up to 1,600 feet in diameter. As such, a minimum of 5 buoys would be needed to control algae in Cedar Lake. A minimum of 4 buoys would be needed in Lake Nokomis. The initial, high-level capital cost estimate to install five MPC-Buoys in Cedar Lake is approximately $285,000. The initial, high-level capital cost estimate to install four

MPC-Buoys in Lake Nokomis is approximately $230,000. It is not advised to keep the buoys installed over winter; therefore, annual maintenance costs would be required to install the systems in the spring and remove them in the fall (about $5,000 per year). It can also be expected that occasional site visits may be required during the monitoring/treatment season to inspect the equipment (about $1,000 per year).

Figure 1 LG Sonic MPC-Buoy: (1) Ultrasonic transmitters, (2) Water Quality Sensors, (3) Solar Panels, (4) Anchoring mechanism, (5) Real-time communications

Due to the increased risk associated with applying a new technology to larger lake systems, annual maintenance requirements (e.g., install/remove annually), and aesthetic and physical impacts of the buoys during summer recreation, the feasibility of using sonication to mitigate cyanobacteria in Cedar Lake and Lake Nokomis is "low". A summary of the ultrasonic treatment system can be found in Table 1.

2.3 Proactive Mitigation Strategies

Proactive measures directly address the cause of cyanobacteria blooms as determined by the stressor analysis. Proactive measures should result in long term control of the cyanobacteria blooms through elimination or control of the driver.

In-Lake Sediment Phosphorus Inactivation

For both lakes, a primary driver of cyanobacteria blooms was high internal P loading from sediment P release under anoxic conditions. One of the most effective solutions for controlling sediment P release in lakes is sediment P inactivation using a metal hydroxide. A number of commonly used metal hydroxides were reviewed for applicability to Cedar Lake and Lake Nokomis (Table 2). The added metal hydroxide binds P in the sediments so that it will not be released into the water column. In the United States, the most common sediment P inactivation agent is aluminum hydroxide, created by adding aluminum in the form of aluminum sulfate, sodium aluminate, or polyaluminum chloride (PAC). Aluminum treatments have occurred on hundreds of lakes in the U.S. and throughout the world. Iron hydroxide can also be effective; however, it typically requires maintenance of aerobic conditions through aeration or direct oxygen injection. Iron hydroxide can be added to the sediments through the addition of ferric chloride or iron filings. Recent research suggests that adding enough iron filings to sediments may result in reducing sediment P release even under anaerobic conditions; however, this control has not been demonstrated on a large, lake-wide scale. Finally, a recent proprietary product, Phoslock, has been used on numerous lakes throughout the world to reduce sediment P release. Phoslock uses bentonite clay treated with lanthanum to produce a hydroxide effective at binding sediment P. Whereas alum has been used for over 50 years and has hundreds of papers demonstrating its use and effectiveness, Phoslock is relatively new and few case studies with more than 5 years of data exist in the literature.

Sediment P inactivation is an effective approach for lakes that demonstrate high sediment P release under anoxic conditions such as Cedar Lake and Lake Nokomis. Because iron requires aerobic (oxygenated conditions), it was eliminated as a potential approach for these lakes. It will be considered in the aeration and hypolimnetic oxygenation approaches if the sediments are determined to be low in iron. Iron filings remain unproven on a large scale without oxygenation, so this approach was removed from consideration. Alum treatment is the most proven method for sediment P inactivation and is commonly done with aluminum sulfate (alum) and sodium aluminate. PAC was not considered since the chloride addition could impact biota. Phoslock should be considered as there is potential for additional control of cyanobacteria akinetes in the sediments from the clay particles. While these impacts are still under research at the University of Minnesota and unproven, cost comparisons may help decide whether Phoslock should be used. It should be noted that the long-term impacts of lanthanum in sediments is not well understood while aluminum, a natural component of all lake sediments is better described in the scientific literature.

Cost estimates for alum assumed between 100 and 200 g Al/m^2. Based on other estimates, Phoslock was assumed to be 1.5 times higher in price than alum. These costs will be further refined in the concept level design.

In-Lake Biomanipulation

Carp Management

Since Cedar Lake is a deeper, stratified lake, it is not expected that the presence of carp will adversely impact water quality to a significant extent unless fish biomass exceeds management thresholds recommended by the University of Minnesota. It is more likely that use of upstream water bodies as a nursery by the existing carp population would represent a bigger impact on the water quality of watershed runoff. Following initial BMP implementation from the Clean Water Partnership, carp migrated from Cedar Lake to the wetland basin at Cedar Meadows through the Cedar Meadows outlet. Several hundred rough fish had to be removed and a fish barrier was installed in the Cedar Meadows outlet to Cedar Lake. For the concept level design, it will be important to consider whether the fish barrier at the Cedar Meadows outlet to Cedar Lake is functioning properly and successfully controlling carp recruitment.

The weaker stratification of Lake Nokomis makes its water quality more susceptible to impacts from higher carp biomass, along with concerns about carp recruitment from the existing watershed BMPs and

Minnehaha Creek. As a result, an Integrated Pest Management (IPM) effort was undertaken and published in 2019 with the following goals:

- Reduce carp biomass in Lake Nokomis to 67 kg/ha (60 lbs/acre)
- Reduce migration between Solomon Wetland and Lake Nokomis
- Collect fish passage data at Lake Nokomis Outlet/Minnehaha Weir
- Preserve project accomplishments through annual data collection efforts
- Public education and outreach

Priority action items identified in the IPM included:

- Installation of a carp barrier on the Solomon Wetland outlet to prevent carp from accessing this nursery
- Additional study of the role of the Nokomis outlet weir with regard to carp movement
- Adult carp biomass removal within Lake Nokomis below the 100 kg/ha ecological tipping point

During Carp IPM plan development, several efforts were made to reduce carp biomass in Lake Nokomis and collect data on fish migration but were later put on hold due to historic high water. It is still expected that future implementation efforts should be devoted to reducing the carp population in the lake, installing a carp barrier (or barriers) in the watershed, and minimize carp recruitment from Minnehaha Creek under high flow.

Aquatic Vegetation Management

Submerged aquatic vegetation are a critical component of shallow lakes, providing a number of ecosystem services including providing habitat, stabilizing sediments, dissipating wave energy, and providing refugia for zooplankton grazers that help maintain low algae populations. For any of the strategies to reach their full potential, native aquatic vegetation establishment and management needs to be a key component of the strategy.

In Lake Nokomis, more than half of the lake should support submerged aquatic vegetation. Currently, the aquatic vegetation community is limited. For a sediment inactivation treatment to be effective, establishment of submerged aquatic plants should be a focus. However, there are several potential outcomes including minimal vegetation response or an over-abundance of vegetation. An action plan should be developed for possible outcomes including balancing aquatic vegetation with recreational uses.

At only 38% littoral and currently supporting a more robust aquatic plant community, aquatic plant management is less critical in Cedar Lake. However, management of the aquatic plant community to reduce invasive species and increase native species will increase the stability of water quality in Cedar Lake. Recreational uses will also need to be balanced in the lake.

Concept design and costs will be developed for aquatic plant management in both lakes in the next phase (conceptual design) of the project. However, it should be noted that Aquatic Plant Management Plans

(APM) should be developed for both lakes that incorporate current conditions and desired outcomes. While an APM is outside the scope of this project, basic concepts and costs will be developed for planning purposes including monitoring, mechanical or herbicide control, and long-term introduction and management of native plants.

In-Lake Structural BMPs

In lake structural BMPs were reviewed for efficacy and high-level costs to determine possible approaches to minimize anoxia, which results in anaerobic sediment P release and internal P loading (Table 2). Micro floc injection was also reviewed as a possible add-on to these systems. Micro floc injection includes adding low doses of iron or aluminum to bind water column P and to increase the available hydroxides in the sediment to bind P and prevent release. These approaches may have other benefits including changing the phytoplankton community through artificial mixing, altering the nitrogen cycle, and expanding fish habitat with oxygenation. However, these changes may not benefit lake water quality. For example, artificial circulation may shift the cyanobacteria community, trading one set of toxin producers for another. Reducing sediment nitrogen sources may lead to earlier onset of cyanobacteria communities or simply favor nitrogen fixers. These factors are summarized in Table 2. The three primary viable structural in-lake BMPs include:

- Hypolimnetic oxygenation without destratification (Cedar Lake)
- Aeration and artificial circulation (Lake Nokomis)
- Micro floc injection as an add-on to the above systems

Hypolimnetic Oxygenation and Microdosing (Cedar Lake Only)

The primary goal of hypolimnetic oxygenation is to maintain oxygen levels in the hypolimnion (bottom water) above 5 mg/L to prevent sediment P release. Since Cedar Lake is a deep lake that strongly stratifies through the summer growing season, destratification with aeration would be extremely difficult and result in entrainment of bottom water P into surface waters. Consequently, a hypolimnetic oxygenation system that uses pure oxygen injected into the hypolimnion without mixing the water column would be required. For this to work appropriately, there must be enough iron in the sediments to bind P in the sediments. If the sediments are lacking enough iron, micro floc injection might be required to ensure sufficient binding. The system will require compressors and a housing facility with electricity, tubes, and diffusers.

Aeration and Artificial Circulation (Lake Nokomis Only)

Since Lake Nokomis only weakly stratifies, an aeration system designed to maintain a mixed water column is the most appropriate approach for maintaining oxygenated conditions over lake sediments. Due to the complex bathymetry of Lake Nokomis, diffusers would need to target deep holes throughout the lake to ensure thorough mixing of the lake. This may require multiple compressors and housing sites around the lake. If the sediments are lacking enough iron, micro floc injection might be required to ensure sufficient P binding. The system will require compressors and a housing facility with electricity, tubes, and diffusers.

Dredging

Table 2 shows that there are considerably more disadvantages than advantages for dredging, combined with the high cost and risk/uncertainty associated with this mitigation strategy. Since limited water quality benefit may result from incrementally increasing assimilation capacity and/or reducing the sediment phosphorus release, it is likely that the high cost of dredging either lake would not be justified. As a result, dredging is not recommended for concept-level design.

Watershed Structural BMPs

The final report of the Minneapolis Chain of Lakes implementation grant established 40 percent and 10 percent phosphorus load reduction goals, respectively, for Cedar and Brownie Lakes. The 1993 diagnostic study indicated that the Twin Lakes subwatershed contributed 50 percent of the flow and 60 percent of the total phosphorus (TP) load to Cedar Lake, while Brownie Lake represented less than 3 percent of the TP load to Cedar Lake. As a result, the Chain of Lakes Clean Water Partnership (CWP) prioritized BMP implementation in the Twin Lakes/Cedar Meadows system to meet the Cedar Lake TP load reduction goals. The CWP implementation project included Twin Lakes dredging and outlet modification, construction of the Cedar Meadows wetland, and construction of the Twin Lakes Park and Cedar Meadows wet detention basins. The combined effect of the BMPs at all four locations, including a storm sewer diversion at West 24th street, was expected to reduce the annual TP load by 40 percent. It is unclear if the storm sewer diversion and BMPs at all four locations have been maintained and are fully functioning as the original design intended.

In addition to the Cedar Meadows stormwater pond and existing structural BMPs in the Twin Lakes subwatershed, the City of St. Louis Park currently conducts street sweeping twice per year and is planning rehabilitation of Lamplighter Pond. It is expected that implementation of new BMPs for untreated runoff from the other direct subwatersheds to Cedar Lake, consistent with the Cedar Lake master plan, will further assist with meeting the TP load reduction goals.

The Lake Nokomis TMDL study established a 38 percent TP load reduction goal for watershed runoff from the City of Minneapolis, based on TMDL allocations that were intended to support a summer average TP concentration (site-specific standard) of 50 µg/L in the lake. The site-specific standard for Lake Nokomis may not be stringent enough to control the harmful algal blooms that were discussed in the first phase of this study. As a result, more significant TP load reductions will likely be required from internal and external source loadings to Lake Nokomis than what was associated with the site-specific standard in the TMDL study.

TMDL wasteload allocations were also established for the City of Richfield; they indicated that the city is complying with the TMDL wasteload allocations by increasing the frequency of street sweeping and completing a major water quality improvement project for Taft and Legion Lakes. Since the remaining municipal separate storm sewer systems (MS4s) in the Lake Nokomis watershed were not expected to make significant reductions to their stormwater loadings to comply with the TMDL wasteload allocations, it is expected that Minneapolis will need to account for the remaining improvements to stormwater treatment to reach the TMDL endpoints for the Lake Nokomis watershed. It is also expected that Minneapolis' credit toward meeting the wasteload allocations could be derived from stormwater treatment in the Solomon Wetland and the treatment ponds and wetlands adjacent to Lake Nokomis. Considering that these ponds and wetlands are concentrated in the southwest tributaries to the lake, it is expected that Minneapolis will also need to implement new BMPs for untreated runoff from the other direct subwatersheds, while also mitigating the adverse impacts of carp in the upstream watershed.

Table 3 provides a detailed summary of watershed BMPs considered for the screening-level analysis, including ballpark costs and suggestions on retrofits and new BMP installations, organized by BMP type. Figures 2 and 3 show the locations of current and proposed BMPs in the Cedar Lake and Lake Nokomis watersheds, respectively. Table 3 shows that further assessment and/or maintenance/retrofit of upstream BMPs will be the highest priority for both lake watersheds. Wetland restoration and implementation of rain gardens, consistent with the master plans for each lake, will also be a priority, along with installation of upstream watershed BMPs by the neighboring cities in each lake watershed. Grit chamber maintenance is also strongly encouraged, although it is not expected to significantly affect phosphorus loading in each watershed.

Watershed Source Abatement

Table 2 shows that a phosphorus-fertilizer ban is already in place and MPRB also has goose and pet waste management plans in place. However, pet waste management efforts are primarily focused on education. Currently, the cities in the tributary watersheds to each lake are primarily street sweeping a couple times each year, except for Minneapolis, where more frequent sweeping occurs in the Cedar Lake watershed. As a result, enhanced street sweeping by the other cities in both watersheds and by Minneapolis in the Lake Nokomis watershed is recommended. Given the existing phosphorus fertilizer ban, it is not expected that fertilizer management will result in improved water quality for either lake (in terms of reducing phosphorus); however, fertilizer management is a method to reduce nitrogen concentrations. Also, it is not expected that any changes to urban forestry in either watershed will improve water quality for either lake if enhanced street sweeping occurs. Urban forestry would assist in managing species composition and tree density with a focus on water quality impacts, but this effort may have minimal impacts on downstream water quality when other watershed source abatement methods are employed and if downstream BMPs are installed.

3.0 Recommendations for Concept-Level Design

3.1 Reactive Mitigation Strategies

Algaecides

While algaecides have their drawbacks and should be used sparingly, there are some potential opportunities where they may be beneficial in Cedar Lake and Lake Nokomis while other mitigation strategies are employed. Some of the potential uses in Cedar and Nokomis Lake include:

- Reduction in the severity of winter and spring cyanobacteria blooms by treating under the ice or early spring
- Bloom suppression during the growing season to eliminate recreational impacts if early bloom formation is identified
- Seed bloom elimination by treating suspected incubations areas such as bays, sheltered areas, or high nutrient areas

These approaches will be further explored in a concept level design for both Cedar Lake and Lake Nokomis. Preference will be given to hydrogen peroxide because it has the least harmful biproduct (water), but other products will be evaluated if they are more effective.

3.2 Proactive Mitigation Strategies

In-Lake Sediment Phosphorus Inactivation

Both Cedar Lake and Lake Nokomis demonstrate high internal P loads as a result of sediment P release. Treatment of the lakes with alum (with sodium aluminate if buffering is required) has been one of the most effective tools for reducing sediment P loading. In fact, the Minneapolis chain of lakes have a history of successful alum treatments. Cedar Lake was treated with alum in the past; however, the dose was too low and modern dosing techniques result in more effective applications for long term control. Phoslock is a relatively new product that shows some promise in sediment P control, however, long term studies of its impacts on lakes are still unavailable. Based on research from the U of M, there may be benefits from the clay in controlling cyanobacteria akinetes. Both products will be evaluated in concept level designs and costs. It should be noted that sediment cores are scheduled to be collected from the lakes this Fall and will be used to determine dose and costs.

In-Lake Biomanipulation

Carp Management

For the concept level design, it will be important to consider whether the fish barrier at the Cedar Meadows outlet to Cedar Lake is functioning properly and successfully controlling carp recruitment. Also, since there is no current information about carp biomass in Cedar Lake, recommendations will be made for a carp population survey.

At Lake Nokomis, under ice seining is likely not feasible, after multiple failed attempts, and open water seining is also likely infeasible based on previous attempts. It is likely that box netting may be the only feasible carp control method, which will likely take a significant amount of time to meet the carp biomass goal for the lake. For the concept level design, each carp management option will be evaluated in more detail to consider which is/are recommended based on individual costs and feasibility of each individual option.

Aquatic Vegetation Management

Conceptual designs for aquatic plant management to support water quality improvements in Cedar Lake and Lake Nokomis in the next phase of this project may include:

- AIS management through targeted herbicide use and harvesting, recognizing the MPRB does not currently allow herbicide use
- Native vegetation management to support recreation
- Native vegetation introduction and nursery area establishment
- Development of an aquatic plant management plan to support MPRB goals

While an actual aquatic plant management plan will need to be developed, scenarios will be developed to estimate the level of effort needed for aquatic plant management following lake renovation.

In-Lake Structural BMPs

The three primary viable structural in-lake BMPs include:

- Hypolimnetic oxygenation without destratification (Cedar Lake)
- Aeration and artificial circulation (Lake Nokomis)
- Microfloc injection as an add-on to the above systems

Conceptual designs will be developed for hypolimnetic oxygenation without destratification (Cedar Lake) and aeration and artificial circulation (Lake Nokomis) with micro floc addition as a possible add-on.

Watershed Structural BMPs

Based on the screening-level analysis and meeting discussion, the following watershed locations were identified for further analysis for concept level design:

- Cedar Lake
    - Cedar Meadows
    - Brownie Lake
- Lake Nokomis
    - Nokomis Wetlands (southwest corner)
    - Solomon Wetland

Wetland restoration and implementation of rain gardens, consistent with the master plans for each lake, will also be considered for the concept level design. Refined estimates of phosphorus load reductions and implementation costs associated with new BMP installation will also be developed.

Watershed Source Abatement

There is a phosphorus-fertilizer ban and MPRB already has goose and pet waste management plans in place. Since the pet waste management efforts are primarily focused on education, it is possible that pet waste ordinance enforcement and/or provision of pet waste bags should be considered for the concept level design. In addition, enhanced street sweeping within the untreated subwatersheds of each lake watershed should also be considered for the concept level design.

Table 1 Reactive Mitigation Strategies Summary

BMP Type	Option	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)[1]	Implementation Timeline
Algaecide	Copper Sulfate (granulated, liquid)	• Rapid toxicity • Extended toxicity duration • Lower cost and application volumes	• Broad-spectrum toxicity – targets all phytoplankton species • Significant reduction of zooplankton biomass observed with slow recovery • Accumulates in lake sediments and can be released back to open water • Repetitive used may induce the emergence of copper-resistant cyanobacteria • Increased sediment oxygen demand from decomposing algae • Nutrients may recycle, allowing for subsequent blooms • Less effective at colder temperatures or high inorganic solid levels	• Algaecide should be applied at early bloom development so that risk of toxin release during cell death is lower • Winter (under ice) application shows potential for early season bloom suppression • MNDNR permit required	• Increased monitoring efforts will be needed to target early bloom suppression • Unknown whether a contract with a treatment applicator be expedited to ensure early bloom suppression	Low	< $30,000/year per lake < $600,000 per lake	Implementation Start: <1 year Implementation Duration: Annually (as needed)
	Hydrogen Peroxide (granulated, liquid)	• Rapid toxicity • Selective toxicity – more toxic to cyanobacteria species, and minor impacts to other phytoplankton species • Initial reduction in zooplankton biomass after algaecide application, but rebound of zooplankton shortly after • Degrades to H_2O and O_2	• Effectiveness can vary between cyanobacterial species: Planktothrix > Microcystis > Cylindrospermopsis • Shorter toxicity duration, so repeated treatments may be required for continual suppression of blooms • Toxic to certain beneficial bacteria species at low concentrations • Potential for higher cost due to application volumes and repeated treatments • Increased sediment oxygen demand from decomposing algae • Nutrients may recycle, allowing for subsequent blooms	• Algaecide should be applied at early bloom development so that risk of toxin release during cell death is lower • Winter (under ice) application shows potential for early season bloom suppression • MNDNR permit required	• Increased monitoring efforts will be needed to target early bloom suppression • Unknown whether a contract with a treatment applicator be expedited to ensure early bloom suppression	Medium	< $30,000/year per lake < $600,000 per lake	Implementation Start: <1 year Implementation Duration: Annually (as needed)
	Peracetic-acid (Peraclean)	• Similar toxicity potency to copper sulfate in the laboratory • Selective toxicity – more toxic to cyanobacteria species, and minor impacts to other phytoplankton species • Initial reduction in zooplankton biomass after algaecide application, but rebound of zooplankton shortly after	• Still experimental for field applications; mixed potency results • Toxic to certain bacteria species at low concentrations • Higher cost and application volumes • Increased sediment oxygen demand from decomposing algae • Nutrients may recycle, allowing for subsequent blooms	• Algaecide should be applied at early bloom development so that risk of toxin release during cell death is lower	• Increased monitoring efforts will be needed to target early bloom suppression • Unknown whether a contract with a treatment applicator be expedited to ensure early bloom suppression • EPA approved; MNDNR permitting confirmation needed	Low	*unavailable*	Implementation Start: <1 year Implementation Duration: Annually (as needed)

BMP Type	Option	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)[1]	Implementation Timeline
Physical Disturbance	Ultrasonic	• Selective management – ultrasonic radiation targets the stability of cyanobacteria gas vacuoles used for buoyancy regulation • Non-chemical alternative	• Knowledge gaps on optimization and scalability of equipment for larger waterbodies • Ultrasonic frequency, radiation durations, and coverage area must be adapted to address differences in gas vacuoles between cyanobacteria species • Impact of equipment on plants, green algae, zooplankton, and fish is still unclear • Ability of cells to rebuild their gas vacuoles can impact efficacy of equipment	• Buoys can be installed during open water season • Buoys removed in winter so no winter algae control	• Relatively new technology – knowledge gaps in treatment optimization and understanding negative impacts to other aquatic species • Aesthetic and physical impacts during summer recreation (e.g., impacts to boating routes)	Low	Cedar Lake < $400,000 Lake Nokomis < $350,000	Implementation Start: <1 year Implementation Duration: Annually

References: (2), (3), (4), (5), (6)

(1) Costs are based on personal communications with local applicators providing a per acre general cost. Costs for the Ultrasonic unit is based on information provided by LG Sonic.

Table 2 Proactive Mitigation Strategies Summary

BMP Type	Product	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)	Implementation Timeline
In-Lake – Sediment Phosphorus Inactivation[1]	Aluminum Sulfate/Sodium Aluminate	• Reduction of phosphorus release from sediments • Anoxic conditions do not negatively impact phosphorus binding • Water column stripping provides 2-4 years water quality benefit • Minimal maintenance costs	• pH control necessary during application (sodium aluminate used to control pH during application) • Sodium aluminate may reduce binding efficiency of aluminum hydroxide • Long term control may require maintenance applications	• Spring/Fall application • Split dose over 4 to 6 years	• Long term control (>30 years) requires new P balance in lake which may take future applications	High	Cedar Lake $850,000 to $1.7 million Lake Nokomis $750,000 to $1.5 million	Implementation Start: <1 year Implementation Duration: 4 to 6 years
	Polyaluminum Chloride	• Reduction of phosphorus release from sediments • Anoxic conditions do not negatively impact phosphorus binding • Water column stripping provides 2-4 years water quality benefit • No pH control required • No maintenance costs	• Increase in chloride concentrations which may impact biota in the short term	• Spring/Fall application • Split dose over 4 to 6 years	• Long term control (>30 years) requires new P balance in lake which may take future applications • Chloride may remain in lake long-term because of long residence time	Medium	Cedar Lake > $1 million Lake Nokomis > $1 million	Implementation Start: <1 year Implementation Duration: 4 to 6 years
	Iron Filings	• Reduction of phosphorus release from sediments with oxic conditions • Potential reduction of phosphorus release from sediments with anoxic conditions • No maintenance costs	• Anoxic conditions impact phosphorus binding efficacy • Requires aeration/oxygenation to ensure P control • Control under anoxic conditions still unproven for large lake systems • Application may be challenging for large lakes • May result in high iron concentrations that leads to iron toxicity • Iron is a micronutrient that supports cyanobacteria	• Application has never been conducted on a large lake • Application of dry material may be challenging	• Long term control in lakes that present significant anoxia has not been demonstrated without aeration. • While iron addition and aeration are proven to work, iron filings have not been used in such a large-scale application • May require future applications	Medium	Cedar Lake < $500,000 Lake Nokomis < $500,000	Implementation Start: <1 year Implementation Duration: 1 year
	Ferric Chloride	• Reduction of phosphorus release from sediments with oxic conditions • No maintenance costs	• Increase in chloride concentrations • Anoxic conditions impact phosphorus binding efficacy	• Spring/Fall application	• Chloride may remain in lake long-term because of long residence time	Medium	Cedar Lake < $500,000 Lake Nokomis < $500,000	Implementation Start: <1 year Implementation Duration: 1 year
	Lanthanum (Phoslock)	• Reduction of phosphorus release from sediments • May provide longer term binding capacity than aluminum • No maintenance costs	• Limited long-term case studies to demonstrate long-term effectiveness • Limited research on dosing and binding efficiency • Application of dry material requires slurry • Does not provide water column stripping, so it is often applied along with alum (Floc and Lock) • Short- and long-term lanthanum toxicity not well defined	• Application of dry material requires slurry production and application	• Limited long-term case studies to demonstrate long-term effectiveness • Proprietary product subject to owner pricing • May require dosing study to verify dose	Medium	Cedar Lake > $2 million Lake Nokomis > $2 million	Implementation Start: <1 year Implementation Duration: 1 year

BMP Type	Product	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)	Implementation Timeline
In-Lake – Biomanipulation[2]	Carp Management	• Increased clarity through turbidity reduction • Possible decrease in internal sediment loading • Decrease in aquatic plant uprooting; improved plant health • Increased habitat area for native fish species	• Targeted fish species are difficult to eradicate/control • Control likely needs to be on-going, rather than a one-time effort to maximize control efforts • Multiple approaches might be needed to control carp: collection of movement data, physical/chemical removal, suppression of carp recruitment (barriers), predator species introduction or enhancement	• Under ice seining • Open water seining, electrofishing, box netting, gill netting, barriers • Recruitment season predator control (e.g., blue gills)	• Applying multiple approaches to manage carp populations (e.g., box nets, electrofishing, barriers, predator species introduction) can be difficult, if carp recruitment and migration extends beyond MPRB boundaries (multiple stakeholder coordination required) • Water levels shown to significantly impact carp movement patterns and removal success	Medium	Lake Nokomis < $500,000 Cedar Lake NA	Implementation Start: 1 -2 year Implementation Duration: 5+ years
	Aquatic Plant Management	• Sediment stabilization to prevent resuspension • Habitat improvement – fisheries benefit, zooplankton benefit • Nutrient and light competition with algae • Management of invasive species	• The switch from algal-dominated to plant-dominated conditions may cause unexpected or undesirable changes to lake recreation (e.g., boating)	• Annual management • Assumes the use of both herbicides and mechanical based on needs	• Uncertainty in aquatic plant response to various management actions • Current IPM MPRB policy does not allow for chemical treatments in waterbodies to control aquatic vegetation. Uncertain if/when policy will be amended to allow chemical treatment	High	<$30,000/year per lake < $600,000 per lake	Implementation Start: <1 year Implementation Duration: Annually
In-Lake – Structural BMPs[3]	Artificial Circulation/ Destratification	• Full column oxygenation – fisheries benefit • Sediment internal load control (phosphorus) • Odor reduction • Non-chemical alternative • Can be implemented prior to carp management • Reduction in dissolved metals (Fe, Mn) • When water column mixing rate exceeds cyanobacteria buoyancy regulation rate, cells are destabilized and sink to depths with low light conditions → growth rate suppression	• Warming of entire water column – negative fishery impact, potential promotion of cyanobacteria • High operation and maintenance needs (labor, capital costs) • On-going electrical power consumption • Without an alum sediment treatment, a mid-season breakdown could lead to rapid water quality changes due to reduced dissolved oxygen in the hypolimnion and internal sediment loading (phosphorus) • If full circulation isn't achieved, hypolimnetic phosphorus may be entrained into the epilimnion • Destabilization and sinking of cyanobacteria may result in high sedimentation and decomposition creating an oxygen deficit layer despite aeration • If system is operated in winter to control early season blooms, less ice thickness can be expected • Cedar Lake: Diffusers may be needed in each bay • Lake Nokomis: Diffusers needed in each deep location	• Limitations for winter operation to maintain ice thickness for recreation • MNDNR permit required	• Impacts to nitrogen cycle is unclear. A shift from denitrification dominance to nitrification dominance would result in higher nitrate/nitrite concentrations • May increase aerobic organic phosphorus decay and release • Visual indication of a bloom is removed due to mixing. High toxin concentrations could be present without visual warning • Oxygenation results in higher sedimentation and decomposition of organic matter. If the sediment oxygen demand exceeds the maximum aeration supply, the sediment surface will remain anoxic despite having an oxygenated hypolimnion	Low	Cedar Lake NA Lake Nokomis > $1.5 million	Implementation Start: <2 years Implementation Duration: 1 year

BMP Type	Product	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)	Implementation Timeline
In-Lake – Structural BMPs[3]	Hypolimnetic Direct Oxygen Injection	• Hypolimnetic oxygenation – fisheries benefit • Sediment internal load control (phosphorus) • Odor reduction • Non-chemical alternative • Can be implemented prior to carp management • Reduction in dissolved metals (Fe, Mn) • Can be utilized in winter without negatively impacting ice thickness • Stratification maintained – hypolimnion temperature not impacted by circulating with warmer epilimnion • Bubbles not visible from surface - aesthetic benefit • Smaller footprint for electrical control than destratification system	• High operation and maintenance needs (labor, capital costs) • On-going electrical power consumption • Without an alum sediment treatment, a mid-season breakdown could lead to rapid water quality changes due to reduced dissolved oxygen in the hypolimnion and internal sediment loading (phosphorus) • Enhanced organic matter sedimentation and decomposition from aeration may result in an anoxic sediment layer • Cedar Lake: Diffusers needed in each bay with depths greater than 30 feet • Lake Nokomis: Diffusers need depths greater than 30 feet to have higher efficacy – less than 0.4% of Lake Nokomis has depths greater than 30 feet	• Can be operated year-round • MNDNR permit required	• Impacts to nitrogen cycle is unclear. A shift from denitrification dominance to nitrification dominance would result in higher nitrate/nitrite concentrations • May increase aerobic organic phosphorus decay and release • Oxygenation results in higher sedimentation and decomposition of organic matter. If the sediment oxygen demand exceeds the maximum aeration supply, the sediment surface will remain anoxic despite having an oxygenated hypolimnion	Medium	Cedar Lake > $1.5 million Lake Nokomis NA	Implementation Start: <2 years Implementation Duration: 1 year
	Micro-floc Systems (Alum Injection Systems)	• Hypolimnetic oxygenation – fisheries benefit • Sediment internal load control (phosphorus) through aeration and alum treatment • Odor reduction • Can be implemented prior to carp management • Reduction in dissolved metals (Fe, Mn) • More efficient binding of water column phosphate than typical sediment application (binding active layer)	• High operation and maintenance needs (labor, capital costs) • On-going electrical power consumption • Without an alum sediment treatment, a mid-season breakdown could lead to rapid water quality changes due to reduced dissolved oxygen, no micro-floc development, and internal sediment loading (phosphorus) • Cedar Lake: Diffusers needed in each bay • Lake Nokomis: Diffusers needed in each deep location	• Cannot be used in winter due to limitations with alum	• This type of system has never been permitted in Minnesota • Impacts to nitrogen cycle is unclear. A shift from denitrification dominance to nitrification dominance would result in higher nitrate/nitrite concentrations • May increase aerobic organic phosphorus decay and release	Low	Cedar Lake > $1.5 million Lake Nokomis > $1.5 million	Never been permitted in MN
	Iron Magnetic Microparticles; Nano-Iron Particles	• Can reduce dissolved inorganic phosphorus concentrations • Permanent removal of phosphorus from the waterbody • Large number of sites for phosphorus binding	• Achievement of significant chlorophyll-a reductions may involve higher iron microparticle or nanoparticle doses • Removal of phosphorus from one location to another location • Knowledge gaps on optimization and scalability of equipment for larger waterbodies	• Install after ice-out and remove in the fall	• Relatively new technology – knowledge gaps in treatment optimization for large waterbodies and cost prohibitive to expand to large, deep lakes • Unclear impacts to aquatic wildlife (ingestion of iron microparticles/nanoparticles)	Low	N/A, new technology	N/A, new technology

BMP Type	Product	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)	Implementation Timeline
In-Lake – Structural BMPs[3]	Dredging		• Can increase organic P release rates depending on • Impacts to aquatic organisms: physical removal or • Will cause turbid water conditions during • Recreation impacts during dredging efforts • Shoreline containment area usually needed to dry • Requires disposal site • May result in only short-term water quality - • Higher costs for deep lakes; logistical challenges • For larger, deep lakes, sectional dredging may be -	• Open water dredging	- - -	Low	Cedar Lake >$5 million Lake Nokomis >$5 million	Implementation Start: <2 years Implementation Duration: 1-3 years
Watershed – Structural BMPs	Maintain or Retrofit Existing BMPs	• Sustainable reduction of nutrients to suppress algal growth • Controls delivery of other unwanted pollutants to downstream water bodies (e.g., metals, sediment, debris) • Can facilitate ecosystem and habitat enhancements	• Higher up-front capital costs • On-going maintenance needed to ensure treatment effectiveness maintained	• Year-round	• There may be considerable lag time between BMP optimization and lake water quality improvements, especially with high internal loading	High	Variable (see Table 3)	Implementation Start: >1 year Implementation Duration: On-going
	Install new BMPs (Filters, Ponds)	• Sustainable reduction of nutrients to suppress • Controls delivery of other unwanted • Can facilitate ecosystem and habitat	• Higher up-front capital costs • On-going maintenance needed to ensure treatment effectiveness maintained	• Year-round	• There may be considerable lag time	High	Variable (see Table 3)	Implementation Start: >1 year Implementation Duration: 20+ years

BMP Type	Product	Advantages	Disadvantages	Application/Timing Options	Risk/Uncertainty	Feasibility	Relative Capital Cost (20 years)	Implementation Timeline
Watershed – Source Abatement[4]	Enhanced Street Sweeping	• Reduces original nutrient sources and decreases effective nutrient loadings to downstream water bodies • Controls delivery of other unwanted pollutants to downstream water bodies (e.g., metals, sediment, debris) and reduces oxygen-demanding substances	• City stakeholder participation required for watershed-wide source control	• Growing Season (enhanced sweeping in spring and fall)	• Most research summarizes mass of material removed from streets rather than direct impacts to downstream water quality • Uncertainty related to City interest in enhanced and/or targeted sweeping	Medium	<$1,000,000	Implementation Start: >2 years Implementation Duration: Annually
	Urban Forestry (managing species composition and density)	• Reduces original nutrient sources and decreases effective nutrient loadings to downstream water bodies	• City stakeholder and resident participation required for watershed-wide source control • High cost and labor needs required to remove and replace trees	• Growing Season	• Limited case studies where urban forestry has led to water quality improvements	Low	< $100,000	Implementation Start: >5 years Implementation Duration: Annually
	Fertilizer Management	• Reduces original nutrient sources (N, P) and decreases effective nutrient loadings to downstream water bodies • Effective method to target N reductions; where other methods may be more complicated and costly in urban settings (e.g., wetland restoration, constructed wetlands, bioreactors)	• City stakeholder (if watershed-wide) and resident participation required	• Growing Season	• P fertilizer ban already in place • Impacts to N loading are unproven • May be unpopular for residents without alternatives for yard management • May be difficult to attach water quality benefit to management actions	Low	< $50,000	Implementation Start: >2 years Implementation Duration: Annually
	Pet Waste Management	• Acts against original nutrient sources and decreases effective nutrient loadings to downstream water bodies • Reduced beach closures from E. coli risks	• City stakeholder (if watershed-wide) and resident participation required • May require ordinance enforcement to ensure water quality improvement	• Year-round	• MPRB has a pet waste management plan already in place, including education of park users (dog poop cleanup campaign, and canines for clean water program) • Pet waste bags are not currently provided to park users	High	< $100,000	Implementation Start: 1 year Implementation Duration: Annually
	Geese Management	• Reduces original nutrient sources and decreases effective nutrient loadings to downstream water bodies • Limits human and goose conflicts • Reduced beach closures from E. coli risks	• Reduction in bird populations could be viewed negatively by some lake users who value the geese	• Spring through Fall	• MPRB has a goose management plan already in place, including habitat modification, education, beach maintenance, goose fencing (when needed), • No goose removal has occurred, recently, for Lake Nokomis or Cedar Lake due to lower nuisance conditions	High	< $50,000	Already in place

References: (2), (6), (7), (8), (9)

(1) Costs are based on application of 100 to 200 g AL/m^2 using recent alum applications costs and applicator estimates for applied alum costs.

(2) Carp management costs are based on Integrated Pest Management costs outlined for Lake Nokomis. Aquatic Plant management costs are based on general average costs for lakes in the Riley Purgatory Bluff Creek Watershed District and Indian Lake in Michigan.

(3) In lake structural BMPs are based on projects presented at NALMS or feasibility studies or assessments completed by Barr staff including Bald Eagle Lake in Washington County, Crystal Lake in the City of Robbinsdale, and Halsted's Bay on Lake Minnetonka. Dredging costs were based on staff experience for dredging projects in Minnesota, South Dakota, and Iowa.

(4) Watershed source abatement costs are based on professional experience working with watershed districts and municipalities in the Twin Cities Metro Area.

Table 3 Watershed Structural BMPs Summary

Activity	BMP Type	Descriptions	Priority	Relative Capital Cost
Maintain or Retrofit Existing BMP	Assessment and retrofit of upstream water bodies/ stormwater ponds	<u>Cedar Lake</u> • Assess water quality conditions of Brownie Lake and correct identified problem(s) based on assessment results. • Assess water quality conditions of Cedar Meadows wetland/stormwater pond and retrofit based on assessment results. • Coordinate with Saint Louis Park to assess water quality conditions of upstream water bodies and storm water ponds tributary to Cedar Lake (e.g., Twin Lakes, Lamplighter Pond) <u>Lake Nokomis</u> • Assess water quality conditions of southwest stormwater ponds (i.e., Gateway Pond, Amelia Pond, Nokomis Knoll Pond) and retrofit based on assessment results. • Coordinate with Richfield on continued stormwater retrofit improvements in Taft Lake and Legion Lake (e.g., lake aeration, alum floc system, subsurface infiltration).	High	< $500,000 per project
	Wetland Restoration	<u>Cedar Lake</u> • Restore wetland fringe and floodplain of Cedar Lake • Assess water quality conditions of Cedar Meadows wetland/stormwater pond and restore based on assessment results. <u>Lake Nokomis</u> • Restore wetland fringe and floodplain of Lake Nokomis • Assess wetland water quality and health in fringe areas of southwest stormwater ponds (i.e., Gateway Pond, Amelia Pond, Nokomis Knoll Pond) and restore based on assessment results • Assess wetland water quality and health of Solomon Park and restore based on assessment results.	Medium	> $500,000 per project
	Grit Chamber Maintenance	<u>Cedar Lake</u> • Coordinate with St. Louis Park on grit chamber maintenance (e.g., more frequent removal of sediment and debris)	Medium	N/A

Activity	BMP Type	Descriptions	Priority	Relative Capital Cost
Install New BMPs on MPRB Property	Tree Trenches	• Store and treat stormwater by routing runoff into subsurface systems that consists of storm piping, aggregate, and filtration soil. • Trees installed on top of the subsurface system are irrigated by the stored stormwater runoff. • Tree irrigation, as well as infiltration that occurs below the pipes, helps to remove stormwater volume and prevents contaminants from flowing downstream. • Can be installed in paved park areas	Medium	> $500,000 per project
	Rain Gardens	• Store and treat stormwater by routing runoff into shallow, landscaped depressions • Landscaped depressions are designed to hold and remove pollutants in a manner similar to natural ecosystems • Iron-enhanced sand trenches can be incorporated to removed dissolved contaminants (e.g., orthophosphate) • Rain gardens can infiltrate and/or filtrate stormwater depending on underlying soil conditions • Can be installed in open green space park areas	High	< $500,000 per project
	Underground Storage	• Stores stormwater by routing runoff into underground storage vaults or pipes • Temporarily routing and storing stormwater in underground storage vaults/pipes helps to reduce peak flow rates • If underlying soil conditions are adequate, infiltration can occur while stormwater is stored, which helps to remove pollutants • Can be installed in paved park areas	Low	> $500,000 per project
Encourage Cities to Install New BMPs	Tree trenches, rain gardens, underground storage, grit chambers	<u>Cedar Lake</u> • Coordinate with St. Louis Park (via MCWD) to target under-treated watersheds for new BMP installation <u>Lake Nokomis</u> • Coordinate with Richfield and Minneapolis to target under-treated watersheds for new BMP installation	Medium	N/A

References: (10), (11), (12)

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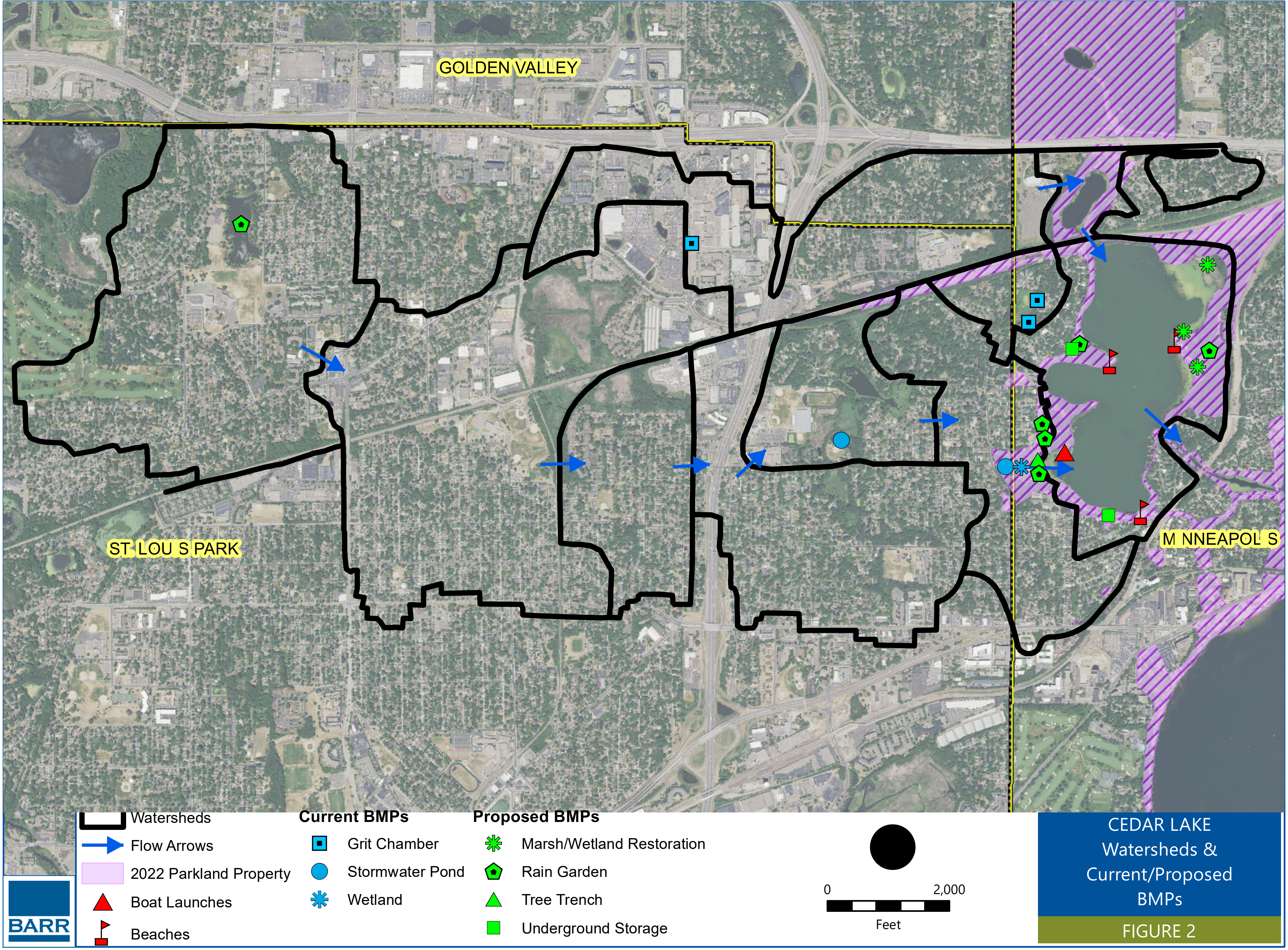
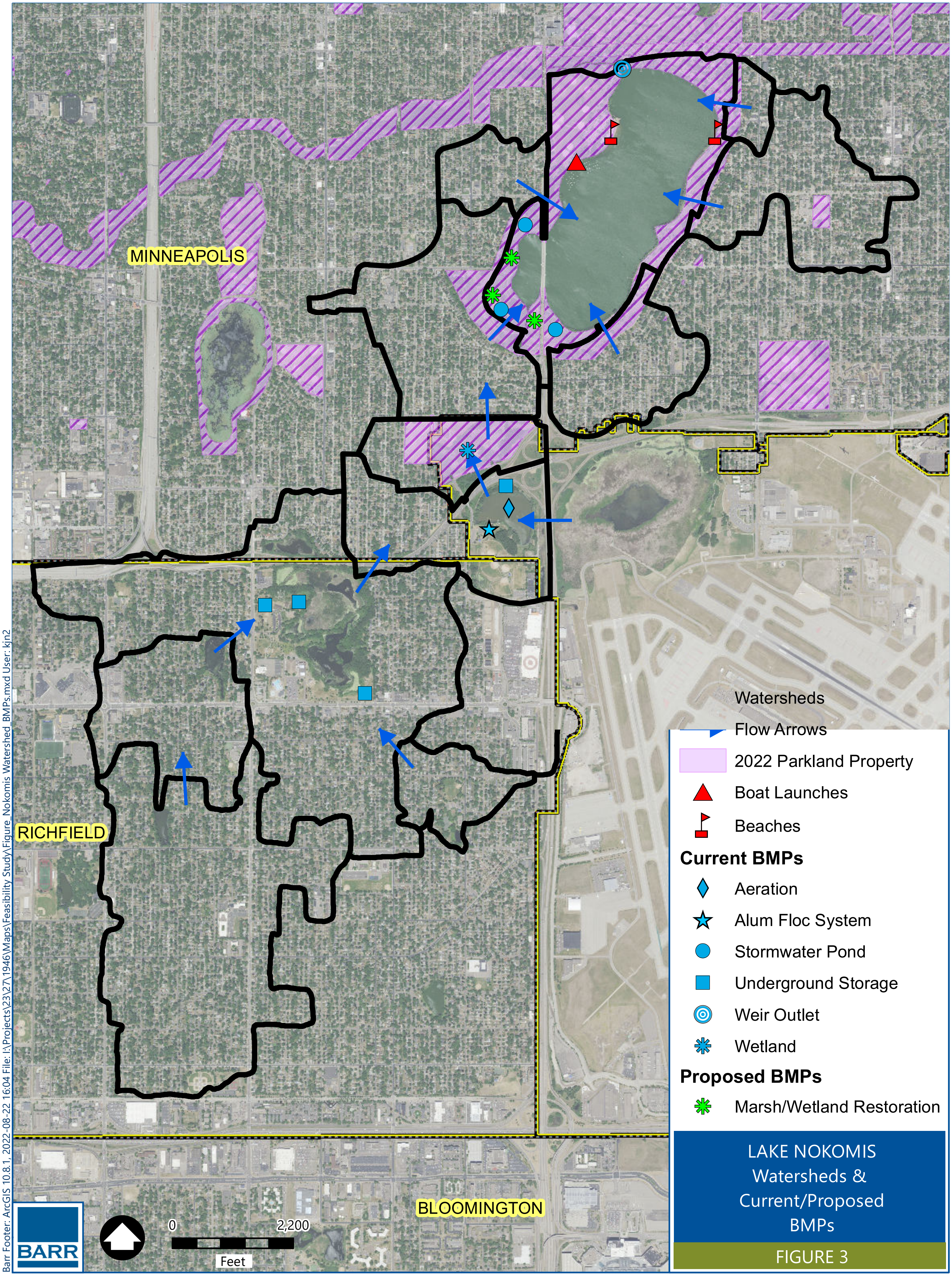


CEDAR LAKE
Watersheds &
Current/Proposed
BMPs

FIGURE 2



LAKE NOKOMIS
Watersheds &
Current/Proposed
BMPs

FIGURE 3

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