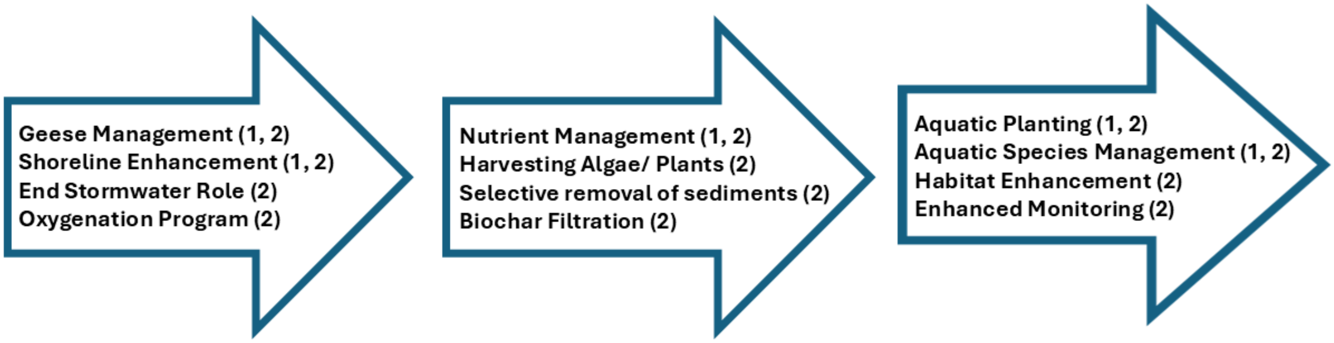
TOWARDS SUSTAINABLE WATER QUALITY FOR SWAN LAKE

Three Steps to Sustainability

STEP #1:
Keep The Bad Stuff Out And Add Oxygen

STEP #2:
Remove The Bad Stuff From the Lake

STEP #3:
Keep it That Way



(1) Phase 1 Program (2) Proposed Phase 2 Program

Submission for Markham's Swan Lake Water Quality Review By

Friends of Swan Lake Park

December 3, 2025

Contents

Swan Lake Park is a biodiverse 14 hectare municipal park located at 25 Swan Park Road in Markham. Swan Lake, within Swan Lake Park, covers 5.4 ha and has a history of poor water quality and poor aquatic habitat. University of Toronto biologists categorized Swan Lake as a "constructed wetland ".

Founded in 2019, the Friends of Swan Lake Park ("FOSLP") are residents of Markham committed to saving Swan Lake and Swan Lake Park through environmentally best practices that will rehabilitate aquatic and terrestrial habitat and provide safe lake water for sustainable human and wildlife activity.

In December 2021, Markham Council approved the Swan Lake Long-term Water Quality Plan which describes a phased adaptive approach with specific actions outlined for Phase 1, the initial 5 years from 2021 – 2025. Markham staff have initiated a review of the long-term plan with a view to seeking approval from the Markham Subcommittee for Phase 2, (2026 – 2030) in April 2026.

The following report summarizes the analysis and recommendations by FOSLP's advisors and FOSLP's recommendations for actions to be included in the Phase 2 program.

I) Phase 1 Activities

A) Lake Management Outcomes

Swan Lake has a history of algal blooms and in 2020 a high level of cyanobacteria was reported. Phase 1 actions were primarily focussed on reducing algae and cyanobacteria through a program targeted to reduce two nutrients essential to the growth of algae, phosphorus and nitrogen. It was stated that the reduction in phosphorus and nitrogen would lead to a reduction in algae and improvement in oxygen levels.

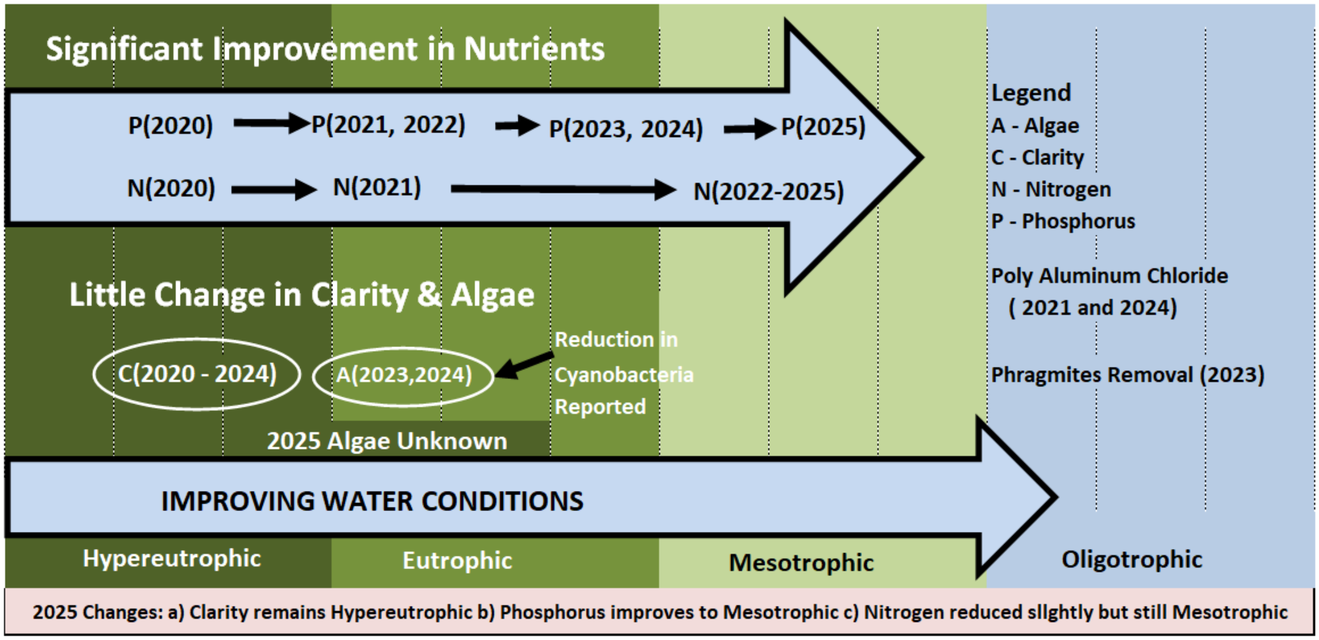
Through their droppings, Canada geese were considered to be the primary "external" source of phosphorus and nitrogen entering the lake. A geese management program was implemented to reduce both the summer resident geese population and to reduce the number of geese staying on the lake during the migration season.

The sediments were considered to be the primary storehouse of nutrients already in the lake. Two treatments of polyaluminum chloride ("PAC") were applied in 2021 and 2024 to reduce the "Internal" source of phosphorus.

In 2022, the TRCA was engaged to remove phragmites from the eastern shoreline of the lake and the North Pond. It is likely that the harvesting of these reeds contributed to the reduction of phosphorus, nitrogen and chloride in the ecosystem during this period.

Phase 1 activities resulted in a significant decline in phosphorus, nitrogen and cyanobacteria; however, only limited progress was made in reducing algal levels in the lake. Clarity and turbidity remain poor.

SWAN LAKE WATER QUALITY: PHASE 1 CHANGES 2020 - 2025



FOSLP is recommending that Phase 2 actions be focussed on sustaining the improved nutrient levels but with additional actions that will directly reduce the high levels of chloride, algae and improve turbidity, including a comprehensive oxygenation system with enhancements to support the aquatic habitat.

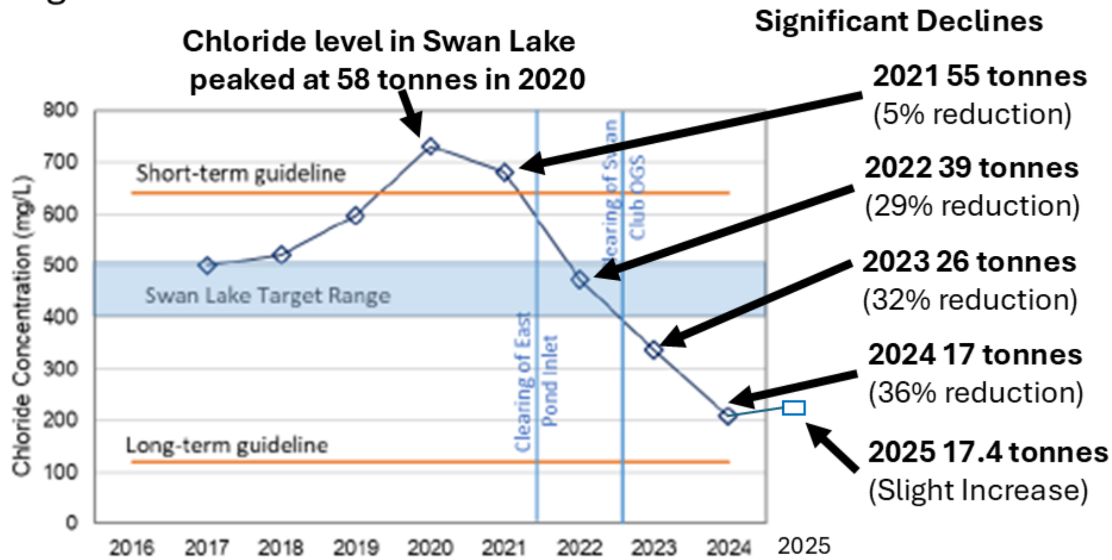
Significant Decline in Chloride Due to Flushing Action

Swan Lake has no natural surface level inflows nor outflows but there are six stormwater sources that direct almost three tonnes of chloride into the lake each year. Chloride does not break down and will accumulate within the lake over time, impairing the health of aquatic plants and many forms of aquatic species.

The other notable change during Phase 1 was a significant decline in chloride levels in the lake. The chloride levels in Swan Lake rose dramatically from 2018 – 2020. This was attributed to a blockage in one of the pipes preventing stormwater flows from entering the East Pond and resulting in a significant increase in flows directed into the lake. Since this blockage was cleared, chloride levels have declined significantly and have levelled off but there are still over 17 tonnes active in the water column and more stored in the sediments.

Though reduced, chloride levels remain well above the Federal guidelines for safe aquatic life.

Significant Decline in Chloride Levels 2021 - 2024
Slight Increase in 2025



Inflows reduced once blocked pipe cleared. Reasons for reductions are not clear.

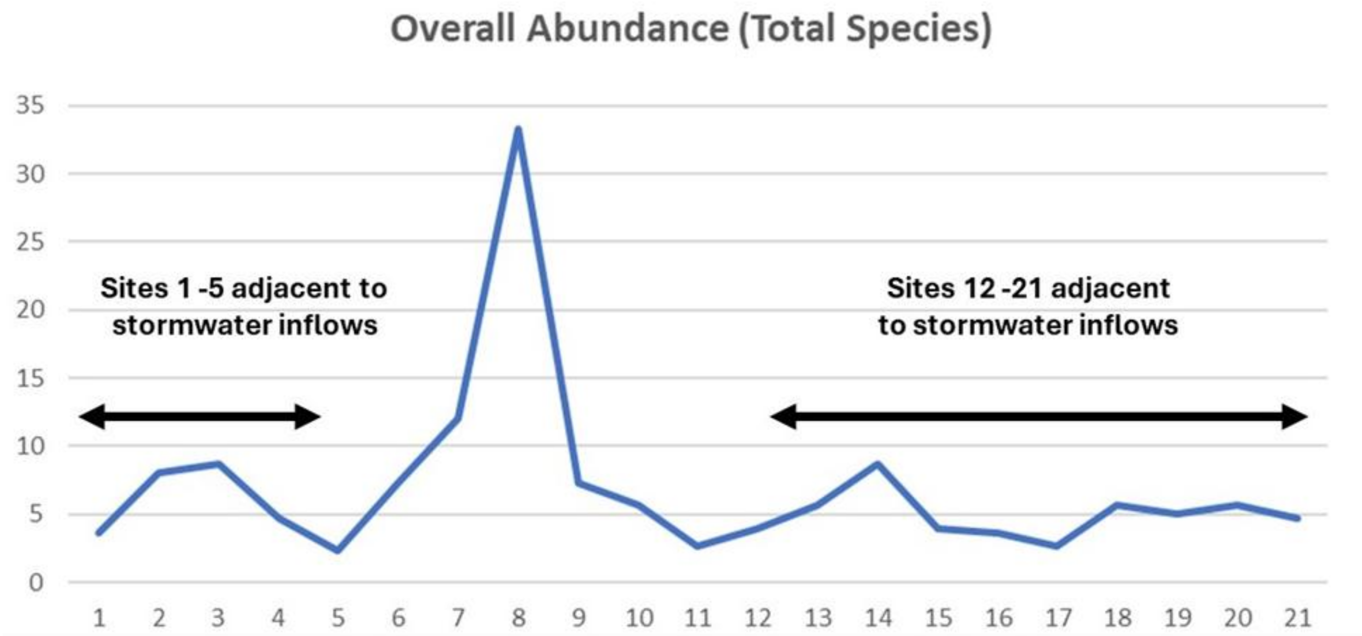
The decline in chloride levels illustrates the ability of the stormwater outflows and the groundwater system to flush chloride from the lake. Markham's Flow Diversion Assessment[b] has identified actions that could reduce stormwater inflows into the lake by 85%. If implemented, it is possible that the flushing action could reduce the existing chloride levels below the Federal guidelines, an essential step in stabilizing aquatic life in the lake. FOSLP is recommending actions be taken during Phase 2 to end Swan Lake's stormwater management role.

B) Phase 1 Lake Monitoring

Throughout Phase 1, there were several groups with different perspectives involved in monitoring the water quality and habitat in Swan Lake.

Markham took physical water samples on a routine basis throughout Phase 1. Initially tests were taken bi-weekly and lately monthly at two near-shore locations at the dock and bridge. The focus was on monitoring the nutrients, oxygen, phytoplankton and other organic elements with the goal of assessing the eutrophication level of the water and the success of various management actions. The Markham program included an annual fish inventory program undertaken by the TRCA but did not attempt to monitor aquatic elements such as zooplankton and Benthic Invertebrate. There was some testing of the sediments in 2020 to help with the design of the chemical applications.

Presence of Ephemeroptera (Mayfly), Plecoptera (Stonefly) and Trichoptera (Caddisfly), or EPT, are indicators of good water quality and overall ecosystem health, In 2022, FOSLP engaged Chris Reeves to undertake an inventory of the Benthic Invertebrate. He observed that significantly fewer species were identified in areas adjacent to the stormwater sources but overall concluded that given the taxa found and percentage of EPT species identified, Swan Lake could be rated as fair or intermediate water quality based on his findings.



In 2025, researchers from York University partnered with Friends of Swan Lake Park to form the Swan Lake Citizen Science Lab ("SLCSL"). The objective was to bring advanced technical capabilities of drone monitoring, artificial intelligence, Virtual Reality and simulation to bear on the environmental elements in Swan Lake and Swan Lake Park. Throughout the growing season, SLCSL project leader, Dr. Ali Asgary collected drone-based multispectral imagery of Swan Lake.

The full report[d] is provided in a separate submission, but the key findings are summarized in Appendix A.

The report concluded that the visual evidence reflected in the RGB (Red/Blue/Green) orthomosaic maps strongly supports the conclusion that the lake's primary water-quality issue is algal overgrowth (eutrophication), which severely degrades clarity and aesthetic appeal during spring, summer, and early fall.

As his report notes: *Overall, the RGB orthomosaic maps provide powerful, intuitive confirmation of the objective index-based analyses:*

1. ***Direct Confirmation of Blooms****: The shift from deep green/olive water in the summer (May–September) to gray-blue/slate water in November provides direct visual proof of the intense and sustained algal bloom that dominates Swan Lake's water quality during the growing season.*
2. ***Visual Severity****: The water on May 20th and throughout the summer is so densely green that it suggests conditions consistent with a severe hypereutrophic state, where light penetration is minimal due to the sheer volume of algal biomass.*
3. ***Visible Scum:*** *The pale, dense patches on the surface in the summer maps visually confirm the low-NDWI, high-concentration surface scums that are a significant feature of the lake's water quality problem.*

Dr. Huy Dang of Trent University provides oversight into work by researchers from Trent, Laval University and the Institut National de la Recherche Scientifique (Quebec City) who have been active in Swan Lake over the past three years. Their focus has been on the impact of the heavy metal elements in the chemicals used to reduce phosphorus (Phoslock and Polyaluminum Chloride) on aquatic life.

In 2025, researchers from Trent gathered extensive data including temperature, oxygen (two depths) and chlorophyll over time with very high resolution and have compiled vertical profiles of various parameters (pH, temperature, oxygen, redox, and electrical conductivity) at 10 sites around the lake. This data will be released in 2026 once the research is published.

In their reports, both R. J. Burnside[e] and Natural Resources Solutions Inc. [f,g] outline the need for a more enhanced water quality monitoring program for Phase 2 that would include monitoring eutrophic levels and the results from the management actions but also provide more specific information on the sediments and the aquatic life within the lake.

University researchers need data to support their advanced research programs, and the lake management activities underway in Swan Lake make it an attractive location for their research. We are fortunate to have two leading research teams interested in integrating Swan Lake into their research programs. Combined with Markham's needs for essential data to monitor its programs, there is an opportunity for Markham to formalize a water quality monitoring program that meets its core needs while providing baseline information for advanced research that will provide Markham and others with critical information on the impact of lake management activities. Both the York and Trent research groups have the technical capabilities, and both have expressed an interest in participating in a co-ordinated and enhanced monitoring effort throughout Phase 2.

FOSLP is recommending that Markham undertake a co-ordinated water quality program during Phase 2 that leverages the talents of the university research teams, gives Markham the core information needed for Phase 2 while providing baseline data for the advanced research projects the university teams are undertaking.

C) TRCA Phase 1 Activities and Recommendations

The Toronto and Region Conservation Authority ("TRCA") was involved in three core lake management activities during Phase 1:

a) The TRCA undertook a fish inventory program that included the removal of certain "bottom feeding" and invasive species that were considered to be undermining the Phase 1 program.
b) Phragmites was removed in the fall of 2022 along the eastern shoreline and at the North Pond. It is likely that the removal of these reeds also resulted in the removal of phosphorus, nitrogen and chloride from the lake system. No estimate has been made of the potential reductions.
c) The TRCA was engaged to plant wild celery (Vallisneria americana) to establish a test base for macrophytes. The program has had limited success with only 30% of the plants taking hold and only those in shallow water. The TRCA attributes the poor results to fluctuating water levels and poor clarity in the water. No mention was made of the potential impact of chloride levels.

In addition, Markham engaged the TRCA to advise on shoreline enhancements. The TRCA outlined their recommendations for shoreline enhancements and "Restoration Opportunities" at a public meeting on April 26, 2022. A summary is provided in Appendix D.

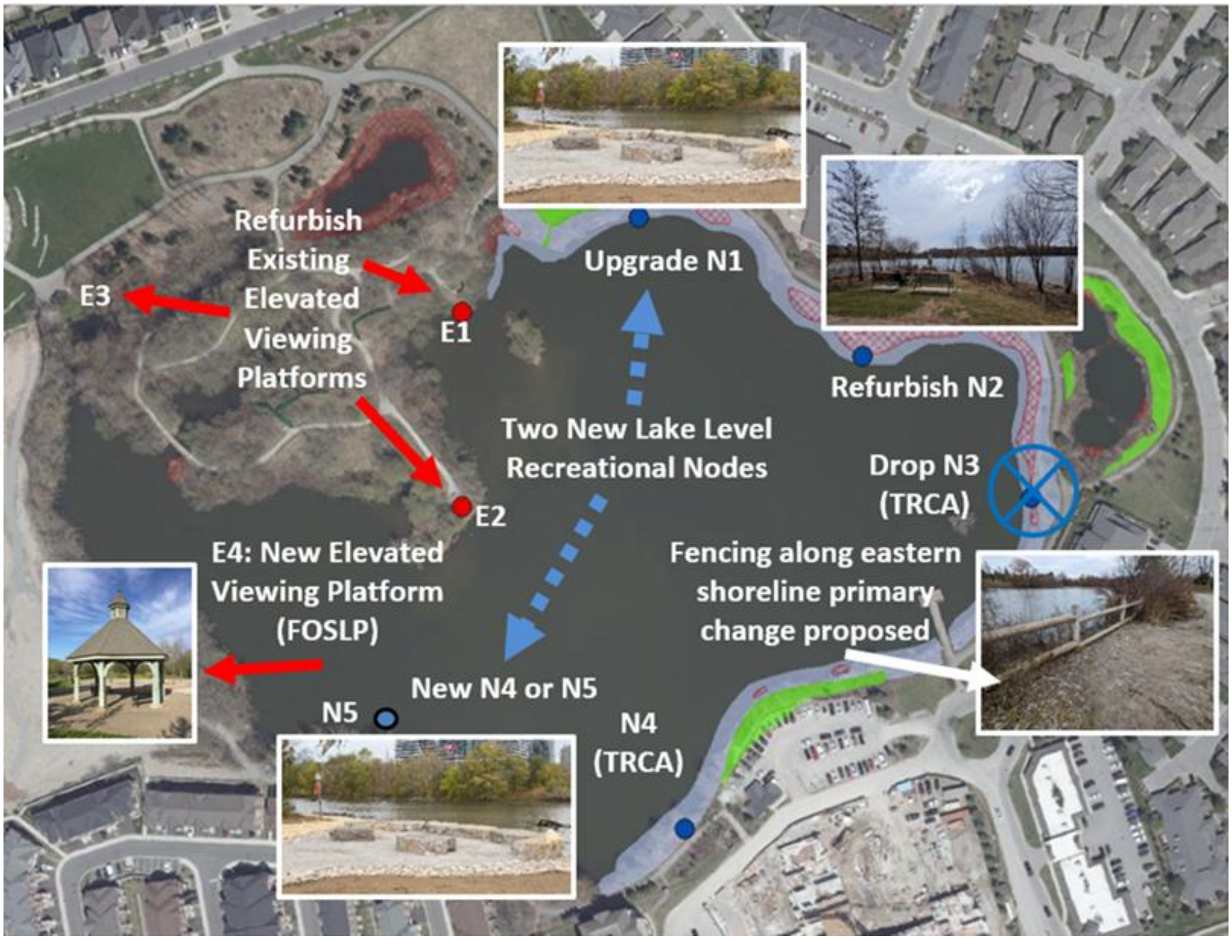
The TRCA's 2022 recommendations included:

a) An invasive plant species removal program for phragmites and dog-strangling vine.
b) An outline of shoreline restoration opportunities that would address the lack of emergent aquatic, terrestrial native plants, shrubs and shallow water habitat.
c) Revegetation of the shoreline to create a diverse naturalized shoreline.
d) Recommendations for the installation of additional stonework along the shoreline to limit geese access.
e) Recommendations for reducing degradation of the shoreline by park users by controlling park visitors access to the lake by installing recreational nodes.

As part of the program to constrain access for the geese, Markham staff installed temporary "snow" fencing as a geese deterrent along the eastern shoreline and in 2025 proposed the installation of permanent fencing as a geese deterrent, rather than the more costly stone work program proposed by the TRCA. At the June 2025 meeting of the Markham Subcommittee, Kathleen Elizabeth Noel outlined her concerns about the impact of the fencing on the habitat and staff agreed to discuss the issue with the TRCA before proceeding. Subsequently, staff reported that they will proceed with the installation of cedar post and paddle board fencing in 2025 noting that design provisions were made regarding wildlife concerns. The project will also entail the planting of approximately 200 native plants to form a low-growing natural border.

Markham staff also recommended against the installation of recreational nodes as proposed by the TRCA. In 2024, FOSLP requested that Markham proceed with a scaled down version of the TRCA recommendations, requesting that two (N1 & N5) rather than four recreational nodes be added to the shoreline, plus requested an additional viewing area (E4) on the western shoreline be added to serve park visitors in the western section of the park.

FOSLP Proposed Shoreline Amenities May 2024



Markham staff recommended against the installation due to equity with other parks. There are, however, only two other parks containing a major water body. FOSLP is requesting that these additional enhancements be implemented during Phase 2.

II) Phase 2 Recommendations by FOSLP Advisory Groups

In 2025, FOSLP engaged two groups of aquatic biologists, R.J. Burnside & Associates Ltd. ("Burnside") and the Natural Resource Solutions Inc. ("NRSI") to review the long-term water quality plan, the actions and outcomes of Phase 1, and to provide recommendations for actions during Phase 2 that would support a long-term sustainable outcome for Swan Lake.

Kathleen Elizabeth Noel, a local naturalist and FOSLP member who has led FOSLP-sponsored birding tours of Swan Lake Park outlined the environmental sensitivity of the shoreline. Her full report will be forwarded as soon as it is finalized.

Link's to the advisors' full reports are provided in the references section but their key findings and recommendations are outlined below in italics.

A) Shoreline Health and Its Role in Maintaining Water Quality (Noel)

Kathleen Elizabeth Noel, a local naturalist and FOSLP member who has led FOSLP-sponsored birding tours of Swan Lake Park, notes that when discussing and addressing the issue of the water quality in Swan Lake, shoreline habitat improvement and restoration should be paramount. Swan Lake's shorelines have become degraded due to several issues including the lack of emergent aquatic vegetation and terrestrial and native plants and shrubs.

Natural shorelines are known as ribbons of life for a reason and work as living filters to help improve and preserve water quality. Healthy, natural shorelines play an important role in filtering sediment and runoff, protecting against erosion, and absorbing excess nutrients. Furthermore, shorelines facilitate the exchange of resources between aquatic and terrestrial ecosystems, and therefore affect the functioning, ecological condition and health of both ecosystems.

She recommends several actions to strengthen and support the Swan Lake's shoreline:

1. **Support and Sustain the Existing Biodiversity**: Swan Lake Park is incredibly biodiverse and home to a plethora of birds and wildlife. Native birds and wildlife benefit and stabilize shoreline health and water quality through the various roles they play in regulating nutrients and maintaining ecosystems. At least 184 distinct native species of birds, aside from Canada geese (*Branta canadensis*) have been recorded in the park, 15 of which are classified as species at risk under Schedule 1 of the Government of Canada's *Species at Risk Act*. The park supports a diversity of mammals and amphibians, including two species of turtles rated as being of Special Concern under Schedule 1 of the Government of Canada's *Species at Risk Act*, all with a reliance on Swan Lake.
2. **Native Shoreline Plants**: Having native vegetation along the shoreline is crucial for healthy water quality as it acts as a living filter which helps to catch pollutants and sediments from runoff before they can reach the water and ergo prevents them from negatively impacting water quality.

   Shoreline buffers are areas along bodies of water where plants grow and are not mowed or disturbed. Many native plants have deep root systems that can help to stabilize soils and will guard against erosion and help create vital habitats for wildlife. Shoreline plants can additionally help ameliorate water quality by providing shade, aiding in the cooling of water necessary to provide a healthier aquatic environment for native species of fish and other wildlife.

3. **Harvesting**: Planting native species of salt-tolerant plants (halophytes), including switchgrass (*Pancium virgatum*), sand dropseed (*Sporobolus crytandrus*), prairie cordgrass (*Sporobolus michauxianus*), and sideoats grama (*Bouteloua curtipendula*), and employing harvesting methods to naturally manage excessive chloride levels in Swan Lake in the long-term. The harvesting process involves planting the native halophytes, allowing them to lay dormant over the winter months and flourish in the spring and summer and be cut at the base of the plant and removed from the site when they are mature the following fall. Research indicates that if

this process is followed for at least three consecutive years, chloride levels in the soil drop and soil remediation is achieved. Less chloride in the soil would mean less chloride in the water, and an improvement in shoreline health and water quality as a result. This method is currently being employed to manage chloride levels at a number of parks throughout the City of Toronto, including Grenadier Pond in High Park, which has long faced issues with having excessive chloride levels that are twice the recommended level for aquatic long-term health and water quality.

Noel outlines three areas of concern.

a) **Invasive Plant Species:** Invasive plant species disturb and degrade shoreline health and the environment as a whole, which in turn has a significant negative impact on water quality. In particular, many invasive plant species including, phragmites and dog-strangling vine (DSV), can decrease water flows and nutrient transportation. Other species of concern include Garlic Mustard, Yellow Iris, Common Tansies, and Burdock. She recommends a follow-up program to remove the returning phragmites and other invasive plant species.
b) **Introduction of Biochar**: She expresses concern about the risk to the environment and native wildlife if biochar filters are employed at Swan Lake Park, noting that multiple scientific studies have detailed the health and environmental risks associated with biochar.
c) **Installation of Goose Fencing:** Noel questions the effectiveness of goose fencing as a deterrent to geese and opposes Markham’s plan to install “post and paddle board” fencing along the eastern shoreline. She is concerned that the fencing can be environmentally disruptive and contribute to the degradation of shoreline health and water quality through fragmentating and destroying the habitat for turtles, birds and other wildlife that help to maintain ecosystem balance.

B) Aquatic Environment Recommendations by Burnside

Following are excepts from Burnside’s Swan Lake Aquatic Conditions review[e].

Executive Summary

- *R.J. Burnside & Associates Limited reviewed aquatic habitat conditions in Swan Lake at the end of Phase 1 of the Long-Term Water Quality Management Plan, on behalf of the Friends of Swan Lake Park, to guide recommendations for Phase 2.*
- *High abundances of phytoplankton continue to cause turbidity and low dissolved oxygen, which may interfere with macrophyte re-establishment and the development of in-water habitat. Elevated internal nutrient loading and chloride concentrations may impede current and future restoration efforts if left unaddressed.*
- *Improving water circulation through a bioswale system and/or artificial aeration may help reduce internal nutrient loading and could assist in nutrient management by helping to remove and sequester internal phosphorus loading.*

- *High chloride levels, limited structural habitat, and predation from abundant Fathead Minnow populations may be suppressing zooplankton grazers (e.g., Daphnia spp.), although no study has yet confirmed this relationship.*
- *Largemouth Bass stocking in 2025 provides an opportunity to potentially reduce Fathead Minnows. Establishment of a population of bass may be supported by adding complex woody material structures in the absence of macrophytes. Future aquatic surveys are recommended to determine whether current lake conditions are suitable for sustaining bass, especially to overwinter, or if further habitat modifications (e.g., deepening the pond or raising the lake level) may be worth exploring to improve survivability. However, it is worth evaluating the bass survival in 2026 to see if these deepening measures are necessary.*
- *There are limited opportunities to use native Unionidae mussels or sunfish species to improve habitat quality.*
- *Due to high turbidity from phytoplankton preventing macrophyte growth, efforts should focus on improving water quality before pursuing further macrophyte restoration.*

Table 7: Summary of Recommendations to Improve Biological/Ecological Conditions During Phase 2

Biotic Group	Mechanism of Action	Effectiveness in Eutrophic Systems	Relevance to Swan Lake
Native Fish	Biomanipulation via top-down control	Moderate – High minnow population may be suppressing desirable zooplankton	Largemouth Bass stocking (>100 mm) may help reduce minnows if overwintering can be demonstrated.
Native Mussels	Nutrient sequestration	Very low – many native mussels sensitive to poor water quality	Paper Pondshell may provide some filtration, but unlikely to contribute significantly
Zooplankton (esp. *Daphnial spp.*)	Grazing on phytoplankton	Moderate to high – if predation and chlorides are controlled	Strong potential water quality improves and reduction in predation (i.e., increased habitat complexity and minnow control). Analysis of zooplankton community recommended before considering stocking.
Macrophytes	Nutrient sequestration, habitat	High local effect; supports DO and stability	Stabilizing effect once water quality permits growth
Habitat Complexity	Increase habitat complexity	High - Placement of woody material (stumps with root mass and	Swan Lake currently offers limited structural habitat. Establishment of a bass population may be aided by

Biotic Group	Mechanism of Action	Effectiveness in Eutrophic Systems	Relevance to Swan Lake
		elevated logs) or bolder complexes may enhance available habitat for Largemouth Bass.	increasing habitat complexity until macrophytes can re-establish. Deepening not recommended – evaluate after 2026 fish survey to determine bass survivability.

Nutrient and Oxygen Management

- *Construction of bioswale may be most effective, low-cost means to reduce and sustain nutrient levels and promote water circulation*
- *Enhance the existing bioswale to provide opportunities to beautify a section of the lake*
- *Artificial aeration may benefit the lake (e.g., assistance in water circulation)*

Chloride Reduction

- *Maintain focus on source control (grit-separator rerouting, winter salt management, etc.)*
- *Target ≤ 120 mg/L Cl^- to aid in restoring zooplankton communities*

Biological Recovery

- *Zooplankton study may be useful to determine current species composition*
- *Add structural habitat (woody material, rock clusters) in absence of large macrophyte beds*
- *Determine if Largemouth Bass stocked in 2025 survive until 2026. If bass can overwinter, bass may help reduce minnow population to alleviate predation on zooplankton*
- *Delay further macrophyte plantings until turbidity is reduced*

Macrophytes Recommended by Burnside (Table 6)

Open Waters 0.5 m to 1.5 m Deep

- *Pond Lily* — *Nuphar variegata*
- *Water Lily* — *Nymphaea odorata*
- *Pondweed* — *Potamogeton richardsonii*
- *Pondweed* — *Potamogeton pectinatus*

Shores and Waters to 0.5 m Deep

- *Wild Celery* — *Vallisneria americana*

Shores and Waters to 0.25 m Deep

- *Arrowhead* — *Sagittaria latifolia*

10.0 Conclusion

Success of Swan Lake's aquatic communities depends on improving water quality before attempting further biological restoration. Lack of noticeable improvements to the lake's water quality is likely a result of persistent problems interacting to keep lake conditions turbid.

Effective recovery may require:

1. *Nutrient stabilization through mechanical circulation through bioswale and/or artificial aeration*
2. *Chloride control by some means of reduction*
3. *Improvement to Daphnia ssp. populations through improvements to habitat complexity, selective predator stocking, and eventual re-vegetation once clarity returns*

This sequence offers a chance of achieving a self-sustaining mesotrophic system that supports a balanced, resilient, aquatic community.

Chloride-induced suppression of Daphnia spp. populations is likely exacerbating Swan Lake's phytoplankton blooms. Increasing Daphnia spp. abundance can yield short-term improvements (<2 years) in water clarity and phytoplankton control (Kibuye et al 2021) and should be considered as part of broader lake-management planning. While some mechanism for chloride reduction is recommended, it alone will likely not resolve the issue. Creating a population of Largemouth Bass may help to improve the Daphnia spp. populations through the reduction of Fathead minnow. However, the current zooplankton community is unknown.

Improvement to the water quality of shallow, eutrophic lakes, such as the case in Swan Lake, are impeded by its slow recovery, as it is hard for people to maintain interest (May et al., 2020). However, actions for the improvement of Swan Lake are promising, and should encourage managers to maintain support and interest.

C) NRSI: Elements of a Comprehensive Oxygenation Program

The following is an extract from NRSI's report on the review of management options and the effects of increased oxygenation in Swan Lake[e].

7.0 Conclusions and Recommendations
Within Swan Lake, any management approach intended to increase DO concentrations must be designed not only to address existing DO deficiencies but also anticipate increases in biological oxygen demand (BOD) that will result from enhanced biological and microbial activity following oxygenation. As oxygen availability improves, aerobic bacteria, benthic invertebrates, and aquatic vegetation will become more active, increasing oxygen consumption and temporarily offsetting some of the initial gains in DO. Accordingly, any oxygenation strategy must account for these feedback effects and be implemented as part of a long-term, adaptive rehabilitation program. Importantly, effective DO enhancement within Swan Lake must also target the underlying causes of poor surface water quality,

Specifically, historic and ongoing nutrient and containment loading from high Canada Geese populations, stormwater inputs and the accumulation of nutrient-rich organic sediments. High organic matter concentrations, low sediment oxygen concentrations, and anaerobic bacterial processes may work against active oxygenation programs in Swan Lake. These conditions can consume oxygen more rapidly than it is introduced, thereby slowing the realization of measurable *improvements reducing the effectiveness of direct oxygenation by continuously releasing nutrients and consuming available oxygen.*

While active oxygenation can be highly effective in addressing short-term hypoxia and improving localized water quality, it rarely provides lasting improvements unless combined with integrated watershed and sediment management actions. Stand-alone oxygenation systems typically require continuous operation to maintain benefits, as discontinuation can lead to a rapid decline in DO concentration, often below pre-treatment level, due to increased BOD and residual nutrient release.

Increased oxygenation in shallow, nutrient-rich systems such as Swan Lake can lead to significant improvements, including:

- *Reduced internal nutrient loading and phosphorus release from sediments.*
- *Decreased bioavailability of heavy metals through oxidation.*
- *Improved surface water clarity and reduced frequency of harmful algal blooms.*
- *Enhanced biological diversity and productivity through improved aerobic habitat conditions.*

However, these benefits are typically realized gradually, as the system responds to improved redox conditions and enhanced biological cycling. Regardless of the oxygenation strategy employed, elevated biological oxygen demand (BOD) can also lead to a sudden decline in dissolved oxygen concentrations, potentially to levels lower than those observed prior to treatment, if oxygenation programs are discontinued without addressing the underlying causes of poor water quality. Effective long-term management will therefore require sustained oxygenation, regular monitoring, and adaptive operational adjustments to maintain DO levels sufficient to counteract high BOD and sediment oxygen demand.

7.1 Oxygenation Program Considerations

Oxygenation represents a viable and effective approach to improving surface water quality and aquatic habitat conditions within Swan Lake. Diffused aeration or fountain aeration systems would likely provide the most balanced combination of performance, reliability, and cost- effectiveness for this small, shallow, and nutrient-enriched lake. When paired with watershed- level nutrient management and ecological restoration efforts, these systems can form the foundation of a long-term strategy to enhance aquatic health, reduce eutrophication, and restore more natural lake function.

However, oxygenation alone will not fully address all water quality deficiencies or the underlying causes of degradation. To improve the effectiveness and sustainability of oxygenation measures, several key factors should be considered when developing and implementing an oxygenation program for Swan Lake.

- ***Address Natural Mixing Limitations**: Any oxygenation program should aim to overcome the lack of natural circulation within Swan Lake to ensure adequate exposure of all areas to elevated DO concentrations.*
- ***Uniform Application**: Oxygenation should be applied uniformly across the lake to prevent the formation of localized hypoxic or anoxic zones.*

- ***Integrated Management Approach**: Oxygenation cannot resolve the underlying causes of poor surface water quality and should be implemented in conjunction with broader rehabilitation measures that address both historical and ongoing nutrient and contaminant inputs.*
- ***Continuous Operation**: Consistent, low-intensity operation is preferable to intermittent high-output cycles, as sudden fluctuations in DO can destabilize the system and increase BOD demand.*
- ***Hydrologic Connectivity**: Recirculation of water through the north channel is expected to provide only limited improvement in DO levels unless underlying nutrient concentrations are simultaneously addressed.*
- ***System Design**: System layout should provide full spatial coverage, including deeper basins and areas of low circulation, while avoiding disturbance of fine, nutrient-rich sediments.*
- ***Operational Schedule**: Continuous, steady operation will help maintain stable oxygen levels and minimize fluctuations in BOD and redox potential.*
- ***Monitoring Program**: Ongoing monitoring of DO, temperature, turbidity, and phosphorus concentrations should accompany installation to evaluate system effectiveness and inform adaptive management.*
- ***Integration with Rehabilitation Efforts**: Oxygenation should complement a broader restoration plan that includes sediment nutrient management, stormwater inflow treatment, and shoreline naturalization to improve long-term system stability.*

In summary, successful improvement of water quality within Swan Lake will depend on an integrated approach that combines active oxygenation with nutrient load reduction, sediment management, and ecological restoration. These combined measures will enhance dissolved oxygen concentrations, promote stable redox conditions, and foster a more balanced and resilient aquatic ecosystem.

In Appendix C, FOSLP outlines a proposed configuration for a comprehensive oxygenation program that will contribute to the management of sediment-based nutrients and enhance the aquatic environment within the lake.

D) NRSI's Outline of Lake Management Options

Following is an extract from NRSI's report on Swan Lake Management Options(f) outlining their recommendations for a comprehensive oxygen, sediment and nutrient management program for Phase 2.

4.1 Swan Lake Management Strategy Program Considerations

Specific management and habitat restoration activities offer the potential to further support the improvement of water quality and aquatic habitat conditions within Swan Lake. These strategy considerations are intended to address some of the causes of degraded water quality conditions as opposed to addressing their symptoms, which support the foundation of an improved long-term strategy for Swan Lake to enhance aquatic ecosystem health, reduce eutrophication, and restore more natural lake function. Based on our understanding of the history of Swan Lake and its role in *the wider stormwater system, both historic and ongoing high concentration nutrient loading is understood to be one of most significant factors contributing to the existing water quality conditions within Swan Lake. To support the enhancement of the surface water quality conditions within Swan Lake the following activities are proposed for this purpose:*

- ***Comprehensive Oxygenation Program:*** *The inclusion of targeted oxygenation measures will serve to directly address low dissolved oxygen levels within Swan Lake. It should be noted that while supplemental oxygenation alone will not induce meaningful long-term improvements in surface water conditions, it does have the potential to address some short-term habitat limitations. An oxygenation program may act to minimize the potential for hypoxia/anoxia, address anaerobic sediment conditions, and generally support widespread aquatic ecosystem health.*

  The implementation of a multipart oxygenation program, in line with the design proposed by the FOSLP as part of their December 2025 submission for Markham's Swan Lake Water Quality Review, including the installation of multiple diffused aeration systems, fountain aeration systems, and the circulation of surface water through Swan Lake to introduce current flows, has the potential to significantly improve surface dissolved oxygen conditions and contribute to the improvement of overall surface water quality conditions.

- ***Sediment & Nutrient Management****: Identifying and addressing the internal and external nutrient sources will directly influence long-term aquatic ecosystem condition stability. Mitigating and controlling the additional nutrient inputs that originate from stormwater and natural sources (e.g., goose droppings) is critical to addressing the underlying cause of the degraded aquatic ecosystem conditions in Swan Lake. While PAC and other phosphorus controlling chemical treatments temporarily help to mitigate surface water concentrations, it does not address the elevated concentrations within the sediment, nor does it influence long-term habitat stability. Following the implementation of targeted sediment and nutrient monitoring, the appropriateness of the additional chemical treatments can be further assessed.*

  An overall sediment and nutrient management strategy would support a more targeted phosphorus-controlling chemical treatments by using a science-based approach to determine scheduling and planning of applications as opposed to only applying the treatment following algae mat formation. The reliance on algae mat formation as the key metric for determining when to apply supplemental chemical treatments is limiting. While algae mat formation does imply a degraded water quality, it has a limited ability to address the underlying cause of the water quality conditions before they degrade to the point where treatment is necessary.

  In addition, the characterization of sediment quality conditions throughout Swan Lake would help to characterize the overall sediment nutrient concentrations and support future management opportunities, including potential targeted sediment removal operations to address areas of significantly elevated sediment nutrient conditions.

While natural phosphorus loading from Canada Goose populations is understood to be short-lived, with most nutrients settling into the sediment, the Canada Goose monitoring and management operations completed to-date appear to have been effective at reducing resident goose populations, thereby helping to reduce additional external nutrient loading (Unckless and Makarewicz 2007). The continuation of these monitoring and management operations would support wider management and restoration operations and contribute to the improvement of surface water quality conditions.

A detailed sediment and nutrient management program, including the characterization of sediment conditions within upstream stormwater management facilities, their sediment and nutrient contributions into Swan Lake, as well as a detailed characterization of the sediment conditions throughout Swan Lake would help to direct restoration and management strategies to address the underlying sources of degraded habitat conditions within Swan lake and support the long-term improvement on surface water and aquatic ecosystem quality conditions.

- ***Chloride Management:*** *Chloride concentrations have reduced somewhat, but still remain above the long-term exposure guidelines. Addressing the inputs from upstream stormwater management, either by addressing outflow to Swan Lake or through application of targeted chloride-reducing measures (such as biochar), is critical to achieving any long-term improvements in surface water and aquatic ecosystems quality. FOSLP chloride reduction programs included as part of their December 2025 submission for Markham's Swan lake Water Quality Review has the potential to significantly reduce Swan Lake's annual chloride loading, contributing to the overall improvement of the surface water quality conditions.*

  Supplementary filtration, through the inclusion of Biochar (or similar) filter systems, would help to further reduce the chloride levels within Swan Lake. If used in conjunction with reducing annual chloride loading this would serve to potentially address the elevated chloride concentrations and support the improvement of the overall surface water quality conditions.

- ***Enhanced Monitoring Program:*** *It is suggested that the water quality monitoring program be expanded and/or enhanced to include sediment quality monitoring (aligned with the Sediment Quality Guidelines for the Protection of Aquatic Life) and should consider the addition of sampling locations to help support the characterization of the existing conditions within Swan Lake, and to provide additional context for supplementary treatments and rehabilitative measures (such as limited targeted removal of contaminated or high concentration sediment deposits). Previous sediment monitoring, completed in 2020, was in line with the assessment of the risk of eutrophication but did little to assess the overall health and suitability of the aquatic ecosystem. Ideally this monitoring would continue an annual basis during and following any restoration and management activities to monitor for changes in sediment conditions.*

- ***Shoreline Habitat Enhancement:*** *Shoreline restoration and plantings would help to support the development of aquatic ecosystem structure, stabilize the nearshore aquatic ecosystem conditions, and contribute to the ongoing aquatic vegetation establishment program. Enhanced riparian habitats would also help to mitigate some of the natural nutrient and* *sediment loading. Engaging the Toronto and Region Conservation Authority to advise and support shoreline enhancements, included as part of the FOSLP's December 2025 Markham's Swan lake Water Quality Review, would strengthen the aquatic and shoreline enhancement program. But, as with other management strategies, shoreline enhancements would be most effective when implanted alongside measures that anticipated root causes of degraded water quality conditions, high nutrient concentration sediments. It is understood that one management strategy being considered involves the removal of excessive nearshore aquatic plants (e.g., phragmites), previously completed in 2022.*

Future aquatic vegetation removals have been proposed by the FOSLP to remove additional aquatic vegetation has the potential to contribute to further reducing internal organic nutrient loading going forward. However, given the high legacy concentrations of organic nutrients within the sediment, this proposed strategy wouldn't provide a notable improvement to the overall conditions, but would need to be applied along with other management strategies.

- ***Algae Management:*** *The continuation of ultrasonic control measures, to inhibit algae bloom formation, has the potential to support natural ecosystem stabilization, improving surface water clarity and supporting aquatic vegetation growth. Similarly, direct algae treatment chemical applications have the potential to address the risk of algae blooms but would do little to address the perceived root causes of the degraded aquatic ecosystem within Swan Lake, the historic and ongoing high concentration nutrient sediments.*

No single Swan Lake Management Strategy component will completely address the degraded water quality or remove impediments to improving the conditions within the local aquatic ecosystem. However, the integration of a combination of these strategies has the potential to improve and enhance the overall sediment and water quality conditions, and foster a more balanced and resilient aquatic ecosystem within Swan Lake. It is recommended that future Swan Lake Management Strategies consider the following components to enhance the effectiveness of individual management strategies and contribute to the improvement and enhancement both sediment and water quality conditions within Swan Lake:

- *Inclusion of a sediment quality monitoring program within Swan Lake and the adjacent Stormwater Ponds to characterize the existing conditions and support wider sediment and nutrient management programs. It is recommended this program continue through Phase 2 and 3 to monitor for changes in sediment loading and quality conditions.*
- *Implementation of targeted oxygenation measures to address low dissolved oxygen concentrations and contribute to improved surface water and aquatic habitat conditions. The FOSLP oxygenation program included as part of their December 2025 submission for Markham's Swan lake Water Quality Review would address these recommendations. It is recommended this program be implemented during Phase 2.*
- *Implementation of an improved chloride management program, through stormwater pond bypassing and filtration, to reduce annual chloride loading. The FOSLP chloride reduction programs included as part of their December 2025 submission for Markham's Swan lake Water Quality Review would address these recommendations. It is recommended this program be implemented during Phase 2.*

- *Shoreline habitat enhancement and rehabilitation to contribute to the enhancement of aquatic habitat and nearshore aquatic ecosystem conditions, supporting the ongoing aquatic vegetation establishment program while mitigating some of the natural nutrient and sediment loading. The FOSLP oxygenation program included as part of their December 2025 submission for Markham's Swan lake Water Quality Review would address these recommendations. It is recommended this program continue through Phase 2 and 3 to account for wider monitor for changes in sediment loading and quality conditions.*

E) NRSI's Outline of a Comprehensive Water Quality Monitoring

Following is an extract from NRSI's report on Swan Lake Management Options[f] outlining their recommendations for enhancements to the water quality monitoring program.

4.0 Water Quality Monitoring Program Enhancements
While the overall Swan Lake Water Quality Monitoring Program, if applied correctly, is appropriate to meet the intent of high-level eutrophic condition characterization, the opportunity exists to expand it to provide a more comprehensive and high resolution water quality characterization to support the overall Swan Lake Water Quality Management Plan. This expanded water quality monitoring program is recommended to include the following new and refined monitoring components:

- *Additional spring freshet and significant precipitation event sampling to account for potential stormwater runoff effects on surface water conditions;*
- *Inclusion of PWQO Guidelines alongside Swan Lake Monitoring Program guidelines;*
- *Inclusion of Recreational Water Quality Guidelines for water clarity;*
    - *Inclusion of minimum and maximum water clarity readings, along side the applicable targets/guidelines, as part of the annual water quality analysis to detail the range in conditions;*
- *Inclusion of CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life guidelines for total phosphorus, nitrate, ammonia, and dissolved oxygen concentration analysis;*
- *Completion of all water quality monitoring components identified as part of the Swan Lake Monitoring Program on an annual basis;*
    - *A summary of omissions or alterations in monitoring from workplan components outlined as part of each annual report;*
- *Include complete bi-weekly water quality results as part of each annual report, along with explanations and justification for gaps in water quality sampling coverage;*
- *Any assertions of significant water quality improvements be presented alongside supporting evidence in each annual report;*
- *The inclusion of aquatic health specific monitoring components to increase the comprehensiveness of the monitoring program.*
    - *Annual aquatic health monitoring can include the inclusion of benthic macroinvertebrate, zooplankton, and fish community composition, aquatic vegetation biomass, or composition assessment, herpetofauna nesting and overwintering assessment.*

FOSLP is recommending that the Phase 2 monitoring program incorporate the key elements outlined by NRSI and be integrated with the research programs underway at both York and Trent Universities.

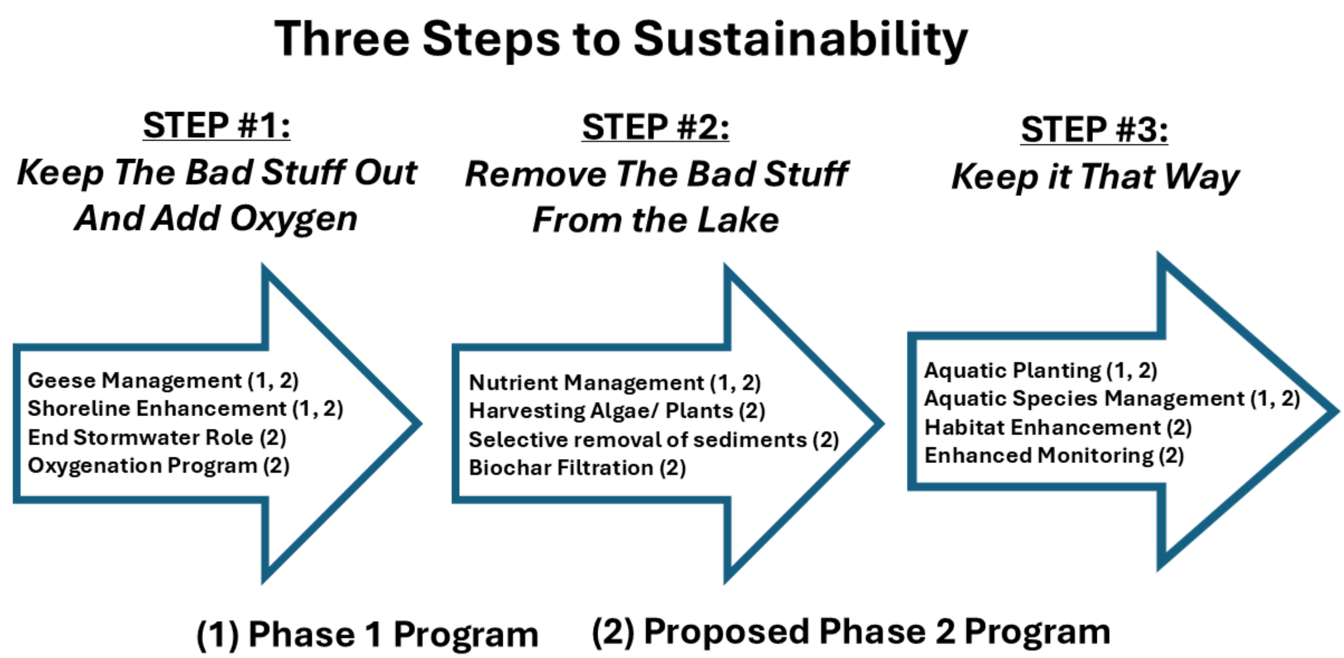
III) FOSLP's Proposed Actions for Phase 2

To be successful, any rehabilitation program for Swan Lake must directly address two structural features that inhibit the chance of achieving a sustainable state of water quality:

1) End Swan Lake's stormwater management role and minimize the inflow of road salt that undermines the aquatic habitat essential to a stable aquatic ecosystem
2) Recognizing that the lake is a stagnant body of water with poor circulation, mixing, and low oxygen levels that undermine aquatic life and triggers the release of nutrients from the sediments.

A) Lake Management Program

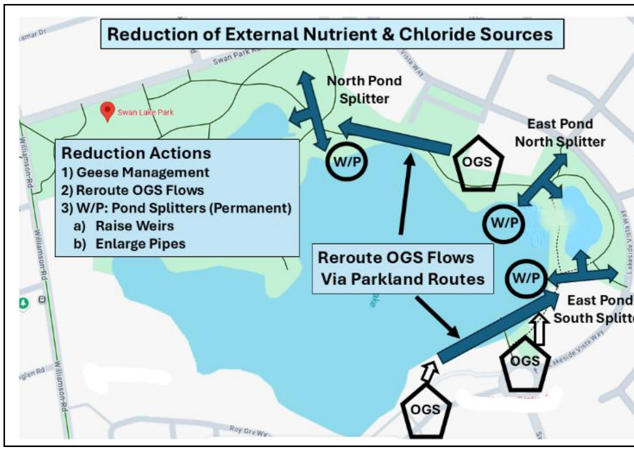
The emphasis in Phase 1 on reducing algae indirectly by reducing nutrients has had limited effect. As noted by both Burnside and NRSI, there is the need for a continued nutrient reduction program backed by an oxygenation program and an increased focus on directly reducing turbidity, algae and chloride. Based on these recommendations, FOSLP proposes that actions during Phase 2 be structured to recognize three core steps to a sustainable ecosystem for Swan Lake:

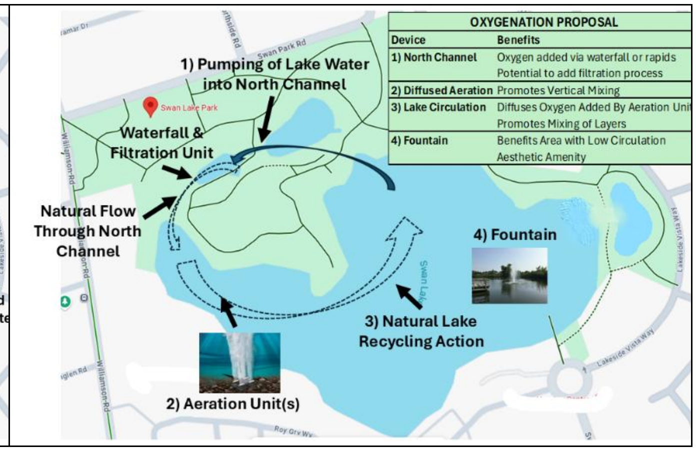


Continue Nutrient Reduction Efforts But Introduce Direct Actions on Oxygen, Algae, Turbidity and Chloride

Step #1: Keep the Bad Stuff Out/ Introduce Comprehensive Oxygenation Program

1) Continue the geese hazing program to reduce external sources of phosphorus and nitrogen.
2) Enhance the shoreline areas as recommended by the TRCA, Burnside and Noel to reduce the impact of nutrients entering the lake and to absorb nutrients already in the lake.
3) End the stormwater role. Minimize chloride inflows entering the lake (see Appendix B)
   a. Eliminate 56% of the chloride flows from the three Oil Grit Separator units using a low-cost parkland route at a cost FOSLP estimates at $1.1 million.
   b. Reduce chloride inflows by 29% by altering the three splitters that control stormwater flows bypassing the ponds (Cost $125,000),
4) Implement a comprehensive oxygenation program. (see Appendix C)

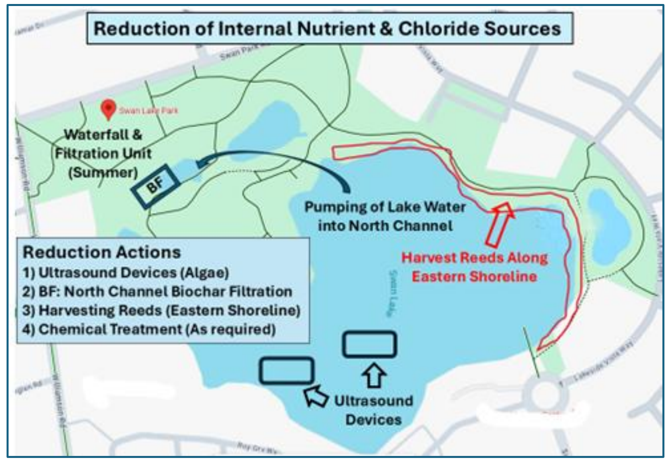




Step #2: Remove the Bad Stuff from the Lake

1) Continue with a program to remove phosphorus and nitrogen from the lake by:
   a. Scheduling another PAC treatment 3-5 years after the latest treatment to contain phosphorus.
   b. At least once during Phase 2, harvest the shoreline reeds in the fall to remove phosphorus, nitrogen and chloride from the ecosystem.
   c. Identify the primary areas where sediments are storing nutrients and chloride, and selectively remove those sediments, in sync with deepening areas to provide a haven for overwintering species. (see Appendix E)
   d. Implement a Biochar filtration unit as a component of the recycling process through the North Channel.

2) Undertake a program directly targeting algae by:
   a. Continuing the use of the ultrasound treatment and consider other locations.
   b. Introduce an algaecide treatment (hydrogen peroxide or similar product) to directly reduce existing algae.
   c. Each spring harvest the algae that floats on the lake surface.



Step #3: Keep It That Way

1) Remove any returning phragmites and other invasive species such as dog-strangling vine
2) Continue with aquatic and shoreline planting to support aquatic and park wildlife
3) Continue with the fish management program and investigate the opportunity to stock zooplankton or mussels to support the algae management program
4) As recommended by NRSI, implement a comprehensive monitoring program in conjunction with university researchers that will monitor the eutrophic levels, aquatic habitat and aquatic life (zooplankton, Benthic Invertebrates), the sediments, and the success of specific management actions undertaken during the rehabilitation program.
5) As recommended by NRSI, establish goals that align with Federal and Provincial guidelines and create triggers to address changes if conditions deteriorate.

B) Habitat and Shoreline Enhancements

1) Consider Burnside's recommendation to deepen areas within the lake to support largemouth bass. One option would be to create trenches linking the deeper portions of the lake. See Appendix E.
2) Re-engage the TRCA to strengthen the aquatic habitat and shoreline by:
   a) Following through on the TRCA's "Restoration Opportunities" outlined in 2022.
   b) Implementing the aquatic habitat enhancement recommendations outlined by Burnside to support aquatic life including structural habitat (woody structures, rock clusters).
   c) Addressing shoreline habitat concerns raised by Noel
   d) Addressing the needs of park visitors and fishers by implementing the recreational shoreline enhancements recommended by TRCA in 2020 and supported by FOSLP in 2024.

C) Rehabilitation Costs

In the original water quality plan, as summarized in Appendix F, Markham staff provided an estimate of $4.9 million for the costs of rehabilitation of Swan Lake over 25 years, of which $1.1 million was allocated to Phase 1. The actual costs incurred during Phase 1 are not known.

The original cost outline provided $865,000 for Phase 2 planned activities, but does not include costs for FOSLP's recommended actions such as an oxygenation program, creating a trench to connect the deeper areas of the lake, selectively removing sediments, restoring the shoreline nor providing shoreline amenities.

The original plan estimated the cost of rerouting stormwater at $5 million. The Flow Diversion report(b) provided an updated estimate of $2.1 million. FOSLP has estimated that adoption of a low cost parkland route would bring costs closer to $1.25 million and asks that Markham investigate the feasibility and cost of this option.

There was an initial concern that groundwater may carry contaminants from the old dumpsite locations on the southern shoreline into the lake. Recorded groundwater tests have indicated that the groundwater flows south and southwest away from the lake so the former dump sites may not be a factor. A more comprehensive sediment testing program could provide evidence as to whether this is a concern. The reduction in chloride suggests that the groundwater has had a positive influence by flushing away the chloride and potentially some of the nutrients.

References/ Links to Full Reports

a) Swan Lake Long-term Water Quality Plan, City of Markham, November 2021
Swan Lake Water Quality Management Plan
b) Consolidated Report, Swan Lake Flow Diversion Assessment, AECOM, May 2025
Agenda Package - Markham Sub-Committee_Jun18_2025.pdf
c) Swan Lake Water Flow and Chloride Analysis, Markham, November 3, 2025
Swan Lake Water Quality Management
d) Swan Lake Water Quality Monitoring with Drone, Swan Lake Citizen Science Lab, Dr. Ali Asgary, November 29, 2025 https://arcg.is/10jfe51
e) Drone-based Monitoring Swan Lake Water Quality, Report #1 (Preliminary Draft): Multispectral Data, Swan Lake Citizen Science Lab, Dr, Ali Asgary, November 26,2025
f) Swan Lake Aquatic Conditions Review, R.J. Burnside, November 2025
Swan Lake Aquatic Conditions Review
g) Swan Lake Long Term Management Plan, Natural Resource Solutions Inc. November 2025
Microsoft Word - NRSI_3645_Swan Lake Water Quality Peer Review_REV1_26-Nov-25_BEB.docx
h) Literature Review of Management Options and Effects of Increased Oxygenation in Swan Lake, Natural Resource Solutions Inc. November 2025
Microsoft Word - NRSI_3645_Swan Lake Oxygenation Lit Review_7-Nov-25.docx
i) Shoreline Health and Why It is Vital for Ameliorating and Maintaining Water Quality at Swan Lake Park, Kathleen Elizabeth Noel, December 2025 (Available on Request)

APPENDIX A: Summary of Preliminary Findings of Drone Based Monitoring of Swan Lake Water Quality

Report #1: Multispectral Data (Preliminary Analysis)

By Dr. Ali Asgary, Director of CIFAL York
Swan Lake Citizen Science Lab

The Swan Lake Citizen Science Lab (SLCS Lab) is an innovative research and engagement initiative based in York University, dedicated to the use of technological innovations in long-term health and restoration of Swan Lake Park. Founded through a partnership between leading researchers from York University (CIFAL York, ADERSIM, and One Water) and community group Friends of Swan Lake Park (FOSLP), the lab was established in 2024 to directly address the complex environmental challenges facing the 5.4-hectare urban lake, particularly concerns related to water quality, biodiversity, and ecosystem stability.

Goals and Objectives of this Study

The drone-based multispectral monitoring conducted in 2025 by the Swan Lake Citizen Science Lab (SLCS Lab) has two primary goals, all aimed at guiding the lake's long-term rehabilitation plan.

Goal 1: High-Resolution Water Quality Mapping

- Use multispectral data to detect, quantify, and map the spatial distribution of chlorophyll-a and algal blooms (cyanobacteria), allowing for precise monitoring of chemical treatment efficacy.
- Quantify and map turbidity and Total Suspended Solids (TSS) to track light penetration, which is vital for the survival of submerged aquatic vegetation (SAV).

Goal 2: Monitor Ecosystem Restoration Success

- Use multispectral indices (e.g., NDVI) to monitor the establishment, growth, and health of the newly planted Wild Celery (SAV) within restoration areas.
- Accurately map the extent and spread of invasive vegetation (like Phragmites) around the lake perimeter to plan targeted removal efforts.
- Generate comprehensive aquatic habitat and morphology maps to establish a high-resolution ecological baseline for evaluating the success of future interventions, such as fish stocking.

Summary of Findings

The following is an extract summarizing the findings outlined in Report #1 which outlines the preliminary findings of the High-Resolution Water Quality Mapping program.

The following charts display orthomosaic RGB (Red/Green/Blue) maps of Swan Lake to provide visual insights into water color during the study period (May to November 2015). RGB maps depict the water's actual visible color, enabling a qualitative yet impactful evaluation of its condition.

The visual evidence from the RGB maps strongly supports the conclusion that the lake's primary water-quality issue is algal overgrowth (eutrophication), which severely degrades clarity and aesthetic appeal during spring, summer, and early fall.

Overall, the RGB orthomosaic maps provide powerful, intuitive confirmation of the objective index-based analyses:

1. **Direct Confirmation of Blooms**: The shift from deep green/olive water in the summer (May–September) to gray-blue/slate water in November provides direct visual proof of the intense and sustained algal bloom that dominates Swan Lake's water quality during the growing season.
2. **Visual Severity**: The water on May 20th and throughout the summer is so densely green that it suggests conditions consistent with a severe hypereutrophic state, where light penetration is minimal due to the sheer volume of algal biomass.
3. **Visible Scum:** The pale, dense patches on the surface in the summer maps visually confirm the low-NDWI, high-concentration surface scums that are a significant feature of the lake's water quality problem.

The analysis was supported by the use of three spectral indices to classify water quality levels:

1) Normalized Difference Chlorophyll Index (NDCI) and Swan Lake Water Quality

The analysis of NDCI maps for Swan Lake from May to November 2025 offers a comprehensive overview of seasonal algal biomass and activity. The NDCI serves as a crucial indicator of eutrophication, with high values (red/orange) indicating concentrated chlorophyll-a, the pigment found in algae and cyanobacteria.

2) Normalized Difference Turbidity Index (NDTI) and Swan Lake Water Quality

The NDTI, calculated from the difference between red and green spectral bands, serves as an effective proxy for suspended matter, including sediment and, importantly for this hyper-eutrophic lake, phytoplankton (algae/cyanobacteria).

The analysis of the Normalized Difference Turbidity Index (NDTI) maps for Swan Lake reveals a strong, consistent seasonal cycle in water quality, characteristic of a lake undergoing seasonal biological changes. According to these results the water quality trend divides into three clear seasonal phases across the seven-month period:

3) Normalized Difference Water Index (NDWI) and Swan Lake Water Quality

The analysis of NDWI maps, spanning from May to November 2025, offers essential insights into water clarity, depth, and surface materials such as floating algal scums or aquatic vegetation. The NDWI employs Green and Near-Infrared (NIR) bands to evaluate water characteristics.

While attempts have been made to minimize the calculation and interpretation of the results, it is very important to note that these are preliminary results based on a rapid calculation and analysis. The data and findings must be further checked and validated, taking into account flight parameters and environmental conditions. This will happen in the next phase of this study when we aim to publish the findings.

RGB Maps and Swan Lake Water Quality
The most striking observation across the images is the dramatic shift in water color, which could directly correspond to the seasonal changes in algal biomass.

Phase 1: Peak Green/Opaque Water (May – Mid-September)
This period features water that is mostly green or olive-green, showing very high levels of suspended matter.

On May 20, June 2, June 7, and June 15, the main lake's water appears dense, opaque, and deep olive-green. This color and density indicate a significant algal bloom, as shown by the NDCI measurements. The green hue suggests a high concentration of green algae or possibly a cyanobacterial (blue-green) bloom that looks green when very dense. The water surface is murky and lacks reflection.

August 23 & September 17: The water remains a solid, light green or pea-soup green. This visually confirms the recurrent, highly concentrated chlorophyll levels measured by the NDCI throughout the summer, suggesting the bloom is persistent, not a one-time event.

In all these summer images, patches of brighter or paler green/white on the water surface are observed, particularly near shorelines (e.g., on May 20 and June 7). This visually confirms the presence of surface algal mats or scum, as indicated by low NDWI values (Red/Orange) in the previous analysis.

Phase 2: Transition to Brown/Clearer Water (October)
As temperatures drop, a visible change occurs in the water body. The October 29 image shows that the watercolor shifts from the dense green of summer toward a brownish-green or gray-brown. This transition suggests two things: First, the primary green algal biomass is dying off (consistent with the reduced NDCI). Second, the remaining suspended matter may be a mix of decaying organic material (giving the brown hue) and a residual amount of sediment.

Phase 3: Lowest Opacity / Clearest Water (November 12)
The final image shows the lake's maximum visual clarity over the entire period. Data from November 12 shows that the water is a noticeably darker gray-blue/slate color. It appears less opaque and more reflective than in any of the summer images. This visually confirms the highest water clarity (Lowest NDTI) and the most expansive coverage of Clear/Deep Water (High NDWI/Dark Blue) observed in the indices.

Summary
The preliminary results from all three indices provide a robust assessment of Swan Lake's water quality dynamics that can be summarized here:

1**. The Cause of Turbidity could be Algae:** The NDTI (Turbidity) peaks on May 20th, directly correlating with the NDCI (Chlorophyll) peaks on the same day. The NDWI seals this conclusion by showing Red/Orange surface scums on May 20th and throughout the summer, confirming that the degradation in clarity is primarily due to dense, surface-floating algal biomass rather than just suspended sediment.

2. Two-Stage Seasonal Stress: The lake experiences two forms of water quality stress during the warm season:

- Spring Peak (May): Widespread algal bloom (High NDCI/High NDTI) with evidence of surface scum formation (Low NDWI/Red).
- Summer/Fall Persistence (July-Oct): The overall NDTI-measured turbidity improves, but the NDCI (chlorophyll) remains intensely high, and the NDWI continues to show Red/Orange surface scums around the perimeter. This suggests the high biomass shifts from a

widespread event to a chronic, highly concentrated shoreline and shallow-water problem fueled by persistent nutrient availability.

3. Chronic Edge/Shallow Issues: The Red/Orange (surface scum) zones in the NDWI maps consistently persist in the shallow nearshore areas and small bays throughout the entire May-to-November period, underscoring the continuous vulnerability of these zones to nutrient loading and highly concentrated blooms. This needs further investigation as the analysis may have included some vegetation on the non-water side.

4. Temperature as the Ultimate Controller: All three indices show the most significant improvement and best water quality when water temperatures drop in late October and November, confirming that temperature remains the ultimate control over the severity of the lake's biological activity.

The indices collectively demonstrate that while the lake's clarity recovers quickly after the initial spring bloom, algal biomass and the formation of dense surface scums are severe and chronic problems throughout the majority of the open-water season (May through early November). Further investigations and analyses are needed to verify these findings.

APPENDIX B: Ending Swan Lake's Stormwater Management Role

1) Why High Levels of Chloride Matter

Swan Lake is a former gravel quarry with no natural surface level inflows nor outflows but there are six stormwater sources that direct almost three tonnes of chloride each year into the lake. In 2025, there were 17.4 tonnes of chloride in Swan Lake.

Chloride does not break down and will accumulate within the lake over time, impairing the health of aquatic plants and many forms of aquatic species.

The Federal government's Canadian Water Quality Guidelines ("CWQG") for chloride were established based on the sensitivity of 28 different species to chloride levels. Current levels of 200 mg/L of chloride in Swan Lake are well in excess of a safe environment for most of the species, including zooplankton, on which the federal guidelines were based.

Zooplankton is a beneficial element in freshwater because it consumes phytoplankton (microscopic algae and microbes).

A healthy zooplankton colony would be an important contributor to controlling algal growth, but the high level of chloride is undermining the existence of zooplankton in Swan Lake.

Research by McClymont[1] concludes that the CWQ Guidelines are too high to adequately protect zooplankton communities. The study's findings were that "At the CWQG (120 mg Cl/L), zooplankton abundances and biomasses were reduced by 30% - 77% …" and notes that other studies have associated low zooplankton levels with increased phytoplankton abundance and increased frequency of harmful algal blooms and the risk of cyanobacteria.

In 2018, several Canadian environmental associations asked the Ontario government to create an Ontario water quality guideline for chlorides to address the shortcomings of the Federal guidelines.

In their report, R. J. Burnside[(e)] notes that Zooplankton, especially Daphnia app, are the dominant grazers of phytoplankton in temperate waters like Swan Lake however current levels of chloride are above the chronic exposure range for some Daphnia species. In 2020, a researcher from Queens University came to Swan Lake to take samples of Daphnia but was unable to detect any.

[1] The Effects of Increasing Chloride Concentration and Temperatures on Freshwater Zooplankton Communities, A.C. McClymont, Queen's University, 2020

Burnside notes that it is possible to stock zooplankton species but recommends that an inventory first be taken to determine which species have survived in Swan Lake before undertaking a stocking program.

Other studies suggest high chloride levels can lead to lower oxygen levels by diminishing aquatic plant life. Controlling oxygen and chloride levels opens up more natural biomanipulation options for the management of water quality in Swan Lake.

In their study of the water quality issues in Lake Wilcox in Richmond Hill Ontario, University of Waterloo researchers[2]identified chloride as one of the factors contributing to the release of nutrients from the sediment.

A successful rehabilitation plan requires addressing the chloride levels with the goal of restoring a healthy zooplankton community

2) Sources of Chloride

In November 2025, Markham released the Swan Lake Water and Chloride Budget[(c)] which estimated the annual inflow of chloride for the 3-year period 2022 – 2024 from the six sources averaged 2.95 tonnes per year.

In March 2025, Markham released the Flow Diversion Assessment report[(b)] by AECOM that estimated the volumes of stormwater entering the lake from three Oil Grit Separators ("OGS") and from three inlets carrying stormwater that bypasses the two stormwater ponds.

3) Eliminating Chloride Inflows

The Flow Diversion Assessment outlined options for reducing the stormwater inflows. Approximately 85% of the chloride entering Swan Lake could be eliminated for a cost of $2.16 million.

- The three Oil Grit separators account for 56% of the chloride entering the lake. These inflows could be eliminated by rerouting the flows at a cost of $2.03 million.
- The remaining 44% of chloride enters the lake in stormwater that bypasses the stormwater ponds and could be reduced by 66% at a cost of $125,000.

[2] Salination as a Driver of Eutrophication Symptoms in an Urban lake, Jovanna Radosavljevic et al, July 18, 2022

FOSLP estimates that the costs of rerouting the OGS flows could be reduced by 50% by using a "Parkland Route", an alternative not considered in the Flow Diversion Assessment.

A Parkland Route would reduce costs in three ways:

1) Leaving the existing OGS units intact would avoid the replacement costs for the OGS units. Outflows from the existing units would be directed into new stormwater pipes along the shoreline.(Savings $50,612)
2) There are no utilities in the park so utility reconnection costs would be avoided. (Savings $101,225)
3) Roadway restoration costs (300 m) are avoided in the Amica and Traffic Circle areas. Some costs would be required to restore pathways in the park. (Savings up to $727,909)

The Flow Diversion Study recognized a parkland route for the Swan Club OGS at an estimated cost of $275,072 but included $40,584 for restoring utilities and for catch basin replacements – costs which may be avoided.

Costs Savings Using Parlkand to Reroute OGS Units

Cost Estimate	S3: Amica & TC OGS To Lake Outlet Roadway Route		S3: Parkland Route	S4: Swan Club OGS to North Pond		Combined Parkland
Supply & Install Stormsewers	674,830	38%	674,830	180,375	66%	
Supply & Install Maintenance Holes	202,449	12%	202,449	54,113	20%	
Sewer Replacement Cost	**877,279**	**50%**	**877,279**	**234,488**	**85%**	**1,111,767**
Allowance for catchbasin replacements	50,612	3%		13,528	5%	
Utility Reconnection	101,225	6%		27,056	10%	
Restoration of Roadway	727,909	41%		-	0%	
Total Costs	**1,757,025**	**100%**		**275,072**	**16%**	

FOSLP estimates the costs of a Parkland Route to eliminate OGS flows to be closer to $1.1 million. We request that Markham undertake an assessment of the feasibility of a Parkland Route and a revised estimate of the costs.

Estimates of Rerouting OGS Flows

	Flow Diversion Report	FOSLP Parkland Estimate	Potential Savings	
Amica & Traffic Circle OGS (S3)	1,757,925	877,279	880,646	50%
Swan Club OGS (S4)	275,072	234,488	40,584	15%
Total	**$2,032,997**	**$1,111,767**	**$921,230**	**45%**

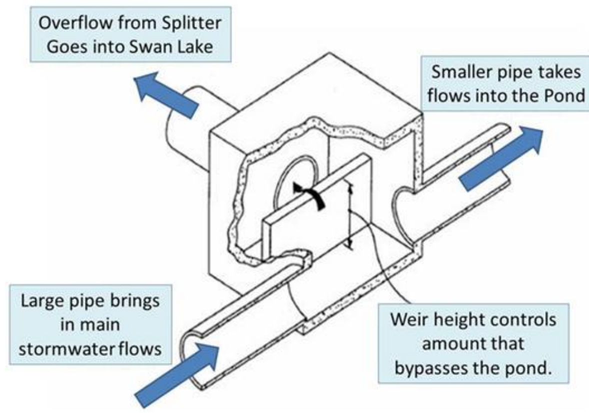
4) Reducing Flows Bypassing the Stormwater Ponds

Stormwater flows from the adjacent residential areas are directed through large stormwater pipes to one of two retention stormwater ponds. Before entering the ponds, the flows go into a "splitter".

The splitters installed at each pond contribute in two ways:

1) Under normal rainfall conditions, the splitters direct stormwater runoff directly to the pond but during large rain events some of the runoff is directed into Swan Lake.
2) As the ponds approach the limit of their storage capacity, the splitters serve to direct overflow from the ponds into the lake.

The splitters consist of a two-part chamber with a dividing wall called a "weir". The initial flows enter one chamber in the splitter and exit through a smaller pipe connected directly to the pond. Once the inlet chamber within the splitter is at capacity, the excess stormwater will go over the weir and flow directly into Swan Lake, bypassing the pond.



The amount of water bypassing the splitters can be reduced by two adjustments:

1) Increasing the height of the weir within each splitter.
2) By increasing the size of the pipe taking water from the splitter into the pond.

The impact would be to keep more of the routine rainfall events within the stormwater pond system, therefore minimizing chloride contaminated spring runoff volumes flowing into the lake. The Flow Diversion Study estimates that 66% of the stormwater flows and thus 66% of the chloride bypassing the ponds bypassing can be eliminated for a cost of $125,000 resulting in a reduction of 29% in the total chloride entering the lake.

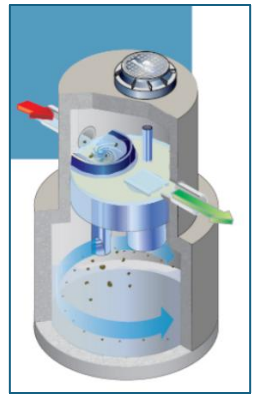
The ponds are currently under the control of the original developer. Markham is in discussions with the developer about assuming responsibility for the ponds. The alterations to the splitter could be undertaken during the pond cleaning and hand-over process or once Markham has assumed control of the ponds.

We estimate that the combined costs of a Parkland Route and alterations to the flow splitters would cost $1,236,554 and reduce inflows by 85% and encourage Markham to implement a program to end Swan Lake's stormwater role – essential to the rehabilitation of the lake.

Chloride Estimates 2022 - 2024 (Markham Nov. 2025)			**Annual Chloride**	**Flow Reduction**	**Chloride Reduction**	**% Total**	**Parkland Route**	**Cost per Tonne**
	Summary of Best Options		**(t/yr)**		**(t/yr)**			
S3	Amica & TC OGS	Reroute to lake outlet	1.41	100%	1.41	48%	$ 877,279	$ 622,184
S4	Swan Club OGS	Reroute to North Pond	0.25	100%	0.25	8%	$ 234,488	$ 937,952
S5(b)	East Pond (2 Inlets)	Raise Weir/Enlarge Pipe	0.91	67%	0.61	21%	$ 84,315	$ 137,670
S5(b)	North Pond (1 Inlet)	Raise Weir/Enlarge Pipe	0.38	65%	0.25	8%	$ 40,472	$ 163,021
			2.95		**2.52**	**85%**	**$ 1,236,554**	**$ 490,558**

5) Biochar Filtration

Researchers from York University have completed a lab test of using Biochar to remove chloride and nutrients from samples of water from Swan Lake and are prepared to undertake a field test of the use of Biochar to remove chloride.



The existing Imbrium Stormceptor OGS units installed at Swan Lake are 25 years old. They remove heavy contaminants from the stormwater but do not have the capability to remove chloride or most contaminants absorbed in the water.

There are now newer OGS units with advanced filtration capabilities available that can remove many more contaminants, but according to a representative from Imbrium there is no effective filtration mechanism currently on the market that can remove chloride.

a) Filtration of OGS Stormwater Flows

Flows from the three Stormceptor oil grit separators release directly into the lake. Keeping the OGS units in place serves an important function by removing the heavy contaminants that would clog the filtrate. The goal is to capture flows from the OGS units and filter the flows before they enter the lake.

The lake is regulated to a depth of 208.3 m above sea level. The filtration process requires a vertical drop of the stormwater through the filtrate.

OGS Unit	Elevation	Above Lake
Amica	208.23	-0.09
Traffic Circle	208.25	-0.05
Swan Club	208.94	0.64

Only the Swan Club OGS unit appears to have the elevation needed to support a filtration chamber. Markham has estimated that the Swan Club OGS unit attributes on average 0.25 tonnes per year, or 8% of the total entering the lake.

Swan Club OGS Outlet

There are two options for the reducing inflows for the Swan Club OGS unit:

a) Reroute flows to the North Pond at cost of $234,468 - $275,072
b) Adding a Biochar filtering processes between the OGS unit and the lake to capture the chloride before it enters the lake

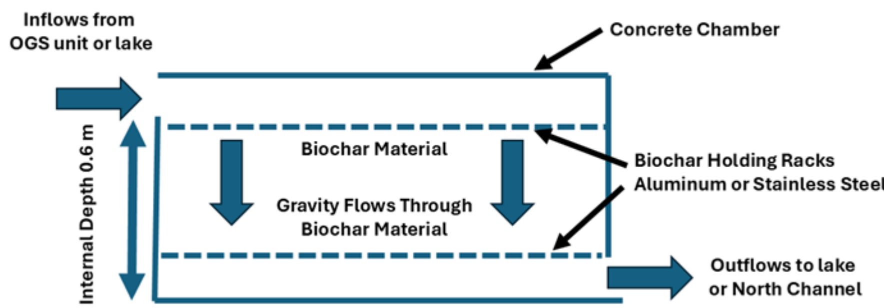
b) Filtration of Chloride Already in the Lake

The second application of the Biochar filtration process would be to add a filtration unit as part of the process of recycling water through the North Channel. This would remove chloride, phosphorus and nitrogen from the lake water.

Water from the lake would initially be pumped into the filtration unit and then flow out to the North Channel.

A similar structure could be installed to filter flows from the Swan Club OGS unit.

Swan Lake Biochar Filtration Chamber



APPENDIX C: Comprehensive Oxygenation Program for Swan Lake

In its report[g] on oxygenation options for Swan Lake, Natural Resource Solutions Inc. ("NRSI") outlined the potential benefits of a comprehensive oxygenation process for Swan Lake.

NRSI noted that oxygenation represents a viable and effective approach to improving surface water quality and aquatic habitat conditions within Swan Lake. When paired with watershed- level nutrient management and ecological restoration efforts, these systems can form the foundation of a long-term strategy to enhance aquatic health, reduce eutrophication, and restore more natural lake function.

NRSI concluded that increased oxygenation in shallow, nutrient-rich systems such as Swan Lake can lead to significant improvements, including:

- Reduced internal nutrient loading and phosphorus release from sediments.
- Decreased bioavailability of heavy metals through oxidation.
- Improved surface water clarity and reduced frequency of harmful algal blooms.
- Enhanced biological diversity and productivity through improved aerobic habitat conditions.

Within Swan Lake, NRSI stated that any management approach intended to increase Dissolved Oxygen ("DO") concentrations must be designed not only to address existing DO deficiencies but also anticipate increases in biological oxygen demand (BOD) that will result from enhanced biological and microbial activity following oxygenation.

NRSI outlined key factors to consider in the design of a comprehensive oxygenation system:

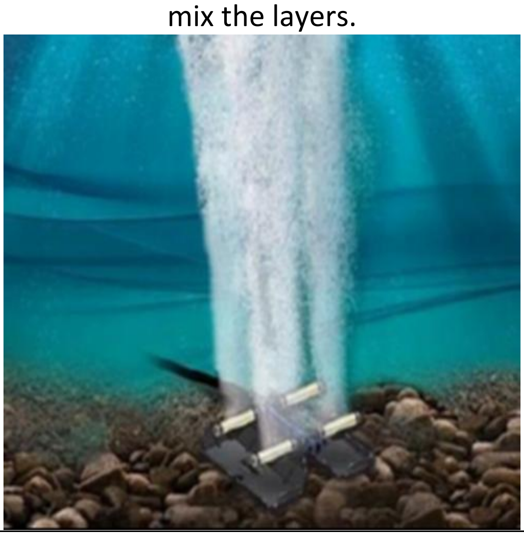
- **System Design**: System layout should provide full spatial coverage, including deeper basins and areas of low circulation, while avoiding disturbance of fine, nutrient-rich sediments.
- **Uniform Application**: Oxygenation should be applied uniformly across the lake to prevent the formation of localized hypoxic or anoxic zones.
- **Continuous Operation**: Consistent, low-intensity operation is preferable to intermittent high-output cycles, as sudden fluctuations in DO can destabilize the system and increase BOD demand.

Based on NRSI's guidance, FOSLP is recommending a comprehensive oxygenation system containing four components that will incorporate the critical design recommendations.

Four Components	**Benefits**
1) Recycling Lake Water Through the North Channel	a) Oxygen added through the North Channel b) Potential to add filtration mechanism using Biochar or Chlorocel in the North Channel to remove nutrients and chloride.
2) 1 – 2 Aeration units near the deeper areas in the lake	a) Primary source for new oxygen b) Mixing of the layers locally
3) Circulation throughout the lake created by North Channel recycling	a) Disperses oxygen from the aeration units b) Mixes layers within the lake

4) Fountain Near the Dock	c) Adds oxygen in an area not likely impacted by North Channel circulation d) Returns a popular lake amenity

Examples of Aeration Options

Bubblers	**Solar Bee® Lake Circulators**
Bubblers add oxygen and will mix the layers. 	Active lake circulation can be limited to only the top layer or to treat the bottom water. 

The units would be operational consistently from April through November powered by the new solar panel complex on the Amica shoreline and repurposed windmill.

Solar Panel Units Powering Ultrasound Devices	Existing Windmill
	

Recycling through the North Channel

The North Channel, about 100 metres long, is designed as an emergency spillway for overflow from the north stormwater pond (SWP #104); however, it has rarely been used. The channel is typically dry, though during wet periods it will hold water from the runoff from the surrounding parkland.

Removing water from the lake and returning it through the North Channel to the lake oxygen enhanced with possibly fewer nutrients could provide a natural enhancement to the water quality in the lake and reduce the dependency on future chemical treatments. A small portion of the channel is a bioswale which it may be possible to extend. It also may be feasible to circulate water from the lake into Turtle Inlet, creating a decorative waterfall. Turtle Inlet is a small, shallow inlet that has potential to be enhanced as a bioswale.

Pumping Options

It is essential to clarify the primary objectives of recycling water via the North Channel and Turtle Inlet:

a. If the emphasis is primarily oxygenation of the lake, then a high-volume pump may be required.
b. If the emphasis is a combination of filtration and oxygenation, then pumping lower volumes in line with the capabilities of the filtration process will be needed.
c. If the bioswale is the primary tool for filtration then very low flow rates may be required.

Swan Lake contains approximately 80,000 m^3 of water. To recycle that volume over the 7-month period from April – October period would require a pump capable of pumping 360 m^3 /24 hour.

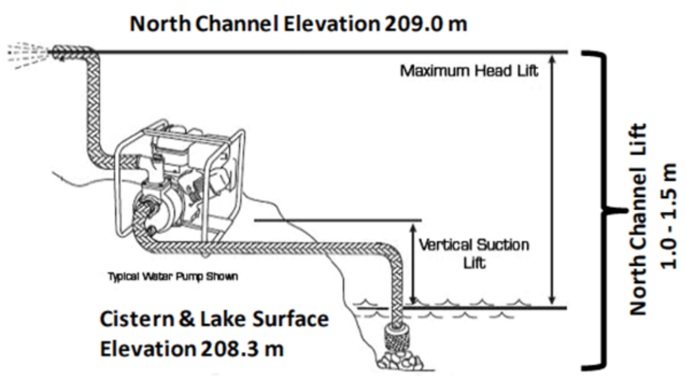
A small "cottage" style pump (1.0 – 1.5 hp), connected to a continuous power source, could recycle 13% - 54% of the lake water through the North Channel.

Driven by either solar sources or by repurposing the existing windmill on the north pond, assuming 50% efficiency, the small pumps would have the capability to recycle 7% - 27% of the 80,000 m^3 of lake water over the summer months which may be sufficient for a filtration process.

Greater lake circulation and improved levels of oxygenation could be achieved if industrial scale pumps, such as those used by Markham's stormwater management department, were deployed. With more powerful pumps, it may be possible to recycle more than 100% of the lake water through the North Channel each season.

To reduce the energy required for the pumps it may be feasible to create cisterns at the start of the North Channel and near Turtle Inlet. The distance from the edge of the lake to the North Channel or Turtle Inlet is approximately 50 - 100 m. A downward sloping pipe from the lake to the cistern could provide a gravity-fed mechanism for getting lake water to the North Channel or Turtle Inlet without pumping. Water in the cistern will rise to the level of the lake water. Pumps would be required to raise the water from the cistern to the North Channel or to a waterfall.

It may be possible to install a filtering process as the lake water enters the cistern.



The eastern end of the North Channel is at an elevation of 209.0 m. or 0.7 m. above the regulated lake level.

Depending on the location of the intake head within the cistern, the maximum head lift height to the North Channel surface is expected to be 1.0 – 1.5 m.

Creation of a decorative waterfall into Turtle Inlet may provided a means for increasing oxygenation content and could be accomplished by pumping the water 5 m higher to approximately 214.0 m.

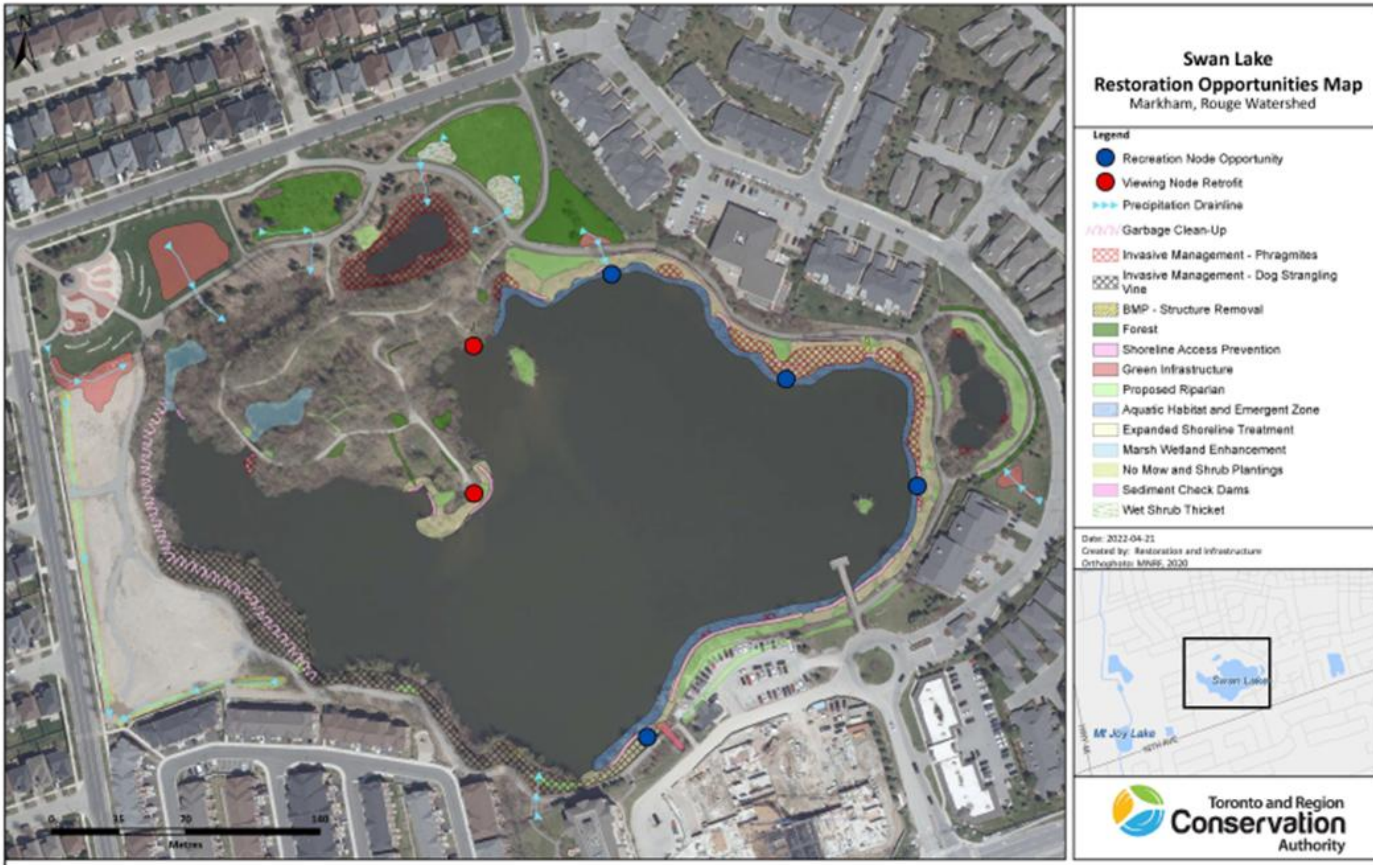
Regulating Rates of Flow To Minimize Disruption of Sediments

In discussions during Phase 1, concern had been raised that circulation through the lake would stir up the sediments, causing the release of more nutrients from the sediments and increasing turbidity. Any potential impact of flows disrupting sediments can be minimized in two ways:

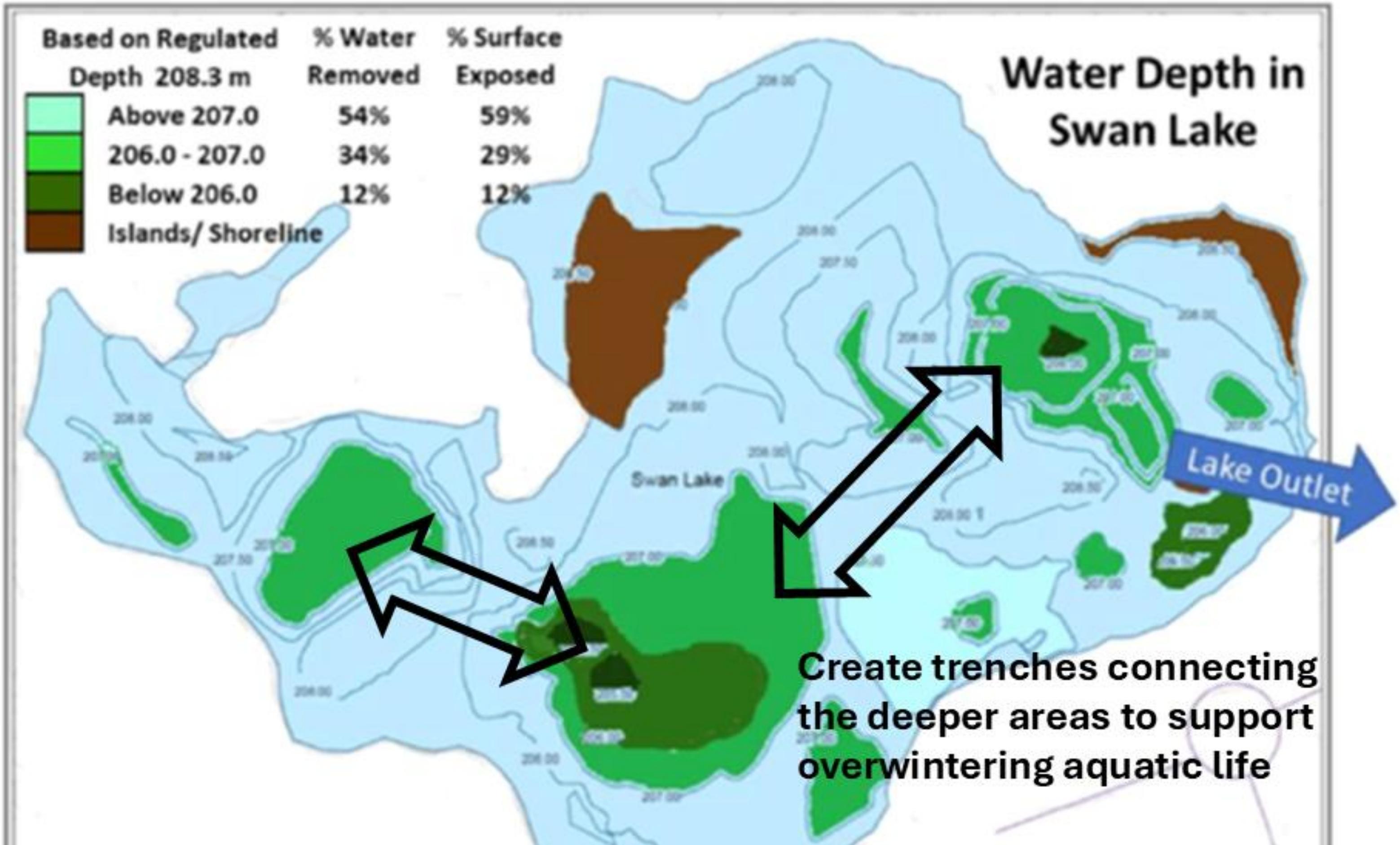
1) By dispersing the inflow sources. Water can be picked up in 2-3 different locations in the north-east area of the lake, dispersing the inflow.
2) The rate of flow through the North Channel can be regulated by the pumping actions. In the initial year of operation, a low rate of flow to would minimize any possible disruption. The flow action may initially alter the pattern of the sediments. Flow rates can be increased in subsequent periods based on any observed impact on turbidity.

Swan Lake Water Quality Review: Submission by FOSLP

APPENDIX D: TRCA Swan Lake Restoration Opportunities (April 2020)



APPENDIX E: Creating Overwintering Haven for Aquatic Species



Lake Parameters	Surface Area	Volume of Water
Maximum Elevation 209.2 m	5.48 ha (13.5 acres)	102,000 m3
Regulated Elevation 208.3 m	4.84 ha (11.9 acres)	80,000 m3

Swan Lake Water Quality Review: Submission by FOSLP

APPENDIX F: 2021 Cost Estimates for Long-term Water Quality Plan

The 2021 Long-term Plan estimated the costs for water quality rehabilitation over the next 25 years at $4.9 million plus $541,000 for maintenance of the stormwater ponds and provides an outline of potential additional costs related to rerouting stormwater flows and addressing potential issues related to former dump sites. The original estimates do not include costs for an oxygenation program, creating a trench to connect the deeper areas of the lake, restoring the shoreline nor shoreline amenities.

Stormwater Management Costs

Finding a cost-effective approach for reducing stormwater inflows is an essential component of a restoration program. The March 2025 Flow Diversion Assessment estimated that substantially all of the stormwater flows could be eliminated for a cost of $2.2 million. FOSLP has estimated costs at $1.25 million using a lower cost parkland route. The original plan had provided an estimate of $5 million.

Potential Dump Site Related Costs

The plan has indicated that costs for addressing groundwater issues could be in the range of $2.0 - $10.0 million. Development of a comprehensive plan for restoration should endeavour to minimize or avoid issues that may trigger costs related to the former dump sites. No issues related to the dump sites was reported during Phase 1.

2021 Long-term Plan Cost Estimates for Rehabilitation (25 Years)

	Phase 1	Phase 2	Phase 3	Total
Years	**1 - 5**	**6 - 10**	**11 - 25**	
Core Measures				
Water Quality Monitoring	149,356	164,901	605,013	919,270
Geese Management	275,037	383,582	1,407,339	2,065,958
Remove Benthic-dwelling fish	38,608	28,165	103,336	170,109
Chemical Treatment	309,181	261,141	806,227	1,376,549
Evaluate measures	25,000	27,602	33,647	86,249
Total Core Measures	**797,182**	**865,391**	**2,955,562**	**4,618,135**
Accelerated Measures (a)				
Fish Management Plan and Fish Stocking (2)	20,000			20,000
Planting of submerged plants (2)	20,000			20,000
New technologies for chloride treatment (2)	50,000			50,000
Evaluate structural modifications (3)	200,000			200,000
Core and Accelerated Measures	**$1,087,182**	**$ 865,391**	**$ 2,955,562**	**$4,908,135**
Ultrasound Panels (Additonal Activity) (Est.)	40,000			
Stormwater Maintenance	4,591	8,282	528,374	541,247
Estimate of Additional Alternative Measures				
Implement structural modifications (b)			$ 5,000,000	
Sediment Removal(c)			$ 30,000,000	
Investigate dumping areas			$ 20,000	
Investigate groundwater			$ 200,000	
Control groundwater loading		$2,000,000 -	$ 10,000,000	

Notes: (a) Accelerated Measures (2) Originally Phase 2 (3) Originally Phase 3
(b) Flow Diversion Study estimates stormwater can be rerouted for $2.125 million
(c) FOSLP May 2023 report estimated of $1.5 - $6.0 million for sediment removal.