Technical Memorandum

To: Minneapolis Park and Recreation Board
From: Barr Engineering Co.
Subject: Cyanobacteria Mitigation Concept Design – for Cedar Lake and Lake Nokomis
Date: December 20, 2022
Project: Lake Nokomis and Cedar Lake Blue-Green Algae Bloom Mitigation Strategies Project
c: Young Environmental

1.0 Results of Cyanobacteria Mitigation Feasibility Study

As a result of the screening level drivers analysis for cyanobacteria blooms and preliminary feasibility study for mitigation strategies, Barr and MPRB staff selected several potential strategies for concept level design including:

1. The potential use of algaecides to reactively manage cyanobacteria blooms in both lakes. Hydrogen peroxide and copper sulfate were selected for concept level assessment.
2. Sediment phosphorus inactivation to minimize sediment P release and internal phosphorus loading. Aluminum and Phoslock were selected for concept level assessment.
3. Aquatic vegetation management. The use of harvesting and aquatic herbicides were selected for assessment.
4. In-lake structural BMPs to eliminate sediment P release. Practices selected include:
    a. Hypolimnetic oxygenation without destratification (Cedar Lake)
    b. Aeration and artificial circulation (Lake Nokomis)
    c. Microfloc injection as an add-on to the above systems
5. Watershed best management practices including:
    a. Cedar Meadows
    b. Brownie Lake
    c. Nokomis wetlands (southwest corner)
    d. Solomon wetland

Other recommendations that were not carried forward to the concept level design included nutrient source abatement and carp management.

2.0 Reactive Mitigation Strategies

2.1 Algaecides

Algaecides are the most commonly used reactive approach for mitigating cyanobacteria or harmful algae blooms. Algaecides are considered a curative measure to temporarily suppress cyanobacteria blooms because algaecides do not significantly reduce the water column nutrient concentrations and alternatively, can cause a delayed increase in water column nutrient concentrations from decomposing algae (i.e., nutrients from decaying algae recycle, allowing subsequent blooms). While algaecides offer rapid reductions in algae concentrations through cell damage and death, these reductions are typically a temporary relief and algae blooms can recover and proliferate later in the season. As such, multiple applications of algaecides may be required annually. Of the algaecides presented in the feasibility study, two were assessed for concept design: hydrogen peroxide and copper sulfate.

There are several factors that should be considered before developing an algaecide management plan for Lake Nokomis or Cedar Lake:

- Phytoplankton monitoring should be frequent enough to describe patterns in bloom timing and frequency so that algaecide is applied at early bloom development reducing the risk of toxin release during cell death.
- Algaecide use can inadvertently select for toxin producing species that are more resistant to the algaecide or have reproductive mechanisms that can avoid application periods.
- Single applications of algaecides may not result in long-term reduction in cyanobacteria abundance. Therefore, repeated treatments may be required for continual suppression of blooms throughout the growing season.
- Because cyanobacteria blooms often start in one area of lake and then move based on wind and environmental conditions, spot treatments can be difficult to locate.

Permitting

Algaecide applications must be permitted with the MnDNR on at least an annual basis. If more than two treatments are proposed, additional permitting and permissions will likely be required. After a permit is approved, the permittee and their agent must notify the MnDNR of the planned pesticide treatment(s) and must post notice signs along the shoreline and/or on buoys prior to the treatment. Instructions for posting notices for algaecide treated areas in public waters can be found here: Instructions for Posting Chemically Treated Areas in Public Waters (state.mn.us). MnDNR permits cost approximately $40 and then $0.40 per acre.

Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is considered a selective algaecide when applied professionally and at the appropriate concentrations because the chemical control mechanism specifically targets cyanobacteria features. When H_2O_2 is added to water, the chemical reacts with UV radiation and produces hydroxyl radicals (OH), which are strong reactive oxygen species that can negatively impact cyanobacteria species. The application of H_2O_2 affects cyanobacteria species more strongly than other algal species (when dosed appropriately) because cyanobacteria photosynthetic apparatuses are more susceptible to H_2O_2 and cyanobacteria have a less efficient pathways for H_2O_2 degradation. Besides being a selective algal control method, another advantage of H_2O_2 is that the chemical's byproducts are non-persistent in aquatic environments because H_2O_2 degrades rapidly into water (H_2O) and oxygen (O_2).

While there are environmental benefits to using H_2O_2 over other algaecides, there are several factors that should be considered before developing an algaecide management plan for Lake Nokomis or Cedar Lake:

- The effectiveness of H_2O_2 can vary between cyanobacterial species; thus, H_2O_2 dosing should be modified based on the dominant species observed. If the dosing is not modified, the efficacy of the treatments may vary. However, care should also be taken to not inadvertently select for toxin producing cyanobacteria species that are resistant to H_2O_2 or have reproductive strategies than can overcome H_2O_2 toxicity. These species could be more problematic than the species killed by the algaecide. Field and laboratory studies have shown that *Microcystis* can have higher tolerance to H_2O_2 due to the production of extracellular polymeric substances that can act as a buffering layer around the cell. The colony-forming characteristic of *Microcystis* can also help to protect cells against H_2O_2 (Kibuye, Zamyadi, & Wert, 2021). A laboratory study by Yang et. al. found *Dolichospermum* (*Anabaena*), *Cylindrospermopsis*, and *Planktothrix* to have a similar resistance to H_2O_2 (Yang, et al., 2018), although this may not translate directly to field applications. In contrast, Lusty and Gobler (2020) found Planktothrix to be highly sensitive to H_2O_2, Microcystis to be moderately sensitive, and Cylindrospermopsis to be most resistant at a dose concentration of 4 µg/L.
- H_2O_2 typically has a shorter toxicity duration than other algaecide options (e.g., copper sulfate) because of the chemical's short residence time and fast decay in waterbodies. Therefore, repeated treatments may be required for continual suppression of blooms.
- Studies demonstrate that H_2O_2 is more effective at suppressing cyanobacteria at high light intensities because elevated solar irradiance can accelerate the formation of OH radicals. Therefore, treatments would likely be more effective at high light conditions, such as less cloudy days and low turbidity conditions (Visser, 2022). If high turbidity conditions are unavoidable, algaecide applications can be timed for when cells are closest to the surface in sunny conditions (Kibuye, Zamyadi, & Wert, 2021).
- The abundance of green algae should be monitored prior to applying H_2O_2 as an algaecide because green algae can assist in the degradation of H_2O_2, which can reduce the efficacy of the treatment for cyanobacteria suppression (Kibuye, Zamyadi, & Wert, 2021; Visser, 2022).
- Low concentrations of H_2O_2 (e.g., 2.5 mg/L) can be effective at suppressing cyanobacteria species and protecting green algae, zooplankton, and fish populations. Lab studies or pre-testing areas could be considered to check the sensitivity of the cyanobacteria species to these low concentrations and assess the rate of H_2O_2 degradation in advance (Visser, 2022).
- Preventative algaecide treatments applied in winter could reduce the viability of winter cyanobacteria blooms and overwintering algal cells (akinetes, vegetative cells) prior to growth in the spring and potentially minimize severity of algal growth later in the year. Consequently, winter treatments could decrease the algaecide frequency or dosing magnitude throughout the growing

season. This is an emerging mitigation technique with lab studies and small-scale field tests completed using H_2O_2. Commercial applicators may not yet be familiar with winter application techniques. Algaecide interactions with constituents in the sediment should also be tested before selecting a winter algaecide type and dose (Calomeni, McQueen, Kinley-Baird, & Clyde Jr., 2022).

Copper Sulfate

Copper sulfate ($CuSO_4$) is a non-selective algaecide and is the most commonly used algaecide to control algae and cyanobacteria blooms. When $CuSO_4$ is applied to a waterbody, cupric ions (Cu^{2+}) are rapidly released, which can impact cyanobacteria species by affecting the nitrogen and carbon fixation process, inhibiting photosynthetic electron transport, and impacting cellular integrity (which can cause cell lysis). While cupric ions are effective at rapidly reducing algal concentrations, they are also effective at binding to sediments. Prolonged copper treatments can result in significant sediment-accumulated copper, which may create concerns for benthic organisms and could create permitting issues for waterbodies that are periodically dredged of sediment.

Numerous subcontractors within the Twin Cities use $CuSO_4$ as an effective algaecide. Before considering copper sulfate for use on Lake Nokomis and Cedar Lake, there are several factors that should be weighed when developing an algal management plan:

- Repetitive use of $CuSO_4$ can induce the emergence of copper-resistant cyanobacteria species. Therefore, $CuSO_4$ treatments may become less effective over time, higher dosing may be required, and the treatments may select for more problematic cyanobacteria species that are resistant to $CuSO_4$ or have reproductive strategies than can overcome $CuSO_4$ toxicity. These species could be more problematic than the species killed by the algaecide.
    - Long-term monitoring of Fairmont Lakes in Minnesota showed that *Aphanizomenon* sp. gradually acquired tolerance to copper, requiring higher $CuSO_4$ dosages for effective bloom suppression (Kibuye, Zamyadi, & Wert, 2021).
    - Studies indicate that *Nostoc* sp. and *Phormidium* sp. are resistant to copper algaecides. Additionally, *Planktothrix* and *Cylindrospermum* have been shown to be less susceptible to copper algaecides than species such as *Microcystis* or *Dolichospermum* (*Anabaena*) (Global Water Research Coalition, 2009).
- The effectiveness of $CuSO_4$ can vary based on environmental conditions. Studies demonstrate that $CuSO_4$ can be less effective at colder temperatures or high inorganic solids levels (Global Water Research Coalition, 2009).
- The toxicity duration of $CuSO_4$ can depend on the type of chemical applied. For example, chelated copper can result in longer toxicity durations by slowing down the rate of cupric ion release (Kibuye, Zamyadi, & Wert, 2021).

- Lab studies or pre-testing areas could be considered to verify the sensitivity of the cyanobacteria species to varying $CuSO_4$ concentrations. By pre-testing, the lowest effective $CuSO_4$ concentration could be selected to reduce impacts to non-target species (e.g., green algae, zooplankton, fish).
- Preventative algaecide treatments applied in winter could reduce the viability of overwintering algal cells (akinetes, vegetative cells) prior to growth in the spring and potentially minimize severity of algal growth later in the year. Consequently, winter treatments could decrease the algaecide frequency or dosing magnitude throughout the growing season. This is an emerging mitigation technique with lab studies and small-scale field tests completed using copper-based algaecides. Commercial applicators may not yet be familiar with winter application techniques. Algaecide interactions with constituents in the sediment should also be tested before selecting a winter algaecide type and dose (Calomeni, McQueen, Kinley-Baird, & Clyde Jr., 2022).

Cost Estimate

We developed concept design-level cost estimates for the application of algaecides to Cedar Lake and Lake Nokomis based on 2022 unit costs. The algaecide cost estimate ranges assume full-lake applications, 3 – 5 times annually. The cost estimate assumes full lake treatments because of the uncertainty of success with spot treatments. While it may be possible to apply spot treatments of algaecides in targeted lake locations (e.g., beaches, boat launches, known cyanobacteria hot spots), the longevity of spot treatments is difficult to determine since cyanobacteria species and/or toxins will relocate and mix with subsequent wind events. It may be possible to apply spot treatments if a silt curtain is installed around the treated area; however, it's unclear if cyanotoxins could diffuse through the curtain.

Algaecide applications can be considered for the following time periods annually, but should be confirmed with routine field monitoring and must be permitted with the MnDNR:

1) Winter application (January/February)
2) Early Spring (April)
3) Early Summer (June)
4) Late Summer (August)
5) Fall (October)

This proposed application sequence is based on phytoplankton data collected between 2012 and 2021 and the toxin data collected in 2021 (as summarized in the *Cyanobacteria Stressor Analysis for Cedar Lake and Lake Nokomis* report (Barr Engineering Co., 2022a)). It should be noted that algaecide application needs will likely change with subsequent management efforts. For example, algaecide application frequency may be reduced after internal sediment loading management and/or the installation of watershed best management practices. Future climate conditions could also impact algaecide application frequency.

Whole lake and spot algaecide treatment costs estimates were developed for Cedar Lake and Lake Nokomis. To develop the cost estimates, we assumed:

- Applied algaecide cost per acre was assumed using costs supplied by applicators and experience in other lakes. These costs do not account for volume adjustments that need to be developed based on monitoring data.
- Winter applications of both hydrogen peroxide and copper sulfate require higher doses and therefore higher costs per acre.

Cedar Lake Algaecide Treatments

Costs were estimated for using hydrogen peroxide and copper sulfate in Cedar Lake using two strategies. The first strategy includes partial lake treatments in the winter and early spring to suppress cold water blooms that may seed early spring and summer blooms (2 applications) as well as whole lake treatments in the summer (3 applications). Five applications represent a worst-case scenario for algaecide use. However, cyanobacteria bloom all year in Cedar Lake and it may be required several times throughout the year. Early season applications were assumed to target known bloom areas such as shallow, protected bays or other areas where blooms were identified under the ice (33 acres). Winter treatments likely require higher doses, so costs were adjusted accordingly. While hydrogen peroxide is preferable since it doesn’t result in heavy metal buildup in the sediments, it cost almost three times as much as copper sulfate (Table 2-1). The use of both algaecides should be preceded by the development of an algaecide application and monitoring plan that outlines how and when the algaecide will be used, and the monitoring data required to inform the application process. We also assumed that additional monitoring would be required annually to inform the spot locations in the winter and early spring.

Table 2-1 Cedar Lake Concept-Design Cost Estimate – Algaecides for Whole Lake Control

Algaecide	Activity	Unit Cost	Unit	Number of applications	Total Annual Cost
Hydrogen Peroxide (H_2O_2)	Winter/Spring H_2O_2 Application[1]	$300/acre	33 acres	2/year	$19,800
	Open Water H_2O_2 Application	$250/acre	167 acres	3/year	$125,250
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$145,685
				Contingency (20%)	$29,097
				Algaecide Application and Monitoring Plan	$30,000
				Additional Monitoring	$20,000
				Annual Total	$224,582
Copper Sulfate ($CuSO_4$)	Winter/Spring $CuSO_4$ Application[1]	$150/acre	33 acres	2/year	$9,900
	Open Water $CuSO_4$ Application	$80/Acre	167 acres	3/year	$40,080
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$50,415
				Contingency (20%)	$10,083
				Algaecide Application and Monitoring Plan	$30,000
				Additional Monitoring	$20,000
				Annual Total	$90,498

[1] Emerging mitigation technique and research currently underway to study algaecide performance for overwintering cells in the laboratory and small-scale field tests. Commercial-scale cost estimates not available to date. Cost estimates presented provide best-guess estimate based on anticipated dosing and equipment needs.

Another strategy that could be employed is to separate the beach areas from the rest of the lake using a nonpermeable silt curtain and just treat the beach area inside the curtain. For Cedar Lake, this includes silt curtains for three beach areas. We assumed that the curtains would extend 250 feet out into the lake while widths were estimated based on the width of the beach. This approach assumes approximately 8.6 acres need to be treated inside the silt curtains. While this significantly reduces the cost and amount of algaecide required, the installation of the silt curtain significantly increases the cost of the approach (Table 2-2). The use of peroxide inside the silt curtains is about half the cost of whole take treatments, but this approach is actually more expensive than whole lake treatments using copper sulfate.

There are several potential drawbacks using silt curtains to separate the beach areas. The curtains prevent fish, turtles, and other wildlife from using these areas, reducing the overall habitat of the lake. The beaches are often used for open water swimming and the presence of the curtains may inhibit these activities. Birds may also use the curtains as resting areas resulting in additional bacteria issues in the beach areas. Further, since the water does not exchange with the rest of the lake, temperatures may increase inside the curtains further supporting cyanobacteria blooms. The silt curtains will also need to be installed every Spring, maintained throughout the Summer, and removed in the Fall. The overall maintenance of the curtain could be problematic and require more effort than originally assumed.

Table 2-2 Cedar Lake and Lake Nokomis Concept-Design Cost Estimate – Algaecides in Beach Areas

Algaecide	Activity	Unit Cost	Unit	Number of applications	Total Annual Cost
Hydrogen Peroxide (H_2O_2)	Silt Curtain[1]	$25/linear foot	2,850 linear feet	1/year	$71,250
	Winter/Spring H_2O_2 Application[2]	$300/acre	8.6 acres	2/year	$5,160
	Summer H_2O_2 Application	$250/acre	8.6 acres	3/year	$6,450
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$83,295
				Contingency (20%)	$16,659
				Algaecide Application and Monitoring Plan	$10,000
				Additional Monitoring	$5,000
				Total	$114,954
Copper Sulfate ($CuSO_4$)	Silt Curtain[1]	$25/linear foot	2,850 linear feet	1/year	$71,250
	Winter/Spring $CuSO_4$ Application[2]	$150/acre	8.6 acres	2/year	$2,580
	Open Water $CuSO_4$ Application	$80/Acre	8.6 acres	3/year	$2,064
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$76,329
				Contingency (20%)	$15,266
				Algaecide Application and Monitoring Plan	$10,000
				Additional Monitoring	$5,000
				Total	$106,595

[1] A new silt curtain was assumed to be included every year. However, the curtain cold likely be maintained and reused. Costs for maintenance were not explicitly quantified; rather the overall cost for a new curtain was used as worst-case scenario.

[2] Emerging mitigation technique and research currently underway to study algaecide performance for overwintering cells in the laboratory and small-scale field tests. Commercial-scale cost estimates not available to date. Cost estimates presented provide best-guess estimate based on anticipated dosing and equipment needs.

Lake Nokomis Algaecide Treatments

Similar to Cedar Lake, costs were developed for whole lake algaecide treatments and for separated beach areas for Lake Nokomis (Table 2-3). Since Lake Nokomis is much more uniform in shape and does not have many protected bays that may be incubators of cyanobacteria, a much broader area was assumed for winter and early spring applications (134 acres). Based on these assumptions, the use of algaecides on lakewide basis could be very expensive with annual costs exceeding $250,000 for peroxide and $100,000 for copper sulfate.

Table 2-3 Lake Nokomis Concept-Design Cost Estimate – Algaecides

Algaecide	Activity	Unit Cost	Unit	Number of applications	Total Annual Cost
Hydrogen Peroxide (H_2O_2)	Winter/Spring H_2O_2 Application[1]	$300/acre	134 acres	2/year	$80,400
	Open Water H_2O_2 Application	$250/acre	208 acres	3/year	$156,000
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$236,835
				Contingency (20%)	$47,367
				Algaecide Application and Monitoring Plan	$30,000
				Additional Monitoring	$20,000
				Total	$334,202
Copper Sulfate ($CuSO_4$)	Winter/Spring $CuSO_4$ Application[1]	$150/acre	134 acres	2/year	$40,200
	Open Water $CuSO_4$ Application	$80/Acre	208 acres	3year	$49,920
	MnDNR Permitting	$87/Permit	1 permit	5/year	$435
				Total Application Costs	$90,555
				Contingency (20%)	$18,111
				Algaecide Application and Monitoring Plan	$30,000
				Additional Monitoring	$20,000
				Total	$158,666

[1] Emerging mitigation technique and research currently underway to study algaecide performance for overwintering cells in the laboratory and small-scale field tests. Commercial-scale cost estimates not available to date. Cost estimates presented provide best-guess estimate based on anticipated dosing and equipment needs.

We also assessed separating the beach areas from the main lake with a silt curtain and, surprisingly, it requires about the same treatment area as Cedar Lake even though there are only two beaches on Lake Nokomis. The main beach on Lake Nokomis is much larger than the other beaches and therefore requires a larger area to be separated from the main lake with the silt curtain. Therefore, the costs outlined in Table 2-2 are applicable to both lakes, with beach area applications still potentially exceeding $100,000 annually.

2.1.1 Algaecide Use in Cedar Lake and Lake Nokomis Summary

The use of algaecides to control cyanobacteria blooms in Cedar Lake and Lake Nokomis requires a clear strategy based on real time data that may require significantly more monitoring than what is currently occurring. Since the areas where cyanobacteria blooms start is currently unknown and may change based on climatic conditions, a program may need to start with whole lake treatments which are estimated to cost between $2.5M to 9.1M over the next twenty years (Table 2-4). Further, we do not recommend using copper sulfate for long term treatments as studies demonstrate that this will cause copper build up in the sediments and may exacerbate internal loading over time and degrade overall lake habitat.

Table 2-4 Cedar Lake and Lake Nokomis Concept-Design Cost Estimate Over 20 Years for Whole Lake Algaecide Applications Assuming 4% Inflation

Activity	Cedar Hydrogen Peroxide	Cedar Copper Sulfate	Nokomis Hydrogen Peroxide	Nokomis Copper Sulfate
Algaecide Application and Monitoring Plan	$30,000	$30,000	$30,000	$30,000
Additional Monitoring	$619,384	$619,384	$619,384	$619,384
Algaecide Applications	$5,204,672	$1,801,514	$8,462,989	$3,235,865
TOTAL	$5,854,056	$2,450,898	$9,112,373	$3,885,249

Separating the beach areas using a silt curtain and treating inside the separated area is a much more cost-effective strategy but still may cost as much as $3.3M over a 20-year period (Table 2-5). This approach reduces the cost for using hydrogen peroxide, the preferred algaecide since it breaks down quickly and does not result in heavy metal build-up in the sediments. However, costs are still relatively high since a silt curtain needs to be installed and maintained every year.

Table 2-5 Cedar Lake and Lake Nokomis Concept-Design Cost Estimate for Beach Area Treatments Over 20 Years for Algaecides Assuming 4% Inflation

Activity	Cedar Hydrogen Peroxide	Cedar Copper Sulfate	Nokomis Hydrogen Peroxide	Nokomis Copper Sulfate
Algaecide Application and Monitoring Plan	$30,000	$30,000	$30,000	$30,000
Additional Monitoring	$309,692	$309,692	$309,692	$309,692
Algaecide Applications	$2,976,438	$2,727,523	$2,976,438	$2,727,523
TOTAL	$3,316,130	$3,067,215	$3,316,130	$3,067,215

Due to the relatively high uncertainty in the outcomes of algaecide use on a spot treatment basis and the high costs for treating lake-wide, algaecides are not a great option for controlling cyanobacteria blooms in Cedar Lake and Lake Nokomis. If a monitoring network was established in the lakes and clear indicators of bloom formation could be identified, a much more cost-effective approach could possibly be developed to suppress blooms. However, due to the high level of uncertainty, we recommend either the whole lake treatment approach or the beach treatments separated from the main lake approach.

3.0 Proactive Mitigation Strategies

3.1 In-Lake Sediment Phosphorus Inactivation

One of the most common strategies for minimizing internal phosphorus (P) loading is the application of a coagulant to inactivate sediment P and prevent release. In the United States, the most common approach is the use of aluminum sulfate (alum) to produce aluminum hydroxide that settles into the sediments and permanently binds phosphorus, essentially eliminating sediment P release. Advantages to alum include:

- Widely available in the United States since it is widely used in water and wastewater treatment
- Commodity pricing only dependent on raw material costs
- Hundreds of peer reviewed publications in the scientific literature regarding dosing, environmental impacts, safety, and effectiveness based on actual case studies, many of which include long term (over 10 years) monitoring
- Numerous case studies in Minnesota demonstrating its effectiveness and safety
- Availability of experienced applicators with the ability to precisely apply alum across multiple dosing zones
- Aluminum hydroxide is not susceptible to typical pH shifts in Minnesota lakes, anaerobic redox reactions, or organic material interference.

The primary concern regarding alum is the toxicity of alum at low pH (<6) or high pH (>9). However, pH is easily controlled during the application process using a buffer (typically sodium aluminate) preventing any variation in pH. Once the application is complete, lakes in Minnesota are usually neutral rarely exhibiting pH outside the 6 to 9 range. There have been more than 70 applications of alum to lakes in Minnesota with no known reports of aluminum release from the sediments or toxicity following the alum treatment. Well-designed alum treatments can last well over 15 years with many demonstrating effectiveness well over 30 years since the initial treatments.

Another product recently introduced to market for sediment P inactivation is a lanthanum modified bentonite clay sold under the trade name Phoslock. Phoslock has only limited applications in the United States with most of the case studies occurring in Europe. Rather than a surficial bond of phosphorus to a metal hydroxide, lanthanum forms a molecular bond to permanently bind P in the sediments. Phoslock was used successfully to eliminate sediment P release in moderately sized lakes in Europe. Some advantages of Phoslock may include:

- Limited susceptibility to pH shifts limiting potential toxicity issues
- Retains P in anoxic conditions at pH greater than 6.8
- Evidence of increased sediment stability reducing sediment resuspension
- Potential inactivation of phytoplankton akinetes (recent research in the very early stages at the University of Minnesota)

While there are some case studies demonstrating the effectiveness of Phoslock at reducing sediment P release, there is little consistent information available on dosing, long term effectiveness, release of lanthanum following the treatment, and potential interference from organic acids. Further, Phoslock does not strip water column P, an added benefit when using alum. Since there are limited applications in the United States, there are few if any applicators available that can apply precise doses across a lake.

Researchers at the University of Minnesota are exploring the effects of clay additions to phytoplankton akinetes and other reproductive spores, hypothesizing that the clay may inhibit algal blooms by preventing these structures from blooming. Since this research may lead to better management actions, we compared Phoslock and alum for Cedar Lake and Lake Nokomis. It is important to note that there is no definitive study showing that clay impacts akinetes and phytoplankton spores and it's not clear if bentonite, the lanthanum delivery mechanism in Phoslock is under investigation.

To compare alum and Phoslock, we collected sediment cores from both lakes to measure mobile P fractions and sediment P release. Sediments were dosed for alum using techniques established in James and Bischoff (2015) and successfully applied to numerous lakes in Minnesota and Wisconsin. There are currently no established analytical dosing techniques for Phoslock, rather general guidelines. Based on input from Phoslock Environmental Technologies (PET), the general approach is to apply 100 pounds of Phoslock for every pound of phosphorus you want to inactivate and typically includes labile organic P, aluminum bound P, and other fractions beyond mobile P. To develop a comparison, we targeted only the mobile P fraction using alum and Phoslock. Aluminum sulfate and sodium aluminate pricing is relatively easy to find since there are numerous providers and costs are based on raw materials. For this comparison, we assumed an applied rate of $2.60 a gallon for aluminum sulfate and $6.80 a gallon for sodium aluminate. For Phoslock, PET suggested a going rate of $2.00 a pound for Phoslock, however this does not include application costs. Since no contractors we contacted in the United States were currently set up to apply Phoslock at the specific rates we developed and the application is a dry material which can be difficult to handle, we assumed an overall applied cost of $4.30 a pound. A 20% contingency was applied to all costs to account for potential price fluctuations.

3.1.1 Cedar Lake Sediment P Inactivation

We collected sediment cores from Cedar Lake in October of 2022 to measure mobile P in the sediment, measure sediment P release rates and to develop sediment phosphorus inactivation doses (Figure 3-1; (Barr Engineering Co., 2022b)). Based on the mobile P profiles and sediment P release rates at the 4 sites, we determined an alum dose of 62 to 104 g Al/m^2 to inactivate mobile P in the upper 8 cm of sediment. Since each of the sites were similar in mobile P profiles, an application rate of 87 g Al/m^2 over all areas greater than 15 feet in depth was determined to minimize sediment P release (Figure 3-1). For cost estimating purposes, we assumed that the treatment would require buffering with sodium aluminate. To achieve this dose, approximately 71,268 gallons of alum and 35,634 gallons of sodium aluminate need to be applied over the 103-acre application area at a total cost of $567,130 (Table 3-1). The application was assumed to occur over two applications (50% dose) about 2 years apart.

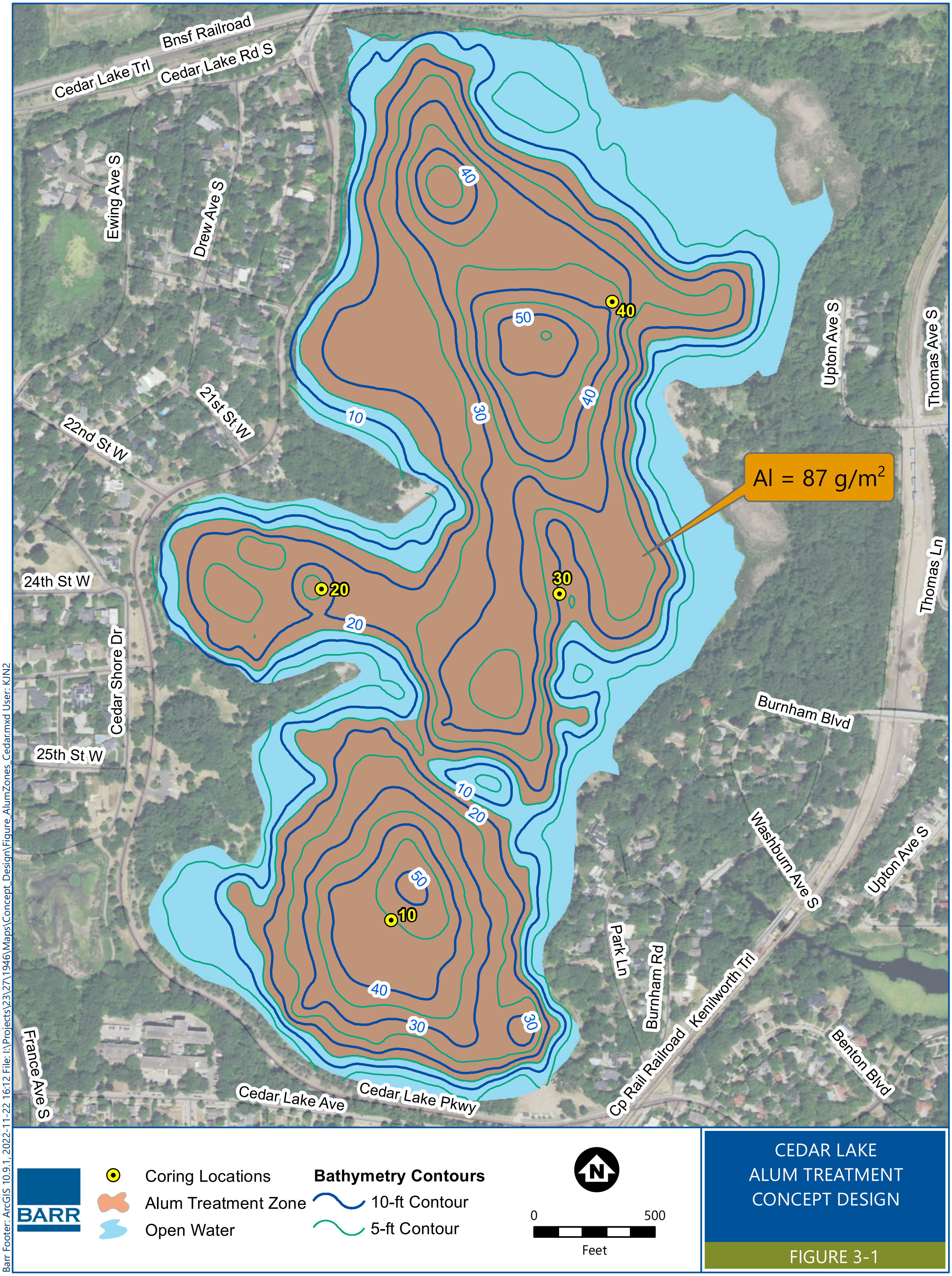
Table 3-1 Sediment phosphorus inactivation cost estimate using aluminum sulfate and sodium aluminate for Cedar Lake. Application assumes treating areas deeper than 15 feet (103 acres) with 87 g Al/m2 to inactivate the top 8 cm of sediment.

Item	Unit	Quantity	Unit Cost	Total Cost
Aluminum sulfate	Gallon $Al_2(SO_4)_3$	71,268	$2.60	$185,297
Sodium aluminate	Gallon $NaAlO_2$	35,634	$6.80	$242,311
Mobilization	Lump Sum	2	$10,000	$20,000
			Total Application Cost	$447,608
			Contingency (20%)	$89,522
			Plans and Specifications; Application Oversight	$30,000
			Total Estimated Cost	$567,130

A similar application using Phoslock to inactivate the same mobile P pool requires an application of 121,492 pounds of Phoslock with a total cost of approximately $742,899 (Table 3-2). It should be noted that we recommend conducting jar testing to refine the Phoslock dose since there are no clear analytical approaches for determining the amount of Phoslock needed to inactivate the mobile P pool. The jar testing would need to be developed since the model of P binding is different than aluminum hydroxide and there is no established analytical method to measure lanthanum bound P following exposure to Phoslock. We included a $50,000 line item for this approach. A recent case study in the Netherlands applied almost 9,312 pounds of Phoslock per acre, significantly more than our dose. This is likely because we didn't include labile organic P in our dose, which may more than triple the dose and overall costs.

Table 3-2 Sediment phosphorus inactivation cost estimate using Phoslock for Cedar Lake. Application assumes treating areas deeper than 15 feet with 100 pounds of Phoslock (lanthanum modified bentonite clay) per pound or redox P to inactivate the top 8 cm of sediment. Estimated treatment dose for Phoslock was 1,177 pounds per acre.

Item	Unit	Quantity	Applied Unit Cost	Total Cost
Phoslock	Pounds Phoslock	121,492	$4.30	$522,416
Mobilization	Lump Sum	3	$10,000	$30,000
			Total Application Cost	$552,416
			Contingency (20%)	$110,483
			Laboratory jar testing	$50,000
			Plans and Specifications; Application Oversight	$30,000
			Total Estimated Cost	$742,899



CEDAR LAKE
ALUM TREATMENT
CONCEPT DESIGN

FIGURE 3-1

3.1.2 Sediment Phosphorus inactivation in Lake Nokomis

We collected sediment cores from Lake Nokomis in October of 2022 to measure mobile P in the sediment, measure sediment P release rates and to develop sediment phosphorus inactivation doses (Figure 3-2; (Barr Engineering Co., 2022b)). Mobile P and sediment P release rates varied spatially in Lake Nokomis with the deep areas demonstrating high mobile P fractions in surficial sediments and high sediment P release rates. Based on this variation and obvious hots spots for P release in Lake Nokomis, 4 application rates were determined to be applied over 6 treatment zones (Figure 3-2). The alum dose was determined to inactivate the top 6 cm of sediment over each treatment zone. For cost estimating purposes, we assumed that the treatment would require buffering with sodium aluminate. The overall treatment requires a total of 106,560 gallons on alum and 53,279 gallons of sodium aluminate (Table 3-3). The treatment area for zone 50 is rather large and includes treating the lake area to the west of Cedar Avenue South. This area could be reduced and evaluated during the split application approach. The application was assumed to occur over two applications (50% dose) about 2 years apart. The costs to complete the aluminum application on Lake Nokomis could be as high as $821,224 (Table 3-3).

Table 3-3 Sediment phosphorus inactivation cost estimate using aluminum sulfate and sodium aluminate for Lake Nokomis. Application assumes treating areas with 82 g Al/m2 to 152 g Al/m2 to inactivate the top 6 cm of sediment.

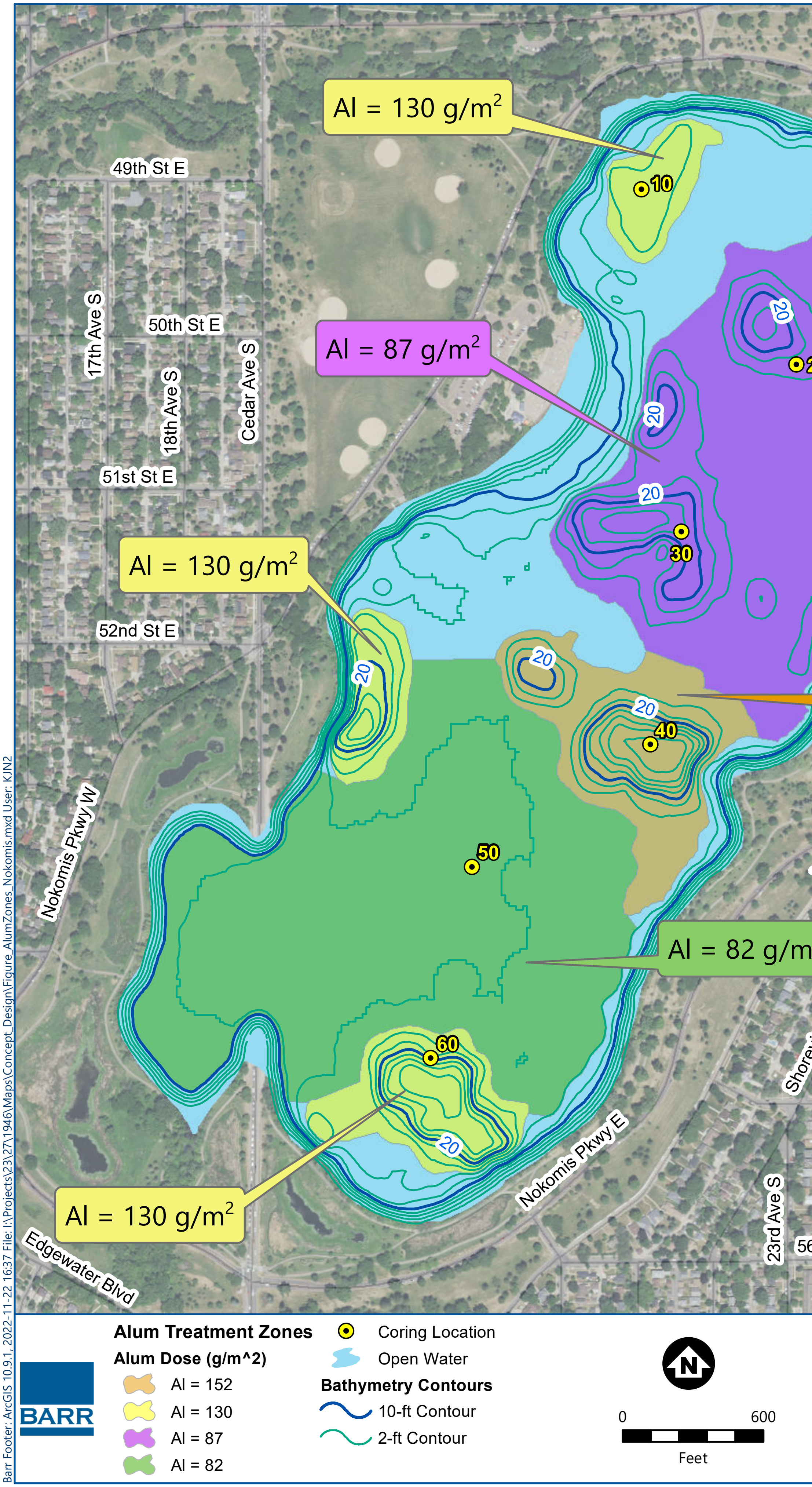
Application Zone	Item	Unit	Quantity	Applied Unit Cost	Total Cost
Zone 10 3.9 acres 130 g Al/m^2	Aluminum sulfate	Gallon $Al_2(SO_4)_3$	4,030	$2.60	$10,478
	Sodium aluminate	Gallon $NaAlO_2$	2,015	$6.80	$13,702
Zone 20/30 50 acres 87 g Al/m^2	Aluminum sulfate	Gallon $Al_2(SO_4)_3$	34,517	$2.60	$89,744
	Sodium aluminate	Gallon $NaAlO_2$	17,258	$6.80	$117,354
Zone 40 14 acres 152 g Al/m^2	Aluminum sulfate	Gallon $Al_2(SO_4)_3$	16,951	$2.60	$44,073
	Sodium aluminate	Gallon $NaAlO_2$	8,475	$6.80	$57,630
Zone 50 58.3 acres 82 g Al/m^2	Aluminum sulfate	Gallon $Al_2(SO_4)_3$	38,010	$2.60	$98,826
	Sodium aluminate	Gal $NaAlO_2$	19,005	$6.80	$129,234
Zone 60 12.6 acres 130 g Al/m^2	Aluminum sulfate	Gal $Al_2(SO_4)_3$	13,052	$2.60	$33,935
	Sodium aluminate	Gal $NaAlO_2$	6,526	$6.80	$44,377
	Mobilization	Lump Sum	2	$10,000	$20,000
				Total Application Cost	$659,353
				Contingency (20%)	$131,871
				Plans and Specifications; Application Oversight	$30,000
				Total Estimated Cost	$821,224

A similar application using Phoslock to inactivate the same mobile P pool requires an application of 483,066 pounds of Phoslock with a total cost of approximately $1,073,621 (Table 3-4).

Similar to Cedar Lake, we recommend conducting jar testing to refine the Phoslock dose since there are no clear analytical approaches for determining the amount of Phoslock needed to inactivate the mobile P pool. The estimated Phoslock applied per acre was also lower than other reported Phoslock projects suggesting that using only the mobile P pool is underestimating the required dose.

Table 3-4 Sediment phosphorus inactivation cost estimate using Phoslock for Lake Nokomis. Application assumes treating areas with various rates of Phoslock to inactivate the top 6 cm of sediment assuming 100 pounds of Phoslock (lanthanum modified bentonite clay)

Application Zone	Item	Unit	Quantity	Applied Unit Cost	Total Cost
Zone 10 3.9 acres 1,765 pounds/acre	Phoslock	Pounds Phoslock	6,884	$4.30	$29,601
Zone 20/30 50 acres 901 pounds/acre	Phoslock	Pounds Phoslock	45,028	$4.30	$193,620
Zone 40 14 acres 3,675 pounds/acre	Phoslock	Pounds Phoslock	51,444	$4.30	$221,209
Zone 50 58.3 acres 3,330 pounds/acre	Phoslock	Pounds Phoslock	46,618	$4.30	$200,457
Zone 60 12.6 acres 2,626 pounds/acre	Phoslock	Pounds Phoslock	33,092	$4.30	$142,297
	Mobilization	Lump Sum	2	$10,000	$20,000
				Total Application Cost	$807,184
				Contingency (20%)	$161,437
				Laboratory jar testing	$75,000
				Plans and Specifications; Application Oversight	$30,000
				Total Estimated Cost	$1,073,621



LAKE NOKOMIS ALUM TREATMENT CONCEPT DESIGN

FIGURE 3-2

3.1.3 Sediment P Inactivation Summary

Sediment P release rates and hypolimnetic P concentrations were high in both Cedar Lake and Lake Nokomis suggesting that sediment P release was a major driver of high hypolimnetic P concentrations and is potentially driving cyanobacteria blooms in both lakes (Barr Engineering Co., 2022b); (Barr Engineering Co., 2022c). To inactivate mobile sediment P fractions, we evaluated both aluminum sulfate buffered with sodium aluminate and Phoslock. We estimated alum application costs on the lakes to be approximately $550,000 for Cedar Lake and $800,000 for Lake Nokomis using current year costs. Targeting the same mobile P fraction, Phoslock was estimated to cost $750,00 for Cedar Lake and $1.1M for Lake Nokomis. Based on this assessment, Phoslock is approximately 45% higher in cost than using alum.

Costs for the sediment P inactivation approaches were estimated over a 20-year life cycle assuming a touch-up application would need to occur at year 10 to extend the life of the application (Table 3-5). It was assumed that the touch-up application was 20% of the original dose and the cost was adjusted for inflation. Overall, the life cycle cost of sediment P inactivation is significantly lower than using algaecides over the same period.

Table 3-5 Comparison of sediment P inactivation approaches over a 20-year life cycle.

Activity	Cedar Buffered Alum	Cedar Phoslock	Nokomis Buffered Alum	Nokomis Phoslock
Initial application plans and specifications/application observation	$30,000	$30,000	$30,000	$30,000
Laboratory jar testing	NA	$50,000	NA	$75,000
Initial applications	$533,130	$662,899	$787,223	$968,621
Follow up application plans and specifications/application observation	$15,000	$15,000	$15,000	$15,000
Follow up sediment monitoring (3 events)	$75,000	$75,000	$75,000	$75,000
Follow up application[1]	$151,762	$188,702	$224,093	$275,730
TOTAL	$804,892	$1,021,601	$1,131,316	$1,439,351

[1]Estimate based on 20% of the original dose

Phoslock was evaluated in this study because researchers at the University of Minnesota are evaluating using clay applications to suppress cyanobacteria akinetes and spores from blooming. However, this research is still in the very early stages and definitive results are not available. Further, the type of clay under evaluation is not clear. In our opinion, Phoslock does not offer any proven advantages over aluminum sulfate. pH is easily controlled during alum applications and pH is not a demonstrated concern following alum treatments in Minnesota lakes. There are several disadvantages to using Phoslock including limited case studies on long term efficacy, limited analytical approaches to developing dosage, and limited information on the release and toxicity of lanthanum following treatment. Further, permitting of a Phoslock treatment is unclear as there are no known Phoslock treatments in Minnesota. Based on this assessment, we recommend pursuing the use of alum buffered with sodium aluminate.

3.2 In-Lake Biomanipulation

3.2.1 Carp Management

Carp management was not selected for further concept design since most of the required activities are already outlined in an Integrated Pest Management (IPM) effort 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 minimizing carp recruitment from Minnehaha Creek under high flow.

3.2.2 Aquatic Vegetation Management

One aspect of controlling cyanobacteria in Cedar Lake and Lake Nokomis is the role and response of aquatic vegetation, especially submerged aquatic vegetation. Aquatic plant communities are fairly limited in both lakes. A June 2015 survey of aquatic vegetation in Cedar Lake demonstrated a plant community dominated by two invasives, Curly-leaf pondweed and Eurasian watermilfoil, and a tolerant native species, Coontail. However, the littoral area was relatively well vegetated at 92%. In contrast, there was very little vegetation in Lake Nokomis in an August 2017 survey, with only 21% of the littoral area vegetated. Lake Nokomis was also dominated by Coontail, Curly-leaf pondweed, and Eurasian watermilfoil.

Controlling cyanobacteria in both lakes will result in increased water clarity and a likely expansion of the aquatic plant community. For Cedar Lake, the expansion will likely be deeper into the lake and not be noticeable to typical lake users. For Lake Nokomis, the increase in plants could be quite dramatic and require substantial management for recreational users. In both cases, we recommend controlling invasive species first, so they don't expand in the lakes and make it harder for natives to establish. Second, some management may be necessary to maintain access to the lake, provide the existing levels of recreation, and to maintain fishing opportunities around piers.

Prior to any major management action, we recommend developing an aquatic plant management plan to outline management objectives, actions, and measurable goals. The plan should include an adaptive management framework so that management actions respond to each year's outcomes. Some key aspects of an aquatic plant management plan include:

- Evaluation of current conditions
- Management objectives and visioning
- Aquatic invasive species control options and potential outcomes
- Native aquatic plant management options and potential outcomes
- Ecosystem services assessment

Following is a cost analysis for aquatic plant management in Cedar Lake and Lake Nokomis.

Cedar Lake Aquatic Plant Management

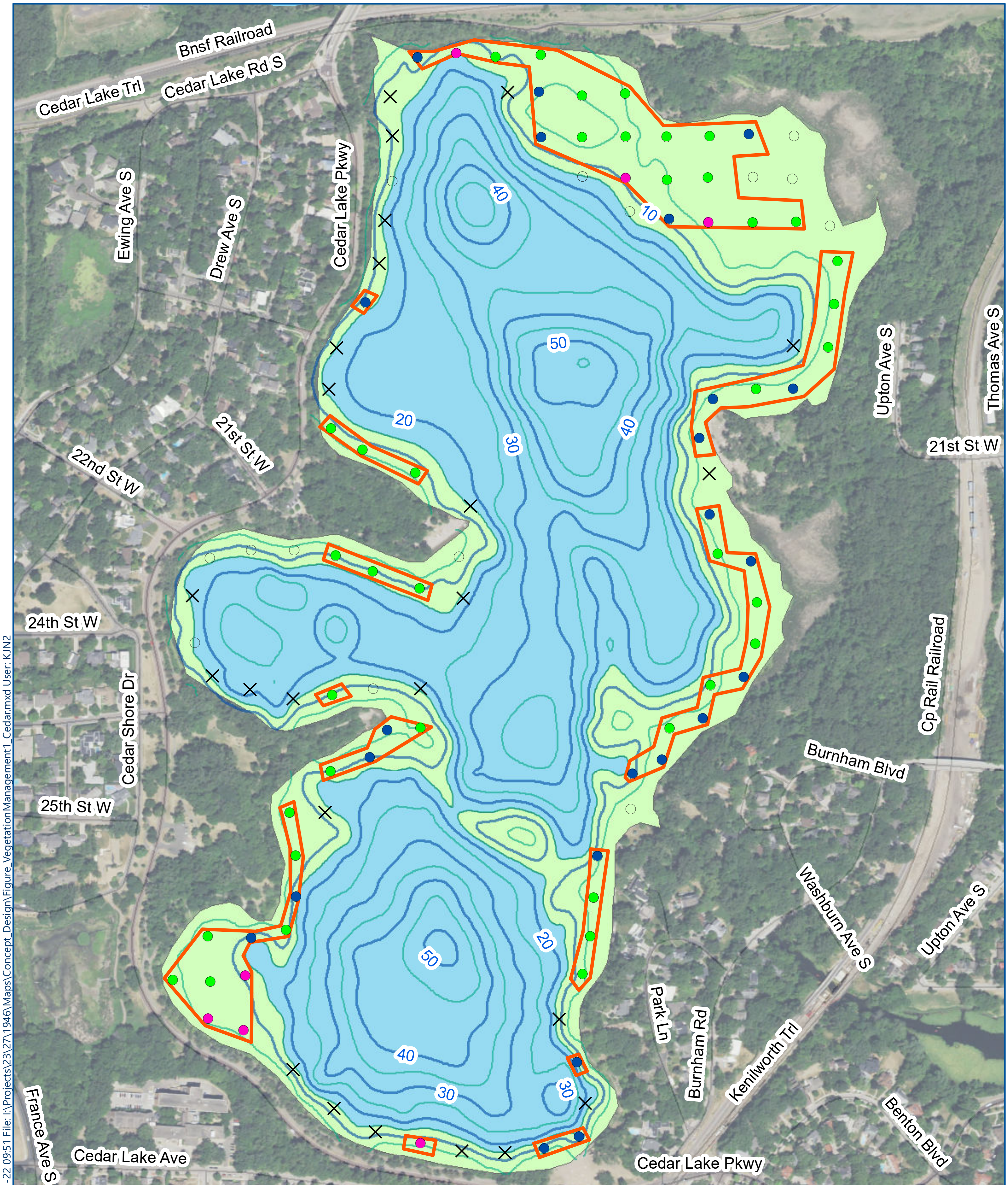
To estimate potential future aquatic plant management costs for Cedar Lake, we evaluated harvesting and herbicide applications. Harvesting is not recommended for Eurasian watermilfoil because it can reproduce from plant fragments and harvesting may further spread the invasive plant around the lake. We recognize that herbicides are currently prohibited from use in Cedar Lake. However, herbicides are currently the most effective tool for AIS management and are successfully applied every year around the State and Upper Midwest. The only other effective tool available is hand pulling which is only feasible for small areas since it is labor intensive.

To estimate aquatic plant management costs, we assumed that an early season treatment to control Curly-leaf pondweed and Eurasian watermilfoil is required. The MnDNR only allows 15% of the littoral area to be treated with herbicide or 50% of the area to be harvested without a variance. The estimated treatment area for Cedar Lake is 20 acres or 33% of the littoral area so a variance would be required (Figure 3-3). For cost estimating purposes, we assumed 20 acres would be treated with herbicide for AIS management. Because most of the stands are mixes of Curly-leaf pondweed and Eurasian watermilfoil, we assumed a mix of ProcellaCor and diquat would be applied for the herbicide. Harvesting was assumed to be completed by a local contractor using standard harvesting equipment. We also assumed a summer harvest or treatment needs to occur to maintain access at the boat launch, clear fishing areas around fishing piers, and to keep beaches clear for recreation. All cost estimates assume that an aquatic vegetation management plan is developed prior to any management actions and that annual monitoring of the plant community will occur. Annual monitoring includes Spring Curly-leaf pondweed and Eurasian watermilfoil delineations to establish treatment zones and late Summer point intercept surveys to track changes in the aquatic vegetation community. We also recommend the use of BioBase to measure biovolume and plant density (these should also be estimated independently by the surveyor).

Using this approach, harvesting for aquatic plant control in Cedar Lake will cost about $16,800 annually based on present cost (Table 3-6). Using herbicides for the same treatment was similar in cost at $14,280 annually based on present cost. Harvesting is slightly higher in cost. More importantly, we do not recommend the use of harvesting to control Eurasian watermilfoil in Cedar Lake as harvesting may contribute to the spread of Eurasian watermilfoil throughout the lake. It can be used sparingly to clear the boat launch or swimming areas, but herbicides are the preferred method for controlling Eurasian watermilfoil.

Table 3-6 Aquatic plant management cost estimates for Cedar Lake.

Activity	Unit Cost	Unit	Number of applications	Total Annual Cost
Spring/Early Summer Harvest	$400/acre	20 acres	1	$8,000
Summer Harvest	$400/acre	15 acres	1	$6,000
			Total Harvesting Costs	$14,000
			Contingency (20%)	$2,800
			Total	$16,800
			Aquatic Vegetation Management Plan	$40,000
			Additional Monitoring	$10,000
			Total	$66,800
Spring/Early Summer Herbicide Application (ProcellaCor+diquat)	$790/acre	10 acres	1	$7,900
Spring/Early Summer Herbicide Application (diquat)	$160/acre	10 acres	1	$1,600
Summer Herbicide Application (diquat)	$160/acre	15 acres	1	$2,400
			Total Herbicide Application Costs	$11,900
			Contingency (20%)	$2,380
			Total	$14,280
			Aquatic Vegetation Management Plan	$40,000
			Additional Monitoring	$10,000
			Total	$64,280



Aquatic Plant Survey - June 2015

- No Plants
- Native Plants Only
- AIS - Eurasian Watermilfoil (EWM)
- AIS - Curly-leaf Pondweed (CP)
- AIS - EWM & CP

AIS Treatment Areas

Littoral Zone - Depth 15 feet

Open Water

Bathymetry Contours

- 10-ft Contour
- 5-ft Contour

0 500 Feet

BARR

CEDAR LAKE MACROPHYTE MANAGEMENT CONCEPT DESIGN

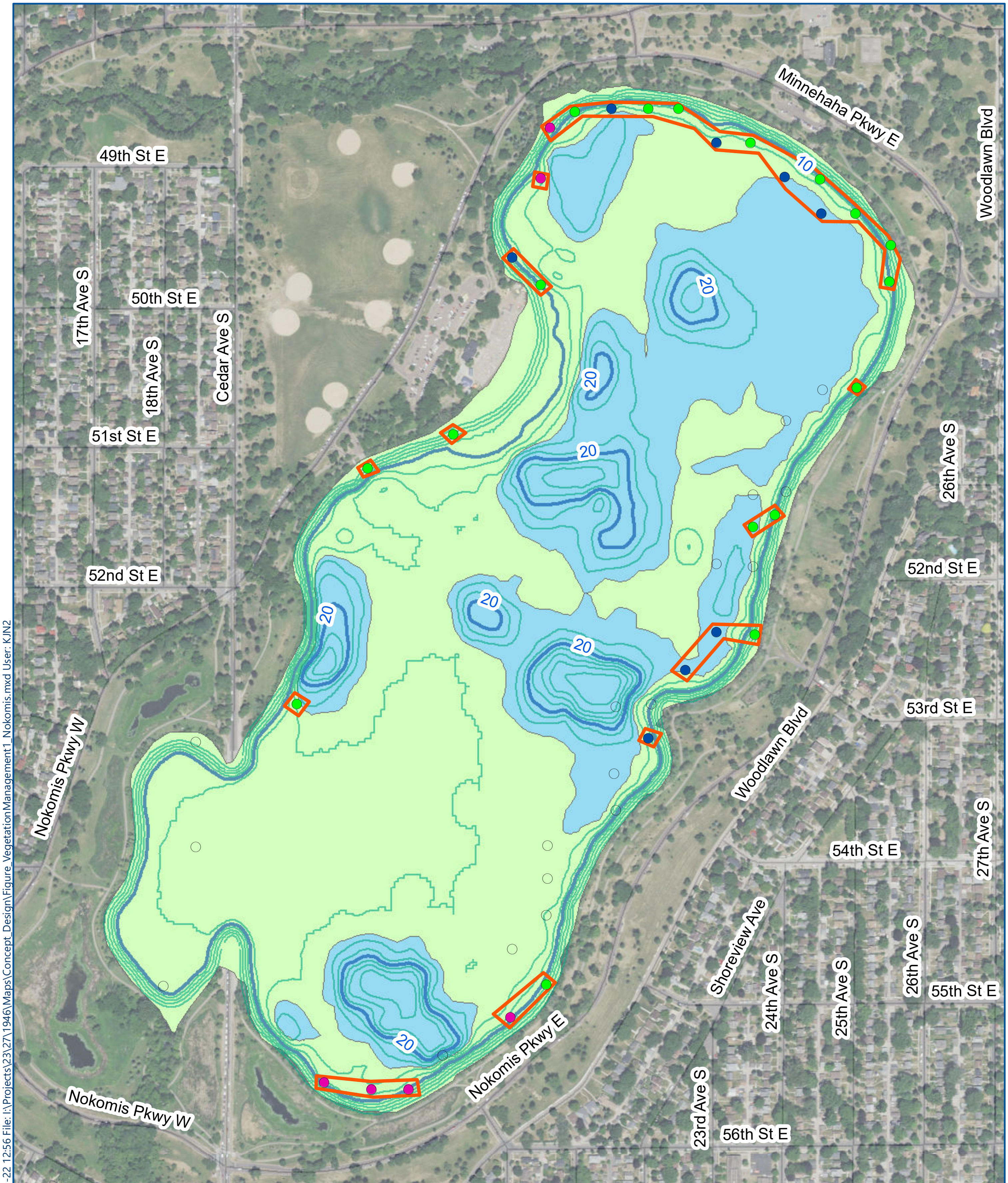
FIGURE 3-3

Lake Nokomis Aquatic Plant Management

Lake Nokomis has a much larger littoral area than Cedar Lake and can support a much larger aquatic plant community (Figure 3-4). However, the current aquatic plant community is rather small, occupying only a small fraction of the potential growth area. So, the MPRB should be prepared for significant expansion of the aquatic plant community if water clarity is increased significantly. Since aquatic plant growth is already low and there are only a few stands of invasive species, it may be easier to get control of the invasive species population prior to implementing management actions that will result in increased water clarity.

Because there are so few plants in Lake Nokomis currently, it's difficult to estimate how expansive the aquatic vegetation community will be following lake renovations. We estimated that 10 acres of Curly-leaf pondweed and Eurasian watermilfoil need to be controlled and that 25 acres need to be managed for recreational access and uses. While 25 acres is only a small fraction of the littoral zone, much of the littoral zone is 10 to 15 feet in depth where submerged plants may not grow to the surface. While many submerged plants can grow this tall, it is less likely in the deeper areas.

Using this approach, harvesting for aquatic plant control in Lake Nokomis will cost about $16,800 annually based on present cost (Table 3-7). Using herbicides for the same treatment was similar in cost at $14,580 annually based on present cost. Similar to Cedar Lake, we do not recommend harvesting in Lake Nokomis due to the presence of Eurasian watermilfoil.



Aquatic Plant Survey - 2017

- Native Plants Only
- AIS - Eurasian Watermilfoil (EWM)
- AIS - Curly-leaf Pondweed (CP)
- AIS - EWM & CP
- AIS Treatment Areas
- Littoral Zone - Depth 15 feet
- Open Water

Bathymetry Contours

- 10-ft Contour
- 2-ft Contour

0 600
Feet

BARR

LAKE NOKOMIS
MACROPHYTE
MANAGEMENT
CONCEPT DESIGN

FIGURE 3-4

Table 3-7 Aquatic plant management cost estimates for Lake Nokomis.

Activity	Unit Cost	Unit	Number of applications	Total Annual Cost
Spring/Early Summer Harvest	$400/acre	10 acres	1	$4,000
Summer Harvest	$400/acre	25 acres	1	$10,000
			Total Harvesting Subtotal	$14,000
			Contingency (20%)	$2,800
			Harvesting Total	$16,800
			Aquatic Vegetation Management Plan	$40,000
			Additional Monitoring	$10,000
			Total	$66,800
Spring/Early Summer Herbicide Application (ProcellaCor+diquat)	$790/acre	6 acres	1	$7,900
Spring/Early Summer Herbicide Application (Aquathol K)	$185/acre	10 acres	1	$1,850
Summer Herbicide Application (diquat)	$160/acre	15 acres	1	$2,400
			Total Herbicide Application Costs	$12,150
			Contingency (20%)	$2,430
			Total	$14,580
			Aquatic Vegetation Management Plan	$40,000
			Additional Monitoring	$10,000
			Total	$64,580

Aquatic Plant Management Summary

Aquatic plant management costs using harvesting and herbicides were summarized over a 20-year life cycle assuming 4% inflation (Table 3-8). We recognize that the MPRB currently does not allow the use of herbicides in the lakes. However, herbicides are the most effective tool for AIS management. Harvesting is not recommended for Eurasian watermilfoil as it will further spread the plant especially as the water becomes clearer. An aquatic vegetation management plan should be developed to establish reasonable approaches for managing AIS. The overall goal of aquatic vegetation management is to minimize the use of herbicides and harvesting by minimizing AIS species and stopping their spread through spot treatments. Herbicide treatments are slightly less expensive and are the recommended approach since both lakes have Eurasian watermilfoil. While costs may vary from year to year as plant populations fluctuate, the goal is to minimize treatments over time and move into a maintenance phase with aquatic plant management. This will minimize the cost of the herbicides applied or harvesting, and monitoring requirements. Also, harvesting and herbicides can be performed simultaneously. For example, Spring herbicide treatments can be used for AIS control, while summer recreational support can be completed through harvesting. However, until Eurasian watermilfoil is controlled, we do not recommend harvesting areas where Eurasian watermilfoil is present in either lake. Hand pulling and removal is acceptable for small areas such as beaches for spot AIS control.

Table 3-8 Aquatic vegetation management 20-year life cycle costs assuming 4% inflation

Activity	Cedar Harvesting	Cedar Herbicide	Nokomis Harvesting	Nokomis Herbicide
Aquatic Vegetation Management Plan	$40,000	$40,000	$40,000	$40,000
10-year Review	$30,000	$30,000	$30,000	$30,000
Management Activities (harvesting or herbicide)	$500,272	$425,231	$500,272	$434,164
Monitoring	$148,890	$148,890	$148,890	$148,890
TOTAL	$719,162	$644,121	$719,162	$653,054

3.3 In-Lake Structural BMPs

3.3.1 Hypolimnetic oxygenation (Cedar Lake)

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 side stream saturation system was identified as the preferred oxygen injection method as it will be most capable of meeting the criteria identified for this project, which include efficiency, minimal aesthetic disturbance (the piping and other aeration equipment should not be visible to lake users), and this system is not anticipated to affect usage of the lake by residents (i.e., winter ice thickness should not be measurably impacted). A side stream saturation aeration system is very different from other methods considered in that water is withdrawn from the lake, aerated with 95% pure oxygen, and discharged back into the lake. Figure 3-5 shows the essential components of the side stream saturation system.

To aerate both basins of Cedar Lake, two separate oxygen generation systems will be required onshore to supply four independent units in the lake. Figure 3-6 shows the potential configuration of a side stream aeration system in each basin of Cedar Lake. The oxygen injection system components would be housed in an approximately 8-foot by 8-foot building. This system is designed to deliver 400 kilograms/day of oxygen. It is important to note that this system must run continuously year-round with no significant interruption in service, or the aeration effect will end and could lead to algae bloom formation.

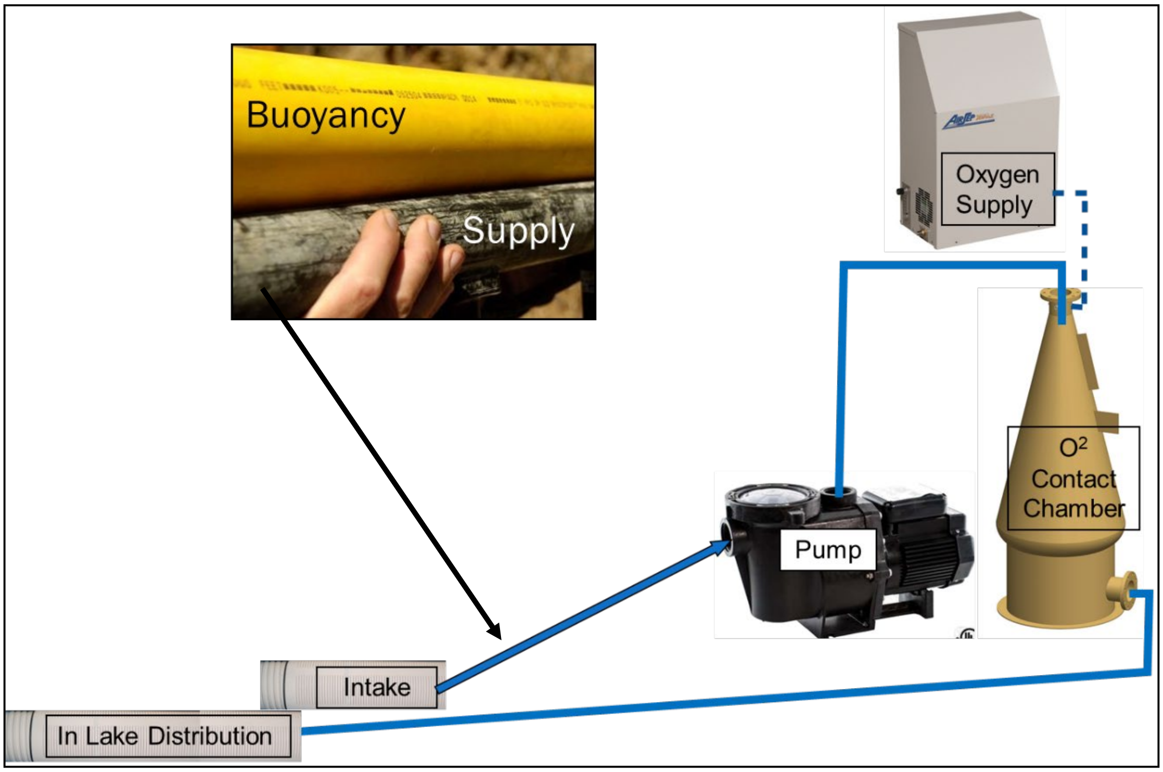


Figure 3-5 Main Components of the Side-stream Aeration System for Cedar Lake

Permitting

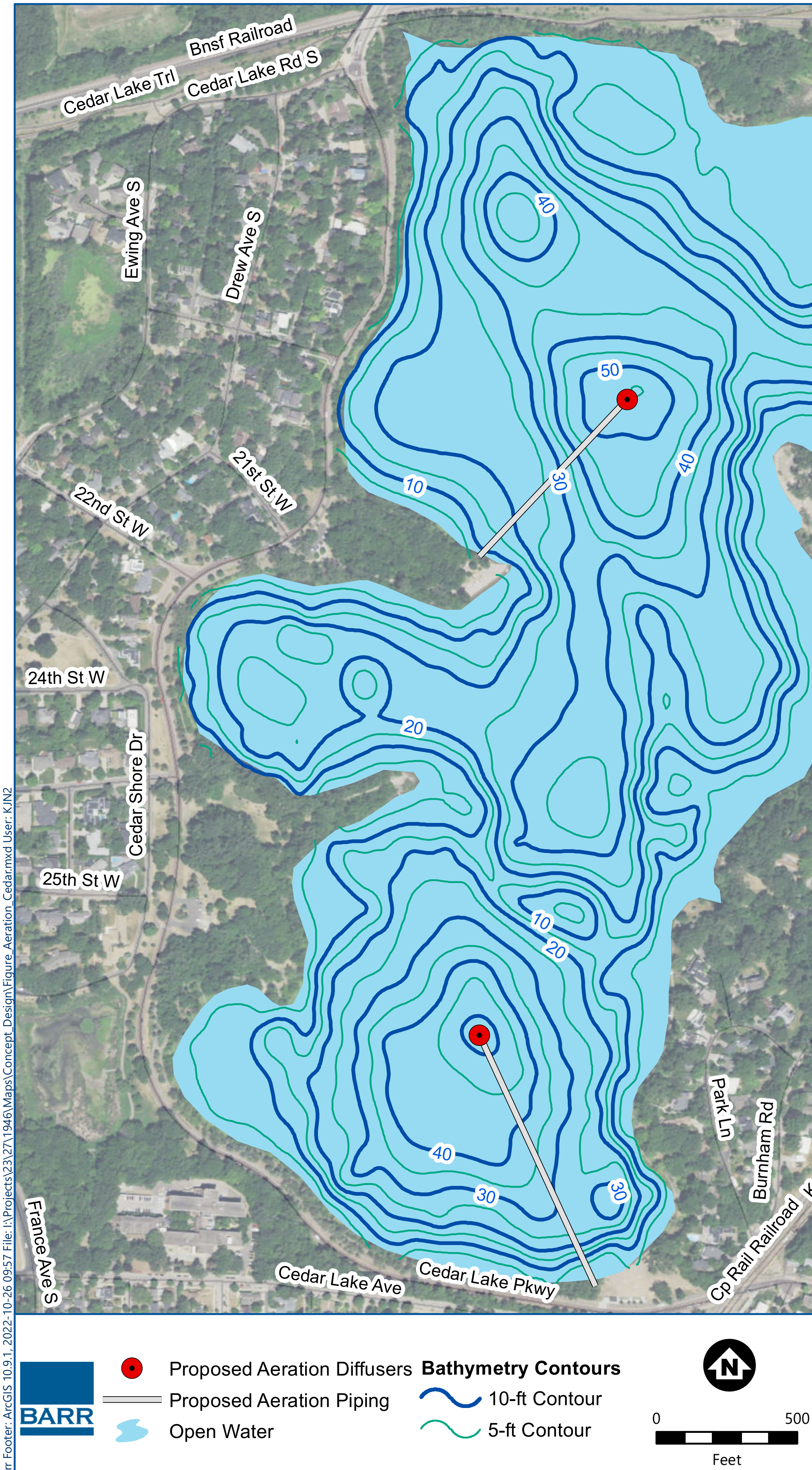
A MnDNR Aeration Permit would be required for installation of the aeration system. The permitting process is straightforward and requires information such as the purpose of aeration, the permittee, period of operation, and a description of the system. It is important to note that while the aeration permit is obtainable, it will require a time commitment for MPRB staff to renew the permit and maintain the necessary records for annual reporting.

Cost Estimate

The planning-level opinion of probable cost for designing and installing a side stream aeration system in both basins of Cedar Lake is approximately $1.93 million (see Table 3-9). The opinion of probable cost is based on engineering judgment, and experience with similar projects. The opinion of cost includes costs for specialty design services and technical support from Gantzer Water during project installation and system start-up including follow-up site visits, as needed. The costs do not include costs for supplying redundant equipment (in case of breakdowns), microfloc injection, annual monitoring, loss of parkland, or MPRB staff time for oversight and permitting. Annual operation and maintenance costs were estimated to be $40,000 per year for electricity and $10,000 per year for maintenance and the present value of the combined cost was estimated based on a 20-year life cycle with a 4% inflation rate. It is recommended that MPRB add iron testing to the lake water quality monitoring program.

Table 3-9 Hypolimnetic oxygenation cost estimate for Cedar Lake

Items	Estimated Cost
Mobilization/Demobilization	$20,000
Safety, erosion control, and site prep	$20,000
Concrete buildings (two) and foundations	$100,000
Electrical extensions/upgrades	$50,000
Direct oxygenation system	$750,000
Site restoration	$20,000
Construction subtotal:	$960,000
Construction contingency (20%)	$192,000
Estimated construction cost	**$1,152,000**
Planning, engineering, and design	$100,000
Present value estimate of 20-year O&M costs	$680,000
Total	**$1,932,000**



CEDAR LAKE AERATION SYSTEM CONCEPT DESIGN

FIGURE 3-6

3.3.2 Aeration and Artificial Circulation (Lake Nokomis)

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 requires multiple diffusers and extensive piping across 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. It is important to note that this system should not be run in the winter as it would result in open water areas and/or weakened ice.

To aerate the five deeper areas of Lake Nokomis, separate aeration diffusers and associated piping will be required in the lake. Figure 3-7 shows the potential configuration of the aeration system for Lake Nokomis. The conceptual destratification diffuser layout for Lake Nokomis is designed to place upwelling plumes (red) at the deepest locations in the lake to provide optimal mixing and good oxygen levels over the sediment. This layout requires long runs of supply piping (white) that increase costs but will be most effective for the conditions. The diffusers will require approximately 200 standard cubic feet per minute of compressed air at a supply pressure of 35 psig. All the aeration system components would be housed in a precast building.

This approach to aeration 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. Studies have hypothesized that mixing of the water column and sediment can be a driver for Microcystis blooms. For example, mixing from strong wind events and spring turnover can transfer overwintering, vegetative Microcystis cells from the sediment phase to the planktonic zone where blooms can develop. There is uncertainty regarding the impact of artificial circulation on the transfer of overwintering, vegetative Microcystis cells to the surface; but this impact should be considered when designing the artificial circulation system. It is also important to note that this system must run continuously during the growing season with no significant interruption in service, or the aeration effect will end and could lead to algae bloom formation. Since this system is not recommended for winter use, it is expected that an internal phosphorus load could build up under the ice and contribute to spring algal blooms.

Permitting

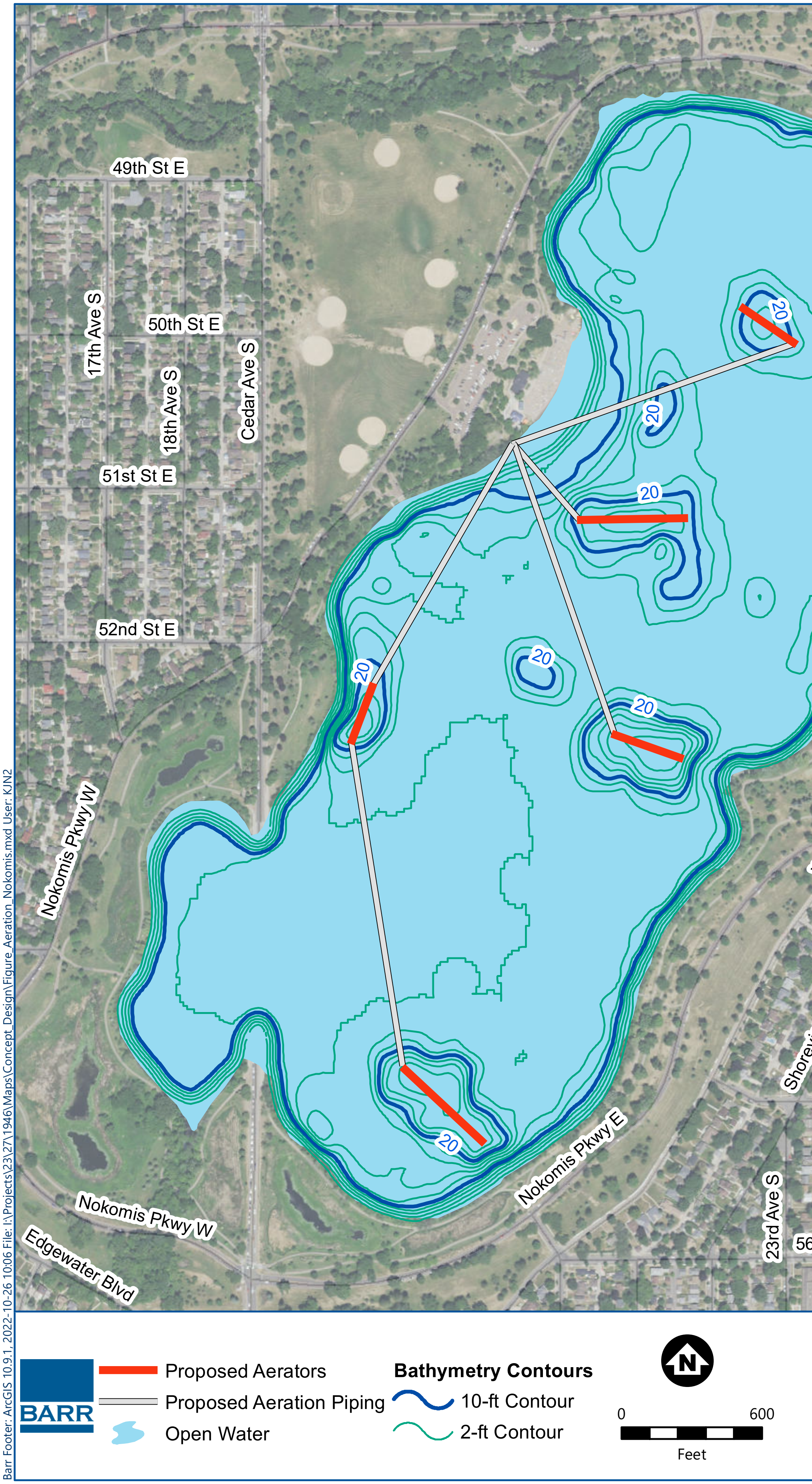
A MnDNR Aeration Permit would be required for installation of the aeration system. The permitting process is straightforward and requires information such as the purpose of aeration, the permittee, period of operation, and a description of the system. It is important to note that while the aeration permit is obtainable, it will require a time commitment for MPRB staff to renew the permit and maintain the necessary records for annual reporting.

Cost Estimate

The planning-level opinion of probable cost for designing and installing a side stream aeration system in both basins of Lake Nokomis is approximately $1.34 million (see Table 3-10). The opinion of probable cost is based on engineering judgment, and experience with similar projects. The opinion of cost includes costs for specialty design services and technical support during project installation and system start-up including follow-up site visits, as needed. The costs do not include costs for supplying redundant equipment (in case of breakdowns), microfloc injection, annual monitoring, loss of parkland, or MPRB staff time for oversight and permitting. Annual operation and maintenance costs were estimated to be $40,000 per year for electricity and $10,000 per year for maintenance and the present value of the combined cost was estimated based on a 20-year life cycle with a 4% inflation rate. It is recommended that MPRB add iron testing to the lake water quality monitoring program.

Table 3-10 Aeration and artificial circulation cost estimate for Lake Nokomis

Items	Estimated Cost
Mobilization/Demobilization	$20,000
Safety, erosion control, and site prep	$20,000
Precast concrete building, door, fans, and foundation	$160,000
Compressed air system, mechanical piping and electrical	$250,000
Site restoration	$20,000
Construction subtotal:	$470,000
Construction contingency (20%)	$94,000
Estimated construction cost	**$564,000**
Planning, engineering, and design	$100,000
Present value estimate of 20-year O&M costs	$680,000
Total	**$1,344,000**



LAKE NOKOMIS
AERATION SYSTEM
CONCEPT DESIGN

FIGURE 3-7

3.3.3 Microfloc Injection

Microfloc injection was also reviewed as a possible add-on to each aeration system. 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 P release. It is expected that the pump used for oxygen addition would also permit microfloc injection on the oxygenator. We also assumed that the primary alum injection volumes (approximately half) would be reserved for spring lake turnover events to take advantage of natural eddy diffusion, while the remaining alum injections would occur during summer and fall stratification to reduce the phosphorus levels in the hypolimnion. The relative ratios of seasonal alum injections would likely differ in each lake and would be tailored based on the lake water quality monitoring.

Along with the MnDNR Aeration Permit for the respective aeration system, an MPCA permit would be required for chemical addition. The permitting process is straightforward and requires information such as the purpose of chemical treatment, the permittee, period of operation, description of the system and prescribed alum dosage. It is important to note that while the aeration permit is obtainable, it will require a time commitment for MPRB staff to renew the permit and maintain the necessary records for annual reporting.

Cedar Lake

We assumed that the same aluminum dose specified for Cedar Lake for sediment P inactivation would be delivered over the course of a 10-year period to the lake and would be accomplished with unbuffered alum, due to the low dose applied to the lake each year (Table 3-11). The unit cost for alum was increased by approximately 50 percent to account for the smaller delivery volumes and inflation during the 10-year period. The costs do not include costs for supplying redundant equipment (in case of breakdowns), annual monitoring or operation and maintenance costs, or MPRB staff time for oversight and permitting.

Table 3-11 Microfloc injection cost estimate for Cedar Lake

Items	Unit	Quantity	Unit Cost	Total Cost
Chemical feed, storage, peristaltic pump, and controls	Lump Sum	1	$40,000	$40,000
Aluminum sulfate	Gallon $Al_2(SO_4)_3$	142,536	$4.00	$570,144
			Total Injection Cost	$610,144
			Contingency (20%)	$122,029
			Plans and Specifications; Permitting	$50,000
			Total Estimated Cost	$782,173

Lake Nokomis

We assumed that the same aluminum dose specified for Lake Nokomis for sediment P inactivation would be delivered over the course of a 10-year period to the lake and would be accomplished with unbuffered alum, due to the low dose applied to the lake each year (Table 3-12). The unit cost for alum was increased by approximately 50 percent to account for the smaller delivery volumes and inflation during the 10-year period. It is important to note that the costs do not include costs for supplying redundant equipment (in case of breakdowns), annual monitoring, operation, and maintenance costs, or MPRB staff time for oversight and permitting.

Table 3-12 Microfloc injection cost estimate for Lake Nokomis

Items	Unit	Quantity	Unit Cost	Total Cost
Chemical feed, storage, peristaltic pump, and controls	Lump Sum	1	$20,000	$20,000
Aluminum sulfate	Gallon $Al_2(SO_4)_3$	213,120	$4.00	$852,480
			Total Injection Cost	$872,480
			Contingency (20%)	$174,496
			Plans and Specifications; Permitting	$50,000
			Total Estimated Cost	$1,096,976

3.4 Watershed Structural BMPs

3.4.1 Cedar Lake

The final report of the Minneapolis Chain of Lakes implementation grant established a 40 percent phosphorus load reduction goal for Cedar Lake. 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. 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 (see Figure 3-8), including a storm sewer diversion at West 24th street, was expected to reduce the annual TP load by 40 percent.

Based on our review of the Minnehaha Creek Watershed District (MCWD) pond basin volume monitoring database documenting surveyed sediment accumulation rates, past dredging, and estimated cleanouts, it appears that the Cedar Meadows basins have been maintained and/or are scheduled for maintenance in 2023 (in the case of the Cedar Meadows wetland cell) to fully restore the treatment functioning as the original design intended. It is unclear if the Twin Lakes basins are fully functioning currently. As a result, we recommend that the constructed and dredged basins at Twin Lakes Park get surveyed and compared to the original water quality treatment design volumes.

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TWIN LAKE TO CEDAR MEADOWS DIVERSION
Concept Design

FIGURE 3-8

A 2021 meeting between MPRB, MCWD, City of Minneapolis, and City of St. Louis Park staff determined that the storm sewer diversion at West 24th Street was likely clogged and not allowing stormwater to bypass to Cedar Meadows as originally designed/intended. As of August 2022, the diversion structure has not been cleaned/jetted. As a result, we recommend that the diversion structure get cleaned, and subsequently monitored/inspected, to ensure that it functions as originally designed/intended. In addition, it is recommended that the cooperating parties assign responsibility for future inspections and maintenance of the diversion pipe.

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. However, BMPs in these direct subwatersheds are not integral to meeting the Cedar Lake water quality goals and we do recommend their implementation at this time.

3.4.2 Lake Nokomis

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.

Based on the TMDL Wasteload allocations established for the municipal separate storm sewer systems (MS4s) in the Lake Nokomis watershed, 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.

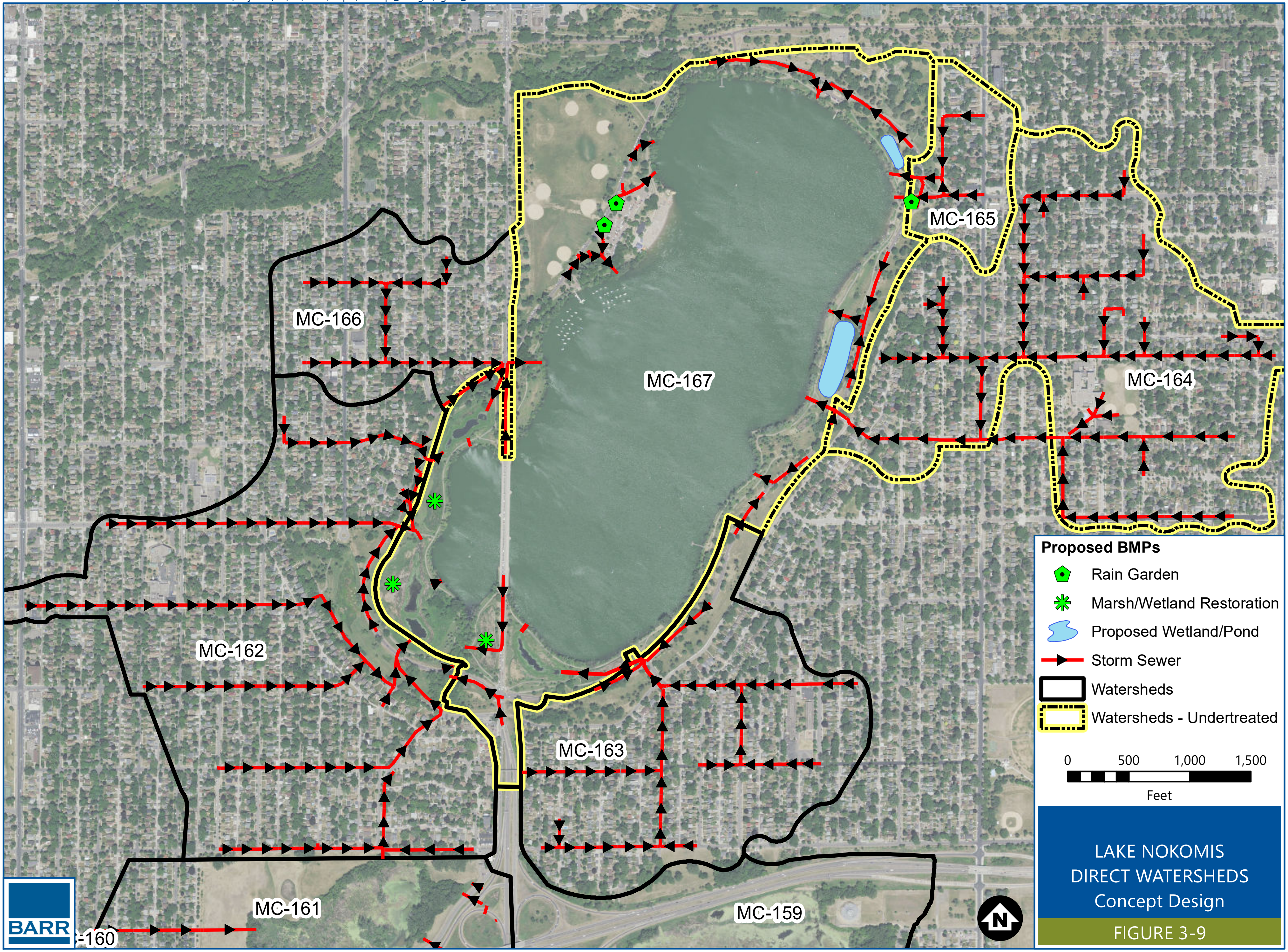
Based on our review of the Minnehaha Creek Watershed District (MCWD) pond database documenting surveyed sediment accumulation rates, past dredging, and estimated cleanouts, it appears that the Nokomis Knolls, Amelia, and Gateway wetland basins have been maintained and/or are scheduled for maintenance in 2023 (in the case of the Nokomis-Amelia wetland cell) to fully restore the treatment functioning as the original design intended and would be meeting the phosphorus load reductions prescribed in the TMDL study.

Under current conditions, Subwatersheds MC-164, MC-165, and MC-167 are not receiving the level of stormwater treatment prescribed by the TMDL study. Table 3-13 provides a detailed summary of watershed BMP costs estimated for each concept design, organized by BMP type. Figure 3-9 shows the locations of the proposed BMPs in the Lake Nokomis watershed. The costs do not include costs for supplying BMP repairs, annual monitoring or operation and maintenance costs, or MPRB staff time for oversight and permitting.

Table 3-13 Watershed BMP cost estimate for Lake Nokomis.

Subwatershed	Item	Unit	Quantity	Applied Unit Cost	Total Cost
MC-164	Wetland	Water Quality Treatment Volume, ft^3	263,500	$6.40	$1,686,400
MC-165	Wetland	Water Quality Treatment Volume, ft^3	38,300	$6.40	$245,120
MC-167	Rainwater Gardens	Water Quality Treatment Volume, ft^3	41,600	$19.20	$798,720
				Total Construction Cost	$2,730,240
				Contingency (20%)	$546,050
				Plans and Specifications; Construction Oversight	$150,000
				Total Estimated Cost	$3,426,290

We expect that implementation of new BMPs for untreated runoff from the other direct subwatersheds to Lake Nokomis, consistent with the Lake Nokomis master plan, will further assist with meeting the TP load reduction goals. However, BMPs such as the marsh/wetland restoration locations shown in Figure 3-9 are not as important for meeting the water quality goals as controlling the internal phosphorus load and we do not recommend their implementation at this time.



MC-165
MC-166
MC-167
MC-164
MC-162
MC-163
MC-161
MC-159
-160
Proposed BMPs
Rain Garden
Marsh/Wetland Restoration
Proposed Wetland/Pond
Storm Sewer
Watersheds
Watersheds - Undertreated
0 500 1,000 1,500
Feet
LAKE NOKOMIS
DIRECT WATERSHEDS
Concept Design
FIGURE 3-9
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4.0 References

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