Environmental Services

Swan Lake Long-Term Management Plan Phase 2

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Markham Environmental Services

Executive Summary

Background

Swan Lake is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road. Swan Lake has an approximate area of 5.3 ha and a maximum water depth of 4.0 m from the edge of the Lake at 209 meters above sea level (masl). At an average elevation of about 208.2 masl (estimated or measured over the last decade), the lake maximum depth is 3.2 m and surface area is about 3.9 ha.

A gravel pit in the 1960s and 1970s, Swan Lake is currently a community feature with multiple trails and urban development surrounding it.

Several issues were discovered with Swan Lake in 2010, including high phosphorus levels and significant algal blooms during the summer months, which led to low oxygen levels and degraded fish habitats. A Phoslock treatment was administered in 2013 to reduce the phosphorus levels and algal blooms in Swan Lake.

In 2019, the City of Markham conducted a study to define a Water Quality Management Strategy for Swan Lake. The Strategy, finalized in July 2020, recommended a chemical treatment in 2021. In August 2021, 13 tonnes of Poly Aluminum Chloride (PAC) were applied to the Lake in a controlled manner over several days.

The Swan Lake Long-Term Management Plan, which was developed based on the 2019 Strategy and extensive consultation with stakeholders, was received by the Markham Sub Committee in November 2021 and approved by the Council in December 2021. It described a phased adaptive approach, including Core, Complementary and Alternative measures, and periodic reviews to adapt the Plan to the Lake conditions.

During 2021-2025, Core measures from Phase 1 and some Complementary and Alternative measures from Phase 2 and Phase 3 of the plan were implemented in an adaptive manner to improve the Lake water quality.

This report provides an update to the Swan Lake Long-Term Management Plan based on an assessment of the effectiveness of measures already implemented, and evaluating other lake management measures to further enhance water quality. This plan is an important step in ensuring the long-term sustainability of Swan Lake as a valued recreational and ecological asset for the community.

Summary of Management Outcomes (2021-2025)

Management actions implemented since 2021 have been highly effective, with all primary interim targets achieved or exceeded. Observed responses align closely with predictions, particularly with respect to the dominant role of internal phosphorus loading and the effectiveness of chemical treatment. Improvements in dissolved oxygen conditions and the establishment of submerged aquatic vegetation (SAV) further confirm that internal loading has been effectively controlled and that key ecological feedbacks are now supporting improved lake function.

Swan Lake has transitioned from a highly eutrophic, internally driven system to a more stable condition in which water quality is governed primarily by external inputs.

Monitoring data and updated modelling indicate that water quality improvements have met or exceeded the interim targets established in the 2021 Plan.

Issues and Opportunities

Through the review of Swan Lake conditions over time and the characteristics of the contributing catchment, a number of issues and opportunities were identified that will drive any rehabilitation options for Phase 2 (2026-2030), as follows:

- Swan Lake is not a natural feature, and water does not enter and exit the system like in most natural systems. Contaminants that enter the system build up over time, leading to poor water quality.
- The land use surrounding Swan Lake has changed significantly over the past 30 years. Starting as farmlands, it has changed to a residential community, including a gated community and senior housing development. Major land use types include community/ infrastructure (75 %) open water, including the Lake (15%) and tree canopy or parks (10 %).
- Average contributions from different sources of water to the Lake include direct precipitation (47%), direct runoff (4%), and controlled runoff (49%). Due to scarcity of data, groundwater has not been quantified independently and rather calculated as the balance of other measured or estimated inflows and outflows.
- Two stormwater ponds and three oil and grit separators (OGS) collect and treat runoff from 80% of the catchment.
- The City owns most of the Lake except for a small portion in the south.
- The two stormwater ponds and two OGS units are owned and maintained by the developers. Storm sewer lines within the catchment are owned by the City and the private condominium corporation. The Region of York owns the 16th Avenue sewer line.
- Winter maintenance of 1 km (15%) of the catchment roads and sidewalks is completed by the City of Markham, and the remaining roads, as well as about 3600 m2 of parking areas, are serviced privately.
- Internal phosphorus loading, historically the dominant source of nutrients to the lake, has been effectively controlled following in-lake treatment and is now negligible.
- External phosphorus inputs, including contributions from stormwater runoff and waterfowl, now represent the primary sources influencing lake water quality.
- Dissolved oxygen conditions have improved substantially, meeting guidelines for aquatic life and limiting internal phosphorus release potential from sediments.
- Submerged aquatic vegetation (SAV) has become established under recent conditions, representing a significant ecological shift toward a more stable, clear-water state.
- While water quality has improved significantly, the lake remains sensitive to external inputs and ongoing watershed influences.
- Chloride concentrations have declined substantially from historical levels but remain governed by external loading associated with road salt use and watershed processes.
- Groundwater contributions to water and chloride balance remain uncertain and may influence long-term system response.
- Stormwater infrastructure performance and maintenance continue to play an important role in controlling water and contaminant inputs to the lake.
- Climate variability, including warmer temperatures and altered runoff patterns, may influence future nutrient and chloride dynamics and water quality.

- The fish community remains simplified, and ongoing management is required to support ecological balance.
- Swan Lake continues to provide important recreational, aesthetic, and ecological value, with strong community interest in maintaining and improving lake conditions.

Multiple management measures were developed in consultation with stakeholders and evaluated to address each of the identified issues. Each optional measure was evaluated for technical feasibility and effectiveness (water quality), maintenance and operation needs terrestrial and aquatic environment, construction impacts, public safety, the cost to the City, and community benefits/impacts.

The residents of Swan Lake Village have been very involved in making observations about the Lake conditions, and have pursued a number of initiatives and provided the City with several reports and presentations. All information and input provided have been thoroughly considered in the updates of this plan.

Goal Statement

The City of Markham's Strategic Plan and the Greenprint Plan aim at building a safe, sustainable, and complete community through protecting and enhancing the natural environment and built form. A goal statement has been defined accordingly for Swan Lake, as follows:

To improve the overall health of Swan Lake, which will provide opportunities for no-contact activities for the enjoyment of the community.

This goal statement is supported by a series of numerical guidelines as interim targets, updated for Phase 2 (2026-2030). The guidelines are as follows:

Parameter	Current Values	Interim Target	Objective and Rationale
Total phosphorus (µg/L)	<20	≤20 (<30 for single events)	Aligns with the Provincial Water Quality Objective (20 µg/L) as a benchmark and reflects current observed conditions. The target is intended to maintain current conditions, recognizing that only modest further reductions may be achievable or warranted.
Secchi Transparency (m)	~0.6–0.8	≥0.6	Represents sufficient light availability to support establishment and persistence of submerged aquatic vegetation (SAV). At current nutrient levels, Secchi is influenced by multiple factors and is no longer a reliable surrogate for phosphorus.
Chloride Concentration (mg/L)	~200 (2024–2025 average)	200–400	Reflects substantial improvement from historical conditions (>700 mg/L). Target maintains concentrations below levels associated with increased ecological risk while recognizing constraints from ongoing road salt use, background concentrations, and potential groundwater inputs.
Frequency of algae blooms	Periodic blooms; densities near guideline thresholds	Reduced frequency, duration, and severity; generally, ≤50,000 cells/mL	Based on Health Canada recreational guidance for primary contact use. Target supports reduced health risk and improved conditions while recognizing that blooms may still occur under certain conditions. Focus is on long-term system response rather than elimination.
Internal phosphorus load (kg/yr)	~0	≈0 (negligible)	Internal loading has been effectively controlled following treatment and is no longer a dominant source. Maintaining negligible internal loading is critical to sustaining current lake conditions.
External phosphorus load (kg/yr)	9–17	≤12–15	External inputs now control lake phosphorus concentrations. Target reflects recent post-treatment conditions with an allowance for variability in flow. Continued BMP implementation is required to maintain gains and limit increases during higher-flow years.

Recommended Strategy

Based on the evaluation of management outcomes (2021–2025) and additional measures, a phased approach is recommended for Swan Lake. This strategy follows an adaptive management approach, through which management activities will be adjusted to maximize benefits and minimize impacts. The phased approach includes the following components:

Phase 1 (2021-2025): Core Measures - Completed:

a) Continue water quality monitoring and report on quality annually through Markham Subcommittee
b) Continue geese management and explore enhanced methods
c) Remove benthic-dwelling fish
d) Maintenance of stormwater management facilities (by developers then City)
e) Community engagement in reducing nutrient and chloride, data sharing, as well as progress reviews and plan updates
f) Chemical treatment in 2021 and 2024
g) Shoreline planting/improvements
h) Chemical oxygenation pilot project (by research institute) – not pursued

i) Evaluate Phase 1 measures

In Phase 1, several Complementary and Core measures that were identified for Phase 2 and Phase 3 were advanced, including:

- Fish stocking
- Planting of submerged plants
- New technologies for chloride (biochar research by York U)
- Flow diversion assessment

In Phase 1, several additional Complementary Measures were identified and implemented including:

- Ultrasound for algae control
- Water and chloride budget
- Submerged aquatic plant survey

Phase 2 (2026-2030): Adapted Core Measures and Complementary Measures:

j) Items a) to e) in Phase 1
k) Chemical treatment with adjusted frequency and dosage
l) Fish management plan and fish stocking
m) New technologies for chloride treatment (complete research by York U and evaluate chloride uptake by halophytes)
n) Lake sediment survey
o) Targeted groundwater flow and chloride monitoring
p) Shoreline plantings/improvements
q) Submerged aquatic plant survey
r) Ultrasound for algae control
s) Evaluate Phase 2 measures

Phase 3 (post 2030): Adapted Core Measures with or without Alternative Measures

t) Items j) to k) in Phase 2 with modifications if required
u) Investigate contribution from groundwater, if required
v) Evaluate/design structural modifications such as lake water recirculation and stormwater redirection, if required

At the end of Phase 2, a 5-year summary report will be completed, summarizing the effectiveness of the Adapted Core measures and evaluating additional Complementary measures to consider in Phase 3. Additional Complementary measures will be advanced based on needs to further improve water quality and considering the technical feasibility and cost-effectiveness of additional measures.

The total cost for implementing Core and Complementary measures for the next 25 years as per the recommended plan, is about $5,584,000 (including pond cleanout), funded from the Environmental Services lifecycle. Implementing all measures, including the Alternative Measures, would cost about 8.7 to 2.6 million dollars (depending on the flow diversion scenario, and the extent of groundwater remediation work).

Glossary of Terms

BMP	Best Management Practices
CCME	Canadian Council of Ministers of the Environment
DFO	Department of Fisheries / Fisheries and Ocean Canada
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DW	Dry Weight
ECA	Environmental Compliance Application
FDC	Foundation Drain Collection
FOSLP	Friends of Swan Lake Park
GIS	Geographic Information System
GLISA	Great Lakes Integrated Sciences + Assessments
LED	Light Emitting Diode
LMP	Long-Term Management Plan
LOI	Loss of Ignition
MASL	Meter Above Sea Level
MDL	Method Detection Limit
MECP	Ministry of Environment, Conservation, and Parks
MNDMNRF	Ministry of Northern Development, Mines, Natural Resources and Forestry
MNR(F)	Ministry of Natural Resources (and Forestry)
MOE(E)	Ministry of Environment (and Energy)
OGS	Oil and Grit Separators
OMNRF	Ontario Ministry of Natural Resources and Forestry
PAC	Poly Aluminum Chloride
REE	Rare Earth Elements
SAV	Submerged Aquatic Vegetation
TBD	To be Determined
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TRCA	Toronto and Region Conservation Authority
US EPA	United States Environmental Protection Agency
VAC	(Swan Lake) Village Amenities Committee
WHO	World Health Organization

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1. Introduction

1.1 Background

Swan Lake is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road. Swan Lake has an approximate area of 5.3 ha and a maximum water depth of 4.0 m (from the deepest point at 205.0 to the Lake edges at 209 meters above sea level). At an average elevation of about 208.2 masl (estimated or measured over the last decade), the lake maximum depth is 3.2 m and surface area is about 3.9 ha.

Formerly a gravel pit in the 1960s and 1970s, Swan Lake is currently a community feature with multiple trails and urban development.

Several issues were discovered with Swan Lake in 2010, including high phosphorus levels and significant algal blooms during the summer months, which led to low oxygen levels and degraded fish habitats. A Phoslock treatment was administered in 2013 to reduce the phosphorus levels and algal blooms in Swan Lake.

In 2019, the City of Markham conducted a study to define a Water Quality Management Strategy for Swan Lake (Freshwater Research 2020). The Strategy, which was finalized in July 2020, recommended chemical treatment starting in 2021. In August 2021, 13 tonnes of PAC were applied to the Lake in a controlled manner over several days.

The Swan Lake Long-Term Management Plan, LMP or the Plan (City of Markham, 2021), which was developed based on the 2019 Strategy (Freshwater Research, July 2020) and extensive consultation with stakeholders, was received by Markham Sub Committee in November 2021 and approved by the Council in December 2021. The Plan described a phased adaptive approach, including Core, Complementary and Alternative measures, and periodic reviews to adapt the Plan to the Lake conditions.

During 2021-2025, Core measures from Phase 1 and some Complementary and Alternative measures from Phase 2 and Phase 3 of the Plan were implemented in an adaptive manner to improve the Lake water quality.

1.2 Purpose

This report provides an update to the Swan Lake Long-Term Management Plan. based on an assessment of the effectiveness of measures already implemented, and evaluating other lake management measures to further enhance water quality. This plan is an important step in ensuring the long-term sustainability of Swan Lake as a valued recreational and ecological asset for the community.

2. Overview of Swan Lake

2.1 Swan Lake Catchment

Swan Lake (the Lake) is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road, as shown below in Figure 1. Swan Lake is located within the Rouge Watershed, which is described as an extraordinary resource in Southern Ontario (Toronto and Region Conservation Authority, 2007). A map of the Lake catchment area is provided in Figure 2.

2.1.1 Climate

The Rouge watershed experiences a continental climate moderated by the Great Lakes. The area is influenced by warm, moist air masses from the south and cold, dry masses from the north (Toronto and Region Conservation Authority, 2007). In an average year, precipitation in the watershed ranges from 700 to 1000 mm. York Region has historically experienced an average total annual precipitation of about 850 mm. Mean annual evapotranspiration is about 500 mm per year, with the highest values occurring during the summer months (June, July, and August).

Global climate change will affect the watershed, along with all the watersheds in York Region. Climate change models differ as to how these changes will manifest during any given year; however, it is expected that the climate of southern Ontario will become warmer, wetter, and more unpredictable with greater variations and increases in extreme weather. These changes may result in changes throughout an ecosystem, such as impacts on water balance, water availability, groundwater levels, streamflow, channel and stream bank stability, surface water quality, and terrestrial and aquatic habitats (Toronto and Region Conservation Authority, 2007).

According to climate models for York Region (Ontario Climate Consortium, GLISA and Clean Air Partnership, 2016), temperatures are very likely to increase in all seasons and on average for the year. While the range in average monthly temperatures is not expected to change significantly, it is very likely average temperatures will increase in all months and seasons (by 3.3 °C on average across seasons). Winter and summer months will likely experience more warming than those in fall and spring by the 2050s. Warmer winter temperatures lead to more precipitation falling as rain instead of snow in York Region and increase the number of winter runoff events from melting snow and ice.

2.1.2 Land Cover and Land Use

Swan Lake's catchment covers an area of about 42.9 ha, with major land use types being community/ infrastructure (75 %), open water including the Lake (15%), and tree canopy or parks (10 %).

Land use surrounding Swan Lake has changed significantly over the past 30 years. Starting as farmlands, it has changed to a residential community, including a gated community and senior housing development.

Figure 1: Swan Lake Location Map

Figure 2: Swan Lake Catchment

Note: Sewer lines are shown in green, while catchment areas are shown in purple
OGS: Oil and Grit Separator, shown as green circles.

2.2 Lake Morphometry and Hydrology

2.2.1 Morphometry

Swan Lake has an approximate area of 5.3 ha and a maximum water depth of 4.0 m (from the deepest point at 205 m to the Lake edges at 209 m asl).

The hypsometric characteristics and morphometry of Swan Lake updated in 2026 using survey data collected in 2016 are shown in Table 1, Table 2, and Figure 3.

Table 1: Hypsometry of Swan Lake (2016 Survey Date, calculation revised in 2026)

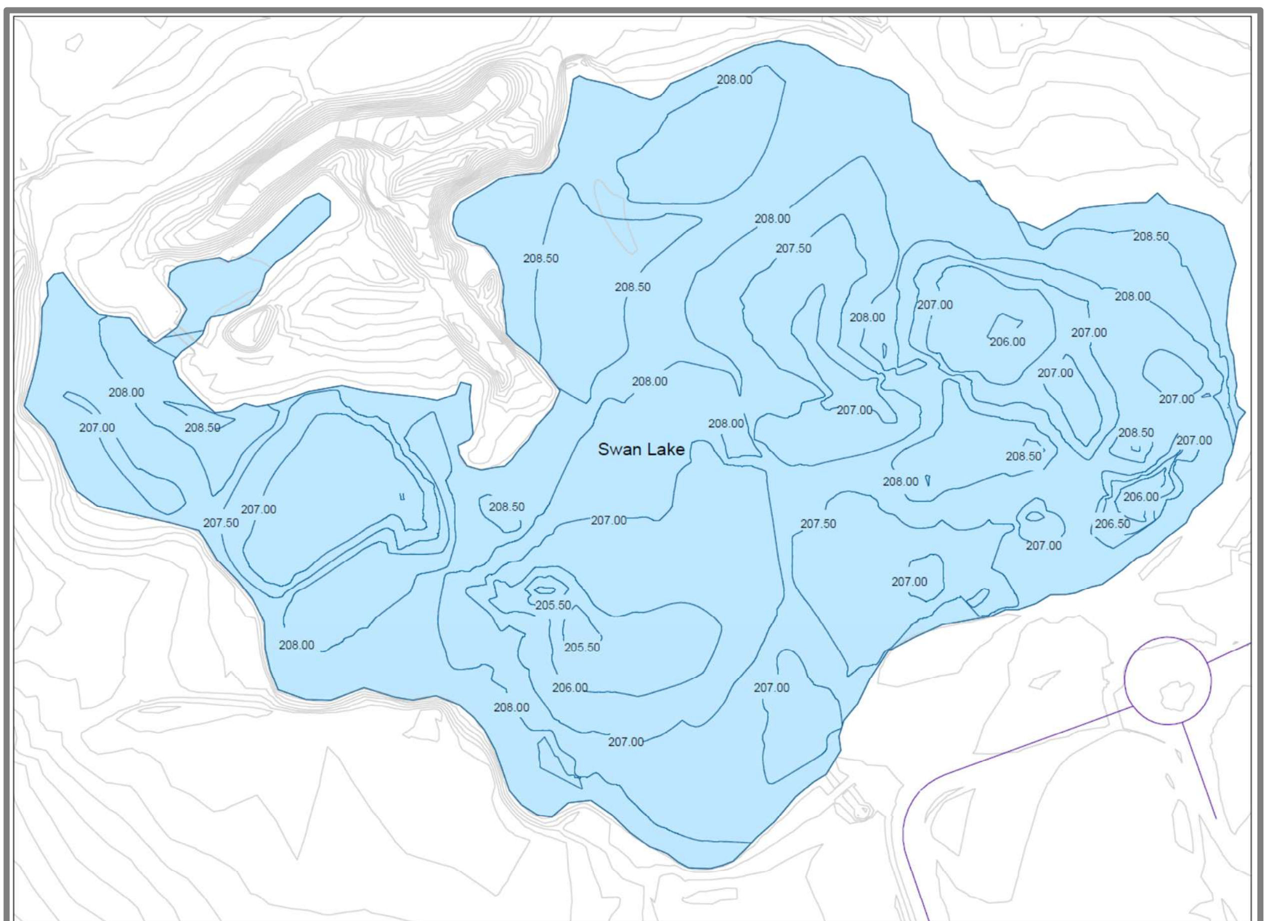
Elevation (masl)	Depth (m)	Volume of Layer (m^3)	Volume below (m^3)	Area of Layer (m^2)
209	0	26,447	76,000	57,000
208.5	0.5	9,153	49,553	47,442
208.3*	0.7	12,388	40,400	44,000
208	1	14,529	28,012	33,385
207.5	1.5	8,825	13,483	23,175
207	2	2,830	4,658	7,408
206.5	2.5	1,499	1,828	4,144
206	3	306	329	1,110
205.5	3.5	23	23	93
205	4	0	0	0

*invert of the outlet weir

Table 2: Swan Lake Average Morphometry

Parameter	Value
Catchment area (ha) including the Lake and the two ponds	45
Surface area (ha) at 209 m	5.7
Volume (1000 m^3) at 209 m	76
Mean depth at 209 masl (m)	1.3
Maximum depth at 209 masl (m)	4

Figure 3: Swan Lake Bathymetry (2016 Survey), Contours in m above Sea Level (masl)



2.2.2 Inflows

Water enters Swan Lake through direct precipitation on the Lake, as well as controlled and uncontrolled stormwater runoff from the surrounding subdivisions. The uncontrolled area relates to the shoreline area (~4 ha). Two wet extended detention ponds (#104- North Pond and #105-East Pond) attenuate the stormwater runoff generated from the controlled catchment (31. 9 ha). Three Oil and Grit Separators (OGS) treat runoff from a combined area of 1.69 ha before discharging to the Lake (AECOM, May 2025).

Runoff is collected by local storm sewers and conveyed to North and East Ponds. Low intensity rainfall events drain directly into these ponds, while high intensity events are diverted to Swan Lake when flows are high enough to spill over weirs located at the inlet of each pond. The North pond discharges treated and attenuated runoff to the municipal storm sewer system on Williamson Road. The East Pond discharges runoff to the private residential development's Foundation Drain Collection System which ultimately drains to the storm sewer south of 16th Ave.

The normal water level elevation within the ponds and the Lake is expected to be similar to the adjacent groundwater elevation.

2.2.3 Outflows

The water captured by Swan Lake is either infiltrated, evaporated, or discharged through a restricted outfall discharging to the 16th Ave. storm sewer. This outfall (invert elevation at 208.3 masl) was built to maintain a constant water level and positive drainage of the Lake. As per the initial plan (Cosburn Patterson Wardman Limited; Cosburn Giberson Landscape Architects; Michael Michalski Associates., 1995), the Lake release rate is limited to 100 L/s to accommodate the downstream drainage constraint at the 16th Ave. storm sewer (2-year peak flow of 1.166 m^3/s).

2.3 Natural Features

Swan Lake is home to a diverse community of terrestrial species; however, the fish community has been very limited.

Members of the resident group Friends of Swan Lake Park (FOSLP) compiled a list of birds observed at the Lake throughout the year (Friends of Swan Lake Park, March 2020). The list includes both resident and migratory species, such as resident and migratory Canada Geese and other waterfowl and Trumpeter swans. For several years, the Village of Swan Lake also brought in a pair of Mute swans to the Lake each year, and a team of residents would care for them during their stay throughout the warm season.

Small mammals usually found in the urban areas of Southern Ontario are frequently spotted in the Park.

Snapping turtles reside in Swan Lake and although anecdotally poaching is commonplace, they are still regularly sighted in the Park.

Based on available records, the Lake was stocked with largemouth bass in 1992; however, none of the fish was left in the Lake by 2005 (Gartner Lee Limited, 2006). In recent years, the Toronto and Region Conservation Authority (TRCA) have completed fish inventories for the City, and encountered a limited number of fish species, including Common Carp and goldfish (non-native), Brown Bullhead, and Fathead Minnow. All these fish species are considered tolerant to poor habitat (e.g., non-ideal water quality) conditions. The small number of only three fish species in a lake does not constitute a well-balanced community (TRCA, August 2021).

Invasive plant species observed included Black Locust, Common Reed Grass (*Phragmites australis*), Dog Strangling Vine, Chinese Elm, Manitoba Maple, Oriental Bittersweet, Tartarian Honeysuckle, and Garlic Mustard (Friends of Swan Lake Park, March 2020).

2.4 Swan Lake Significance

The original objective for the Lake set out by the developers in 1993, was to transform the inactive gravel pit into a diverse natural habitat for aquatic and terrestrial wildlife… that incorporates passive use opportunities surrounding the Lake' (Cosburn Patterson, Cosburn Ginnerson and Michal Michalski, 1993).

While the objective of diverse natural habitat for aquatic life has not been realized despite many studies completed over the years by the developers and the City, Swan Lake has been a community feature within the Swan Lake Park (the Park), with multiple trails and urban development surrounding it. The Park is widely used by residents and visitors. Many avid bird-watchers and photographers enjoy and record the diversity of natural features within the Park.

A survey conducted by the Friends of Swan Lake Park in 2020 (Friends of Swan Lake Park, 2021) indicated that residents "support a long-term plan that involves investment in sustainable solutions and restoration of the aquatic and land-based habitat".

Through ongoing consultation described in Section 5.9, Friends of Swan Lake Park have advocated for Official Plan designation of Swan Lake Park as a Natural Heritage Feature and Swan Lake as a 'Key Hydraulic Feature' given groundwater interactions identified through water budget analyses. Official Plan designations updates are being assessed city-wide as part of the current Official Plan update (see Section 6.3).

2.5 Ownership and Maintenance

2.5.1 Swan Lake

In early 2001, the City took ownership of most of the Lake as part of the subdivision assumption process, except for a small portion of the southeast corner (within Block 9). This was due to the risk of liability associated with the elevated metal concentration within the sediment of that portion of the lake. This portion of the lake is currently under private ownership. The owner of Block 9 undertook a Risk Assessment of the contamination in 2006 and recommended leaving the contaminated sediment at the bottom of the lake portion of Block 9 without disturbance (Water and Earth Science Ltd., March 2006).

2.5.2 Catchment Servicing

The Swan Lake catchment includes residential development, including a gated condominium community and the Swan Lake Park.

The two stormwater ponds and three OGS constructed to collect and treat runoff from 80% of the catchment are owned and maintained by the developers. Currently, the developers are responsible for the stormwater ponds and their maintenance. The ponds will be assumed by the City at a future date The ponds will require sediment removal by the developer prior to assumption which can improve treatment efficiency. City staff have been advised that this cleaning activity is currently being planned to complete in the short term (A. Hossein personal communication, April 23, 2026). Ultimately, the Swan Lake Boulevard and the Park blocks will also be conveyed to the City. All other works, including the upstream storm sewer will remain private.

Storm sewer lines within parts of the Pond 104 catchment are owned by the City, and the remaining sewers are privately owned. The Region of York owns the 16th Ave. sewer, which receives flows from the stormwater ponds and the Lake. This system discharges south of 16th Ave. into the City of Markham's storm sewer system, currently undergoing flood capacity upgrade design as part of the Markham Village Phase 2 Flood Control implementation.

Winter maintenance of 1 km (15%) of the catchment roads and sidewalks is completed by the City of Markham and the remaining roads, and about 3600 m^2 of parking areas are serviced privately (E. O'Hara, personal communication, July 21, 2021).

3. History of Lake Management

3.1 Before 2010

In 1993, the Swan Lake (Markham) Limited completed an Environmental Management Study (Cosburn Patterson, Cosburn Ginnerson and Michal Michalski, 1993) to provide input to the proposed development of the Swan Lake Community for the rehabilitation and use of the former gravel pit, and to address stormwater drainage design. Through this study, an environmental master plan was developed to transform the inactive gravel pit into a 'diverse natural habitat for aquatic and terrestrial wildlife… that incorporates passive use opportunities surrounding the Lake'. This would be accomplished through the implementation of a variety of approaches to create fish and waterfowl habitat, preservation and enhancement of lakeshore vegetation, stabilization of fill slopes, and management of access. Best management practices included the use of extended detention facilities to control runoff from a 25 mm rainfall event with subsequent release over a 24-hour period. A rehabilitation plan was prepared in 1994 to support the application and propose a fisheries compensation plan for the habitat loss caused by the construction of the two ponds (Cosburn Patterson Wardman, 1994).

On October 11, 1995, the (then) Town of Markham established a Senior Management group to address the environmental issues at Swan Lake. The Town engaged the Department of Fisheries (DFO), Ministry of Natural Resources (MNR), Ministry of Environment (MOE), and the TRCA in the review and approval process for the rehabilitation of Swan Lake. In 1996, copper sulphate (an algaecide) was applied to the Lake.

A number of environmental studies were completed in the 1990s to mid 2000s primarily in support of the development of Swan Lake Village and other areas, several of which dealt with the proposed land severance for Block 9 in Swan Lake (see Figure 1).

In 2003, Gartner Lee Limited was retained to provide technical opinion on aquatic sediment quality in Block 9 (Gartner Lee Limited, 2003). This study found slightly elevated concentration of metals and nutrients in the Lake water and slightly elevated concentrations of metals in the Lake sediments mostly concentrated within the water portion of Block 9, but recommended that the contaminated sediment be left undisturbed to avoid releasing the metals and nutrients back into the Lake. The study also concluded that, although low levels of some contaminants were present, sediment quality did not threaten either the use of Swan Lake by aquatic life or the health of aquatic life in Swan Lake.

Additional sampling was completed in December of 2005 to further assess the environmental condition of sediment, water quality, and aquatic habitat in Swan Lake, both within and adjacent to Block 9 (Gartner Lee Limited, 2006). Gartner Lee recommended that management actions be undertaken both on the site and in the watershed drained by the stormwater discharges to Swan Lake, to reduce urban runoff (especially phosphorus) into the Lake in order to prevent any future deterioration of water or sediment quality in Swan Lake. They also recommended that a management plan be developed to protect and enhance Swan Lake as an urban amenity, which could include habitat for aquatic life.

In 2007, Daniels Corporation (Swan Lake landowner) hired the service of Michalski Nielsen Associates Ltd. to prepare a report regarding the rehabilitation of Swan Lake. The report indicated that total phosphorus and turbidity were above acceptable levels. No actions were recommended in the report (Michalski Nielsen Associates Limited, 2008). The report was circulated to the Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF) and DFO. MNDMNRF indicated that they closed their file and are no longer considering any further rehabilitation of Swan Lake. DFO, in their letter dated October 22, 2008, were "pleased that Swan Lake has been rehabilitated".

3.2 2010 to 2020

In 2010, Professor Van Loon, a resident of the Swan Lake community, raised concerns about the water quality in Swan Lake (Van Loon, Jon, 2010). In response, the City initiated a study including the monitoring of the Lake and adjacent stormwater management ponds. In 2012, the City hired a consultant (Freshwater Research), who studied the Lake and found out that high levels of phosphorus in the Lake were contributing to the growth of blue-green algae, low oxygen levels in the water, and hence degraded fish habitat (Freshwater Research, 2012).

In 2013, Council authorized a project to help improve the Lake water quality (City of Markham, February 4, 2013). In the summer of 2013, 25 tonnes of Phoslock, a bentonite clay with lanthanum ions, was applied across the Lake to remove phosphate from the water column and intercept phosphorus released from the bottom sediments at the cost of about $100,000.

Water quality has been monitored in Swan Lake since 2013 to track the effectiveness of the Phoslock treatment. In 2014, water quality monitoring indicated a 60% reduction in total phosphorus in surface and mid-layers of lake water. This reduction improved Lake's trophic state from hypereutrophic to eutrophic (Freshwater Research, February 2015).

Active geese management started in 2014, focusing on resident geese at the beginning and extended to the management of migratory geese in 2016.

In 2016, however, the Lake returned to hypereutrophic conditions (Freshwater Research, January 2017).

In 2019, the City initiated a study to define a short-term and a long-term strategy for water quality management in Swan Lake (Freshwater Research, July 2020). This strategy described the development of Swan Lake's water quality based on the review of historical monitoring data. It determined the contribution of various sources to the phosphorus mass balance and separated external loads from internal ones. Management goals and targets were proposed as a sequence of triggers for the initiation of appropriate management actions as follows:

1. The surface bloom of a potential or proven toxic strain of cyanobacteria to trigger direct attention.
2. The occurrence of two blooms within a period of four years that cover at least 25% of the Swan Lake area.
3. Water quality not compliant with the interim goal of growing period average 0.15 mg/L total phosphorus concentration in the surface mixed layer.
4. Water quality not compliant with the interim goal of growing period average 0.45 m Secchi disk transparency.

A number of management approaches were developed and evaluated, and the following recommendations were made:

- A treatment to address internal loading as phosphorus release from sediment
- Sediment analysis to assist with proper chemical treatment dosing.
- Continued waterfowl management.
- Continued water quality monitoring at two shore sites.
- Determination and potential management of the abundance of bottom-dwelling fish.
- Application of best management practices to decrease the nutrient contribution from the shoreline.
- Investigation of phosphorus load from historic dumping areas.

These recommendations were presented to the City Council on June 15, 2020, and the following resolutions were passed (City of Markham, 2020):

- Continue annual water quality monitoring; and,
- Continue with the annual geese control and review additional options relating to vegetation, tree planting, and strobe lights with regard to geese control and report back in the fall of 2020 with recommendations; and,
- Undertake the sediment analysis in fall of 2020, which will provide data related to the frequency and dosage of the chemical treatment and will provide direction on the service level and timing of future treatments; and,
- Undertake a chemical treatment commencing in 2021 based on the results of the sediment analysis, and further,
- Introduce a new fish management program in 2021.

4. Swan Lake Conditions (2010-2025)

4.1 Water Quality

Water quality monitoring of Swan Lake has been conducted annually since treatment in 2013 to track water quality and the continued effectiveness of the Phoslock application. Water quality was monitored at the deepest point (main or central station) and since 2017 at two shoreline sites, the Dock and the Bridge. The water depth at the dock is approximately 2-2.5 m, which allows it to represent Swan Lake as a whole. This was confirmed through a comparison of existing data (Freshwater Research, March 2018). The water depth at the bridge is about 0.5 meters deep, and it is used to represent the conditions of the shallow bays around Swan Lake. Annual reports are prepared each year to provide a picture of current water quality and identify trends. The following summary presents key water quality conditions for the historical period 2010–2020 (as presented in the 2021 Plan), followed by an update for the Phase 1 implementation period (2021–2025).

In order to provide a perspective on the water quality conditions, Federal and Provincial guidelines and standards are listed here. It should be noted, though, that Swan Lake is not a natural waterbody, and there is no requirement for it to comply with these limits. Where technically and economically feasible, the City will aim to meet these limits to protect and enhance the aquatic environment.

Dissolved Oxygen (DO) and Temperature

The minimum dissolved oxygen concentration required for the protection of warm water fish is 5 mg/L for water temperatures up to 20 °C and 4 mg/L for temperatures above 20 °C (MOEE, 1994).

Historical records of DO and temperature profile show that Swan Lake thermally stratifies during the summer despite its shallow depth. Low oxygen (<2 mg/L) conditions have been observed at depths below 2 m, to a depth as shallow as 1 to 1.5 m (in 2016). The majority of surface concentrations have been above 5 mg/L since 2014.

Lower concentrations could have lethal or sub-lethal (physiological and behavioral) effects on fish. However, some fish can acclimate to lower oxygen levels and survive concentrations between 1 and 3 mg/L.

Anoxic water at the sediment/water interface triggers phosphate release, and it was found to be the main reason for low water quality in Swan Lake in earlier years.

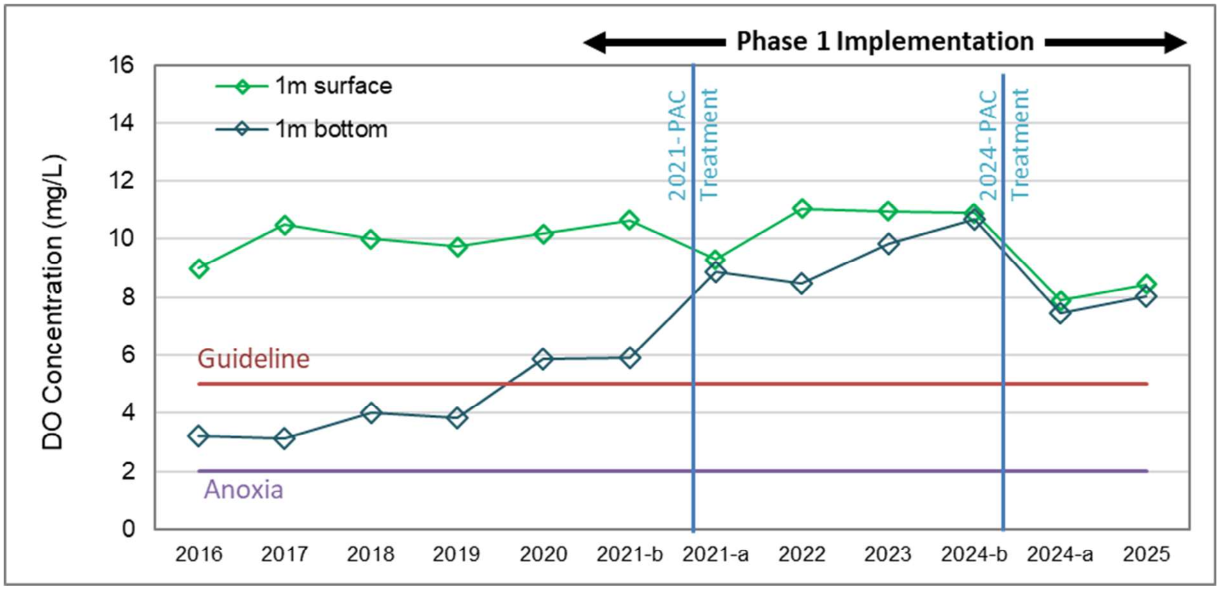
Following the 2021 PAC treatment, bottom DO concentrations improved substantially, with measurements generally exceeding 7–8 mg/L during daytime sampling events (Figure 4). This improvement indicates a reduction in sediment oxygen demand and a corresponding decrease in potential for internal phosphorus loading due to anoxia.

To better characterize diel variability in DO, continuous monitoring was implemented beginning in 2024, recognizing that lower concentrations may occur at night and between routine sampling events, and are not always captured through daytime monitoring. Data collected in 2024 and 2025 indicate that hypoxic conditions (DO <2 mg/L) were limited to depths of approximately 2.5 m below the water surface and occurred for short durations during periods of low precipitation and warmer-than-average temperatures. These results are consistent with DO monitoring by Trent University researchers at a deep location in the lake, providing confidence in the data collected at the City's Dock site. Under typical summer water levels, transient hypoxia would affect only about 1% of lake area and less than 0.5% of lake volume. Even if low oxygen extended upward to 2.0 m below the surface, the affected zone would remain limited to about 5.5% of lake area. For comparison, historic low-oxygen conditions extending to approximately

1.5 m below the surface would affect about 13% of lake area and nearly 8% of lake volume. These changes represent a substantial reduction in both the extent and persistence of low-oxygen conditions compared to pre-Phase 1 conditions.

Following the 2024 PAC treatment, mean surface DO concentrations decreased relative to earlier years. This change is interpreted as a positive response, reflecting reduced phytoplankton biomass and lower rates of photosynthetic oxygen production, rather than a decline in water quality. The reduced difference between surface and bottom DO concentrations indicates a more balanced oxygen regime and improved overall lake condition.

Figure 4: Growing-season Dissolved Oxygen Concentrations at Surface and Bottom Stations in Swan Lake (2016–2025).



Improvements in bottom DO following the 2021 PAC treatment and reduced surface supersaturation after 2024 reflect reduced phytoplankton productivity and improved oxygen balance.

Chloride

Chloride guidelines developed based on generic environmental data (CCME, 2011) include a long-term guideline (120 mg/L) and a short-term guideline (640 mg/L).

Chloride concentration had been increasing in Swan Lake from about 400 mg/L in 2013 to above 700 mg/L in 2020. Spot measurements of chloride in stormwater runoff (courtesy of FOSLP) in 2021 indicated concentrations ranging from 80 mg/L in the inlet from North Pond to 670 mg/L in the inlet from East Pond.

Chloride does not biodegrade, readily precipitate, volatilize, or bioaccumulate. It does not adsorb readily onto mineral surfaces, and therefore when introduced, concentrations remain high in surface water.

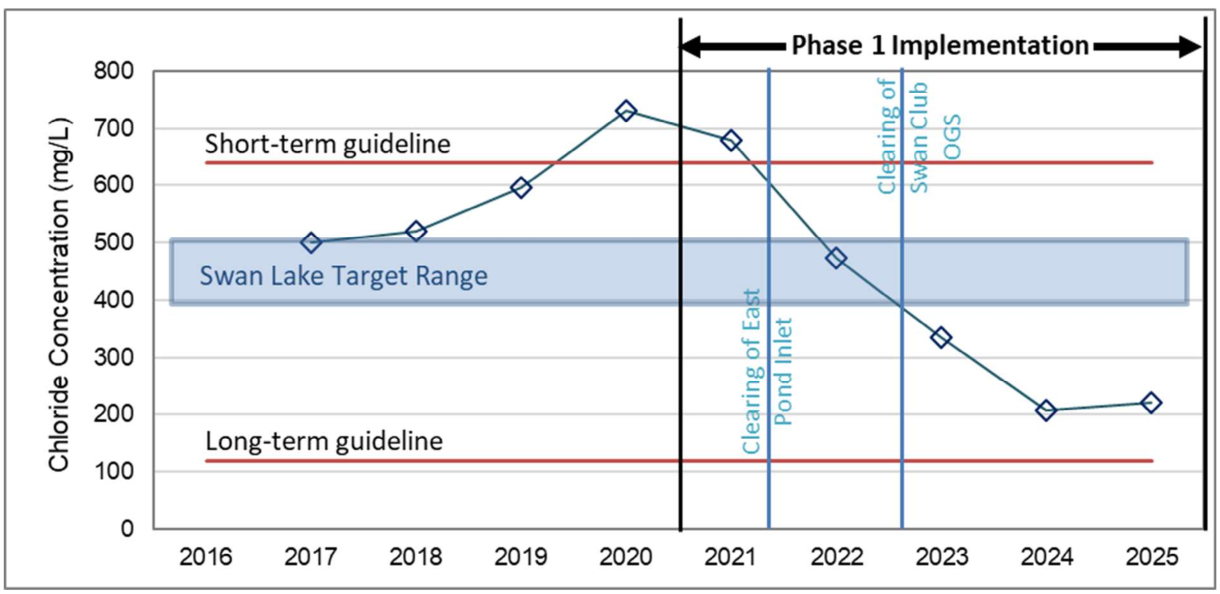
The long-term exposure guideline has been developed to protect all organisms (present in Canadian aquatic systems) against negative effects during indefinite exposure. The short-term exposure guideline will protect most species against lethality during a sudden hike in chloride concentration for a short period (24-96 hrs). These guidelines may be over-protective for areas with an elevated concentration of chloride and associated adapted ecological community. For example, watercourse concentrations in Rouge River watershed urban areas and shallow groundwater concentrations in the GTA help characterize background concentrations and are consistently higher than the short-term guideline. For such circumstances, it has been suggested that site-specific (higher) targets be derived considering local conditions such as water chemistry, background concentrations, and aquatic community structure. In 2021, a site-specific interim chloride management target of 400–500 mg/L was established, consistent with concentrations observed in 2013–2014. This target was intended to be revisited as additional monitoring and modelling data become available to improve understanding of chloride sources and loading dynamics, and implications for aquatic biota. Future refinement of the chloride management target, however, should consider both ecological thresholds and the practical limits of reduction achievable through active stormwater management, recognizing that additional reductions may be constrained by site conditions and background sources (e.g., chloride in groundwater).

Chloride concentrations in Swan Lake increased through 2020 and 2021, reaching peak levels exceeding 700 mg/L. As part of Phase 1 implementation, corrective actions were undertaken, including removal of a blockage at the East Pond inlet and maintenance of the Swan Club oil-grit separator (OGS). These measures reduced the contribution of untreated stormwater flows with elevated chloride concentrations to the lake (see Figure 5).

Following these actions, chloride concentrations declined substantially. Since 2022, concentrations have remained within or below the interim management target range of 400–500 mg/L, with further reductions observed in recent years. Average chloride concentrations were approximately 200 mg/L in 2024 and 2025, representing a significant improvement relative to pre-Phase 1 conditions.

Recent concentrations are also below endpoint concentrations reported for sensitive aquatic organisms (e.g., zooplankton species, 259–454 mg/L) used in the derivation of the long-term Canadian Water Quality Guideline. These results indicate a reduced potential for adverse ecological effects associated with chloride under current conditions.

Figure 5: Growing-season Average Chloride Concentrations in Swan Lake (2016–2025).



Chloride concentrations increased through 2020–2021, followed by a substantial decline after implementation of Phase 1 management measures, including stormwater infrastructure maintenance.

Markham Environmental Services

Nutrients and Trophic State

The supply of nutrients, primarily phosphorus and nitrogen, is one of the main factors that control the growth of plants and algae in lakes. In Swan Lake, phosphorus is the limiting nutrient for algae production and algal biomass is generally strongly related to phosphorus. Nitrogen is usually in large supply relative to phosphorus and increases in nitrogen alone do not typically increase algal biomass (but can enhance algal production when phosphorus levels are high). In productive, stratified lakes like Swan Lake, the concentrations and chemical species of phosphorus and nitrogen are variable within and between years due to the complex cycling of these elements by physical, chemical, and biological processes.

Total phosphorus (TP) is the total of all phosphorus in water and includes particulate and dissolved forms. Algae, however, can only take up dissolved (soluble) reactive inorganic phosphorus, called orthophosphate. Nitrogen in lakes occurs in several forms, including organically bound and inorganic (nitrate, nitrite, and ammonia) nitrogen. As with phosphorus, the relative amounts of different forms of nitrogen are strongly controlled by physical, chemical, and biological processes, and vary within the water column and between seasons.

The amount of primary production (plants including algae and cyanobacteria) during the growing period defines a lake's trophic state. Lakes with low, moderate, high, and excessively high productivity are termed oligotrophic, mesotrophic, eutrophic, and hyper-eutrophic. There are several indicators of lake productivity; however, the trophic state is best described using a combination of indicators given the complexities of factors controlling primary production and variability in those indicators. Thresholds generally applied for different trophic conditions in lakes are provided in Table 3.

Table 3: Trophic State Classification

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
Secchi Transparency (m)	> 4	2-4	1-2.1	<1
Total Phosphorus (µg/L)	< 10	10 - 30	31 -100	> 100
Total Nitrogen (µg/L)	< 350	350 - 650	650 -1200	> 1200
Chlorophyll a (µg/L)	< 3.5	3.5 - 9	9.1 - 25	> 25
Anoxic Factor (d/yr)	< 20	20 - 40	41 - 60	> 60

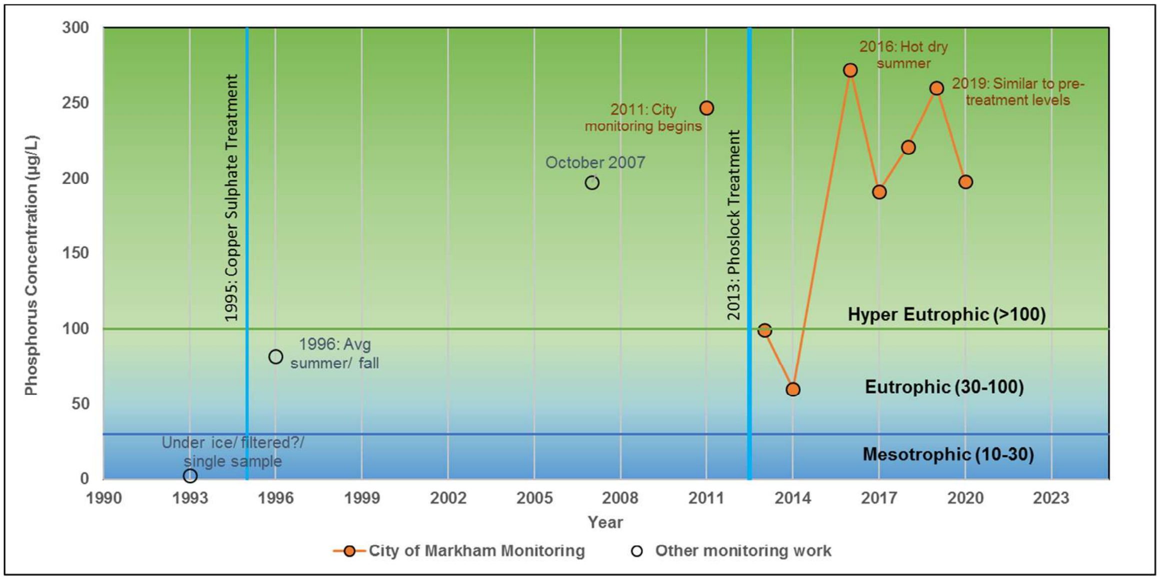
Note: The Anoxic Factor is a measure of anoxia and is defined as the number of days per year that a sediment area equal to the lake surface area is covered by anoxic water.

Historical average growing period (May - October) TP concentrations indicated hyper-eutrophic conditions in all monitored years except for the two years following Phoslock treatment, 2013 and 2014 (2015 was not monitored, see Figure 4). The lake returned to hyper-eutrophic conditions by 2016, reflecting a gradual loss of treatment effectiveness following the 2013 Phoslock application. TP concentration typically decreases after spring and increases in late summer and fall, partially caused by phosphorus release from sediment during summer anoxia and the arrival of migratory geese (Freshwater Research, July 2020). In Swan Lake, whole lake TP is usually higher than the upper mixed layer concentration. This higher water column average is due to elevated TP concentrations at deeper depths, closer to the sediments (Freshwater Research, August 2021).

Historical total nitrogen (TN) concentration over the growing period was above 1.2 mg/L, representing a hyper-eutrophic condition, except in the post-Phoslock treatment year, 2014. Nitrogen is, however, not believed to be the limiting nutrient for eutrophication in Swan Lake. Nonetheless, inorganic nitrogen compounds (nitrite, nitrate, ammonia) have often been below detection limits, indicating relatively low levels of bioavailable nitrogen concentrations (Freshwater Research, July 2020).

Figure 6 provides a schematic of trophic state classification for Swan Lake based on solely phosphorus concentrations.

Figure 6: Historical (1990-2020) Trophic State Classification for Swan Lake based on Mixed Layer Growing Period Average Phosphorus Concentration



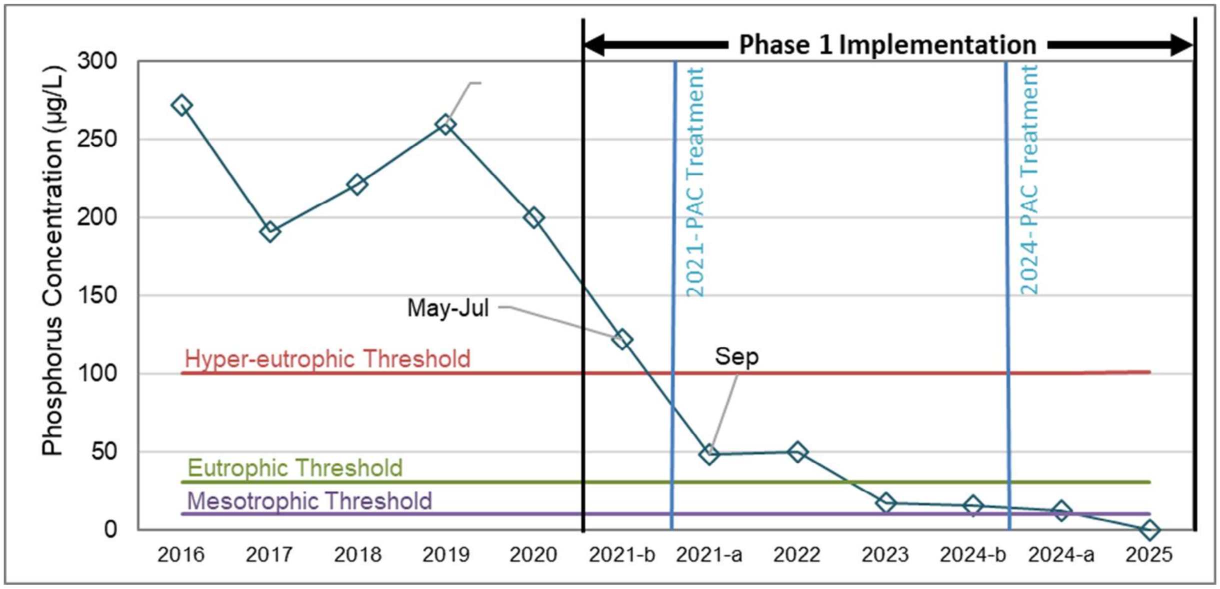
Following implementation of Phase 1 management measures, including the 2021 and 2024 PAC treatments, total phosphorus (TP) concentrations declined substantially (Figure 7). Growing-season average TP decreased from hyper-eutrophic levels (>100 µg/L) observed prior to 2021 to approximately 40–50 µg/L immediately following the 2021 treatment, and further declined to below 30 µg/L by 2023. TP concentrations have remained within the mesotrophic to low eutrophic range since that time, with 2024 and 2025 values approaching or within the mesotrophic threshold. This represents a marked and sustained shift in trophic state from hyper-eutrophic conditions to mesotrophic–eutrophic conditions.

Total nitrogen (TN) concentrations also declined significantly following Phase 1 implementation (Figure 8) Prior to 2021, TN concentrations were consistently within the hyper-eutrophic range (>1.2 mg/L). Following treatment, TN concentrations decreased to approximately 1.0 mg/L in 2021 and further declined to approximately 0.5–0.7 mg/L in subsequent years. These values are consistent with mesotrophic conditions, indicating a transition from hyper-eutrophic to mesotrophic trophic status based on nitrogen concentrations.

The observed reductions in both phosphorus and nitrogen are consistent with improvements in overall lake condition, including reduced algal biomass and improved dissolved oxygen conditions. Despite the reduction in nitrogen concentrations, phosphorus remains the limiting nutrient in Swan Lake, as TN:TP ratios remain elevated (generally >15 by mass based on growing season averages), indicating sufficient nitrogen availability relative to phosphorus. For this reason, changes in trophic state continue to be primarily driven by reductions in phosphorus loading and availability.

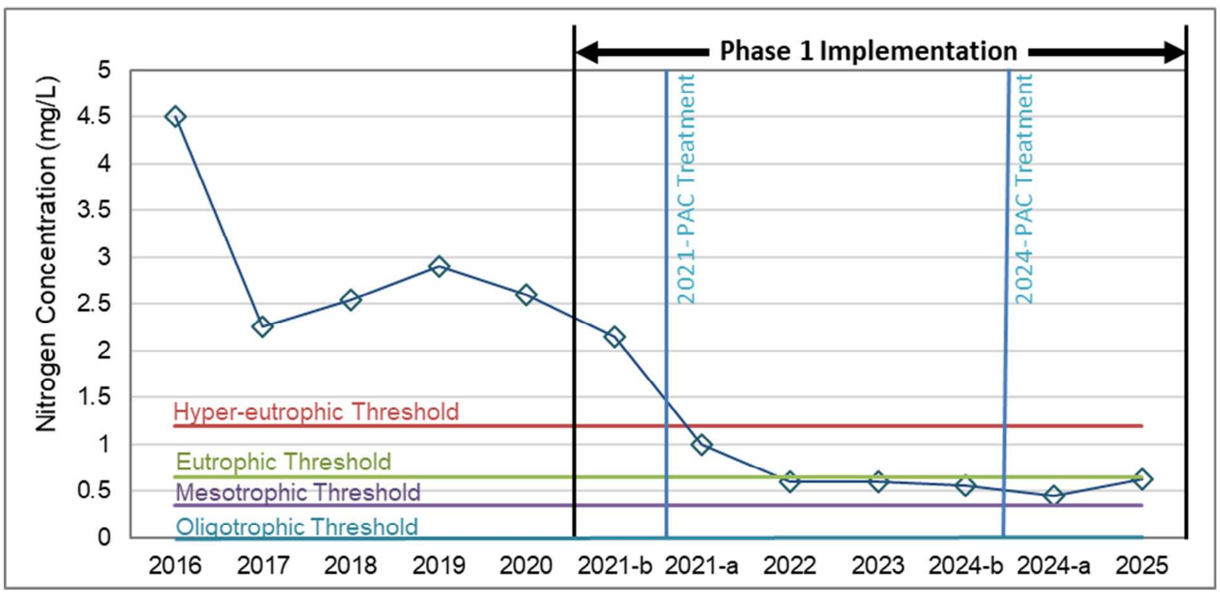
Overall, the sustained reduction in nutrient concentrations achieved in Phase 1 supports a fundamental shift in trophic state to a meso-eutrophic state.

Figure 7: Growing-season (June–September) Average Total Phosphorus (TP) Concentrations in Swan Lake (2016–2025) with Trophic State Thresholds



TP concentrations were consistently within the hyper-eutrophic range prior to 2021 and declined substantially following Phase 1 implementation, with concentrations remaining within the mesotrophic to low eutrophic range since 2023.

Figure 8: Growing-season (June–September) Average Total Nitrogen (TN) Concentrations in Swan Lake (2016–2025) with Trophic State Thresholds



TN concentrations declined from hyper-eutrophic levels prior to 2021 to values consistent with mesotrophic conditions following Phase 1 implementation.

Markham Environmental Services

Phytoplankton and Water Clarity (Secchi Transparency)

Chlorophyll a is the primary photosynthetic pigment produced by plants, and is commonly used as an indicator of algal production in lakes. Chlorophyll a was measured for several years, and it was shown to be highly and significantly correlated with the Secchi disk readings (Freshwater Research, July 2020).

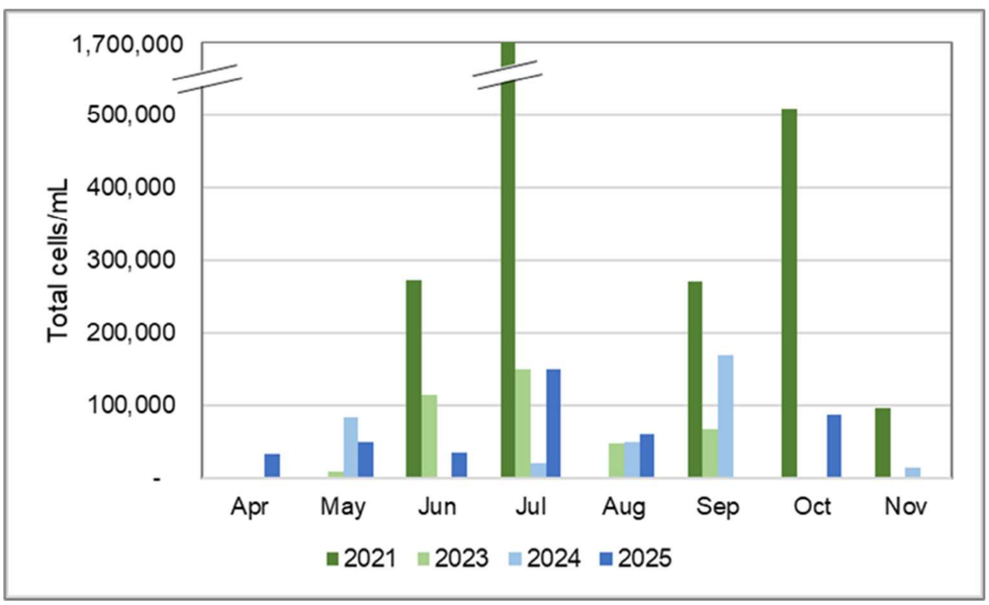
In Swan Lake, Secchi Transparency has typically been quite low throughout the summer, but it increases in November, reflecting the end of the growing period for phytoplankton. The average growing period values are historically all below 1 m, except in 2014, the year following the Phoslock treatment.

Following implementation of Phase 1 management measures, indicators of phytoplankton biomass and water clarity show measurable improvement, although responses are more variable than nutrient concentrations.

Chlorophyll a is not routinely monitored due to analytical constraints, including sample preservation requirements and longer laboratory processing times. In 2023, chlorophyll a was measured and was consistent with reduced phytoplankton biomass relative to pre-Phase 1 conditions, but was still characteristic of hyper-eutrophic conditions in August and mesotrophic conditions in June.

In recent years, phytoplankton densities have been used as primary indicators of algal abundance, as they provide a more direct and reliable measure of phytoplankton levels. Phytoplankton densities have generally declined following Phase 1 implementation and have remained lower in recent years (Figure 9). Average growing-season cyanobacteria densities in 2025 were similar to those observed in 2024 and approximately 40% lower than in 2023, with mean values of approximately 65,000 and 44,000 cells/mL at the Dock and Bridge stations, respectively. These values are near or below the Health Canada indicator guideline of 50,000 cells/mL for the potential presence of cyanotoxins above primary contact recreational thresholds (i.e., for swimming), and indicate a reduced risk relative to historical conditions.

Figure 9: Average Cyanobacteria Cell Densities at Dock and Bridge Stations in Swan Lake (2021–2025).

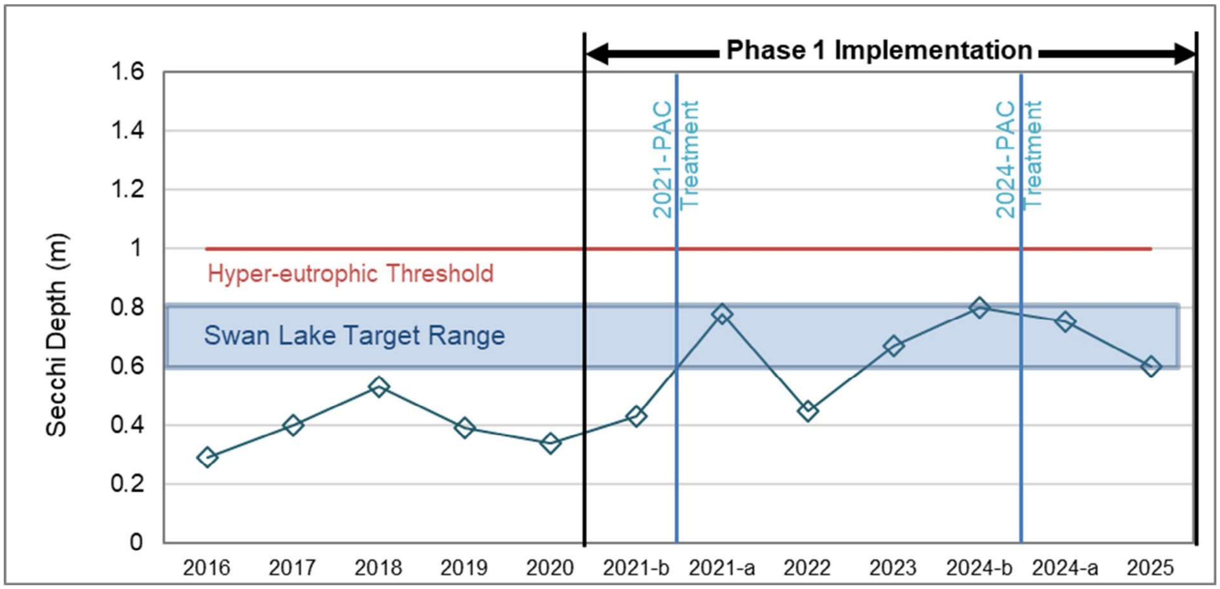


Cell densities decreased following the 2021 PAC treatment and remained lower through 2025, with values generally near or below the Health Canada indicator guideline of 50,000 cells/mL.

Secchi depth has shown modest improvement, increasing from approximately 0.3–0.5 m during the 2016–2020 period to approximately 0.6–0.8 m in 2023 and 2024, with a value of 0.6 m observed in 2025 (Figure 10). While these values remain within the hyper-eutrophic eutrophic range, the observed increase in transparency is consistent with reduced algal biomass and improved water quality.

Although the increase in Secchi depth following Phase 1 implementation was modest in absolute terms, it substantially improved light penetration to the lakebed. Based on the lake hypsometry and an estimated euphotic depth of approximately two times Secchi depth, the proportion of bottom sediments receiving light under typical summer water levels increased from about 50% during the 2016–2020 period to about 84% under recent conditions (2023–2025). This increase in illuminated bottom area is sufficient to support establishment and expansion of submerged aquatic vegetation, as discussed later in the report.

Figure 10: Growing-season Average Secchi Depth in Swan Lake (2016–2025)



Showing modest improvements in water clarity following Phase 1 implementation.

Algae Bloom and Cyanotoxins

Prior to implementation of Phase 1 management measures, algal blooms were observed intermittently, with more extensive and persistent events occurring in some years (e.g., 2018–2020). Cyanotoxin testing conducted between 2011 and 2016 generally reported concentrations below detection limits, with the exception of a single elevated measurement of 73 µg/L in 2016. Subsequent screening in 2019 and 2020 indicated microcystin concentrations below 10 µg/L. These results suggest that while blooms were present, toxin-producing cyanobacteria were not consistently dominant.

In 2021, elevated cyanobacteria biomass was observed prior to PAC treatment in August, and while the application reduced concentrations initially, biomass levels increased again later in the season. Since 2022, however, a sustained change in conditions has been observed.

Surface scums have not been widespread since 2022 and have generally been limited in extent and duration. These observations are consistent with phytoplankton monitoring results, which indicate reduced cyanobacteria biomass and increased community diversity relative to pre-Phase 1 conditions. As described in the previous section, phytoplankton monitoring indicates a continued shift toward lower cyanobacteria densities, with total cell counts declining substantially in 2023 and a further reduction of approximately 40% observed in 2024. These lower densities have been maintained through 2025.

Cyanotoxin monitoring results since 2021 have remained below recreational guideline values where measured, indicating a low risk of adverse health effects under current conditions. While individual sampling events have exceeded Health Canada's indicator value of 50,000 cells/mL for potential cyanotoxin production, these occurrences have been episodic and not associated with widespread surface accumulations.

Overall, these results indicate a shift away from bloom-prone conditions toward a more stable system with reduced cyanobacteria dominance and lower potential for toxin occurrence.

Table 4: Records of Algae Blooms and Toxicity

Year/Period	Algae Blooms Observation	Toxicity Test Result
Before 2011	Several blooms of cyanobacteria were observed	Microcystin concentration under detection limit
2013-2016	No apparent cyanobacteria proliferation and blooms; no resident concern related to the Lake's water quality	Microcystin concentration under detection limit
2016	A bloom was detected at one location	Microcystin concentration of 73 µg/L in one sample tested (recreational guideline is 20 µg/L)
2017	No bloom was observed	-
2018	Extended blooms were observed at several sites	Not tested for toxicity; cell density was at half of WHO's threshold for significantly increased risk for human health (Chorus I, 2021)
2019	Extended blooms were observed at several sites	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L
2020	Blooms were observed at several sites	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L
2021	Blooms were observed at several sites before treatment; the high biomass was inhibited by the August PAC treatment; however, by October, cyanobacteria were as high as in previous summers and falls.	Not tested for toxicity
2022	Surface scums were not widespread; Lab results showed lower diversity and higher total counts compared to 2021.	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L
2023	Surface scums were not widespread; Lab results showed higher diversity and significantly lower total counts compared to 2022.	Not tested for toxicity
2024	Surface scums were not widespread; Lab results showed higher diversity and about 40% decline in total counts compared to 2023.	Not tested for toxicity
2025	Surface scums were not widespread; Lab results showed similar diversity and total counts compared to 2024.	Not tested for toxicity

Markham Environmental Services

Bacterial Contamination

Animal droppings in and around the Lake may result in elevated levels of *Escherichia -Coli* in the water; however, since direct contact is not defined as a beneficial use of the Lake, *E-Coli* is not measured.

4.2 Water Balance

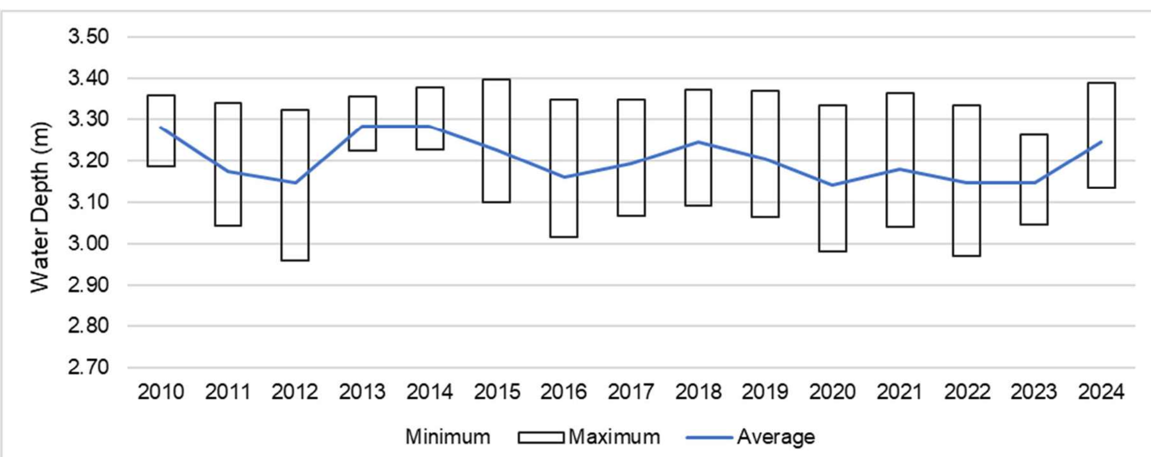
A water balance model was developed to support the 2019 water quality management report. The model was updated in 2020 using runoff estimates from the PCSWMM model to support the Swan Lake chemical treatment planning and scenario analysis. In 2024, surface runoff calculation was further refined using a more detailed InfoWorks model as part of a feasibility analysis for diverting stormwater runoff away from Swan Lake.

Meteorological data were taken from the Markham Museum meteorological station, complemented with data from the Mount Joy Community Center and the Buttonville Airport station. Evapotranspiration was estimated using the Priestley-Taylor model. Surface runoff from all outfalls was used from the 2024 model.

Various reports, including those prepared in support of development applications in the area, were reviewed to develop an estimate of groundwater exchange between the Lake and the surrounding area. Based on these reports, groundwater flow in and out of the Lake was estimated to range between 10 and 300 m^3/day; however, there is not enough spatial and temporal resolution to use these values in the water balance analysis, and therefore, a reliable estimation of groundwater contribution is not feasible.

Collected water level data were used to estimate outflow by assuming that discharge starts when the water level reaches an elevation of 208.3 m, i.e., the invert of the overflow weir. The existing water level data (2017-2024) were extrapolated to the previous years by correlating water level with rainfall and evapotranspiration, and outflows were estimated accordingly. Outflow data measured in 2023, and a more refined lake volume calculation were used to further refine this estimation (Figure 11). Table 5 provides a summary of the annual water balance established for Swan Lake and used in the nutrient budget (City of Markham, April 2026).

Figure 11: Measured or Estimated Monthly Water Level



Environmental Services

Table 5: Swan Lake Annual Water Balance (m^3)

Year	Precipitation on Lake	Evaporation from Lake	Inflow from Pond 104	Inflow from Pond105	Shoreline Runoff	Inflow from OGSs	Outflow	Balance
2010	36,529	40,307	3,870	8,227	3,270	9,937	51,128	7,064
2011	30,140	42,770	5,596	10,306	2,841	8,467	51,527	7,015
2012	23,329	41,834	327	905	2,126	6,335	24,556	16,104
2013	34,252	44,593	6,717	12,122	3,126	9,764	47,648	14,224
2014	33,246	41,523	2,586	5,706	3,270	9,937	19,079	26,447
2015	33,167	39,966	4,005	7,972	3,142	9,377	36,698	14,501
2016	29,887	42,900	6,044	11,665	2,915	8,781	39,598	4,099
2017	25,546	44,556	458	1,710	2,620	7,566	17,533	2,091
2018	32,798	45,700	2,099	5,131	3,227	9,693	24,477	15,886
2019	41,175	43,560	6,993	61,830	4,040	11,971	36,173	93,720
2020	40,779	42,093	4,751	56,818	3,973	11,723	33,258	79,138
2021	34,551	46,140	4,788	48,893	3,226	9,765	20,110	66,453
2022	37,831	43,711	7,330	57,197	3,623	11,015	47,649	70,841
2023	29,524	39,324	1,263	2,913	3,131	9,171	13,878	14,697
2024	34,971	41,605	5,205	9,689	3,046	9,484	33,872	26,253

4.3 Nutrient Budget

Phosphorus has been established as the most important variable to control water quality in Swan Lake, and the relative contribution from various sources influences the most efficient management options. Phosphorus sources include external (stormwater runoff, precipitation, and geese) and internal sources (release from bottom sediments and sediment resuspension).

The mass balance analysis conducted previously (Freshwater Research, July 2020) and (Freshwater Research, August 2021) was based on monitoring data and water balance estimates available at the time and provided estimates of external and internal phosphorus loading.

Quantification of the internal load is challenging as phosphorus originating from anoxic bottom sediments, macrophytes, or sediment disturbances immediately mixes with the phosphorus already present in lake water so that any fluxes or inputs cannot be directly estimated in shallow lakes. Annual internal loads were estimated from monitoring data in a mass balance analysis and confirmed by other methods (Freshwater Research, July 2020).

The contribution of geese to external load was estimated using the enumeration by the City staff, the geese management contractor, as well as data provided by residents volunteering to assist with geese count. According to this information, the waterfowl population (mainly Canada Geese, *Branta canadensis*) has been stabilized at lowest levels since 2016with approximately 20-30 resident geese throughout the year and higher numbers during migration (sometimes in the order of 1000). The nutrient budget assumes 0.6 g/d of phosphorus for each goose.

Other external sources of phosphorus were estimated based on the annual volumes and selected phosphorus concentrations in the rain and runoff from various land cover types (Table 6).

Table 6: Representative Phosphorus Input Parameters for Atmospheric Deposition and Runoff Concentrations from Stormwater Sources

Phosphorus Source	Phosphorus Concentration	Comment
Atmospheric deposition	16.7 mg/m^2	(Ministry of Environment, 2010)
Stormwater ponds	0.116 mg/L	2011/2012 monitoring data
Untreated from pervious areas	0.121 mg/L	(US EPA, 1983)
Untreated from rooftop	0.192 mg/L	
Untreated from other impervious areas	0.383 mg/L	

Source: (Freshwater Research, July 2020)

The phosphorus mass balance model was updated using an expanded monitoring dataset, revised lake morphometry and water balance information, and refined assumptions regarding external loading and in-lake processes (BlueCycle Canada, Inc., 2026). Updated estimates of annual loading over the open water season (April-November) from external and internal sources are presented in Table 7.

Table 7: Calculated Annual Phosphorus Loads (Apr-Nov) for External and Internal Sources (kg/yr)

Year	Atmospheric Deposition	Shoreline Runoff	Stormwater (Ponds/OGS)	Geese	External (Total)	Internal Load	Total Load
2014	0.47	0.40	2.2	16	19	22	41
2015	0.45	0.37	2.6	17	20	-	20
2016	0.43	0.27	0.7	17	18	85	103
2017	0.45	0.34	1.4	14	16	50	66
2018	0.47	0.47	11.8*	10	23	60	83
2019	0.44	0.44	9.8*	14	25	63	88
2020	0.42	0.27	6.0*	27	33	29	62
2021	0.45	0.40	9.8*	11	22	17	39
2022	0.42	0.34	1.0	12	14	3	17
2023	0.44	0.33	2.1	6	9	0	9
2024	0.46	0.48	5.2	5	11	0	11
2014–2020 Average	0.45	0.37	4.9	16	22	51	66
2021 (Transition Year – PAC Treatment)	0.45	0.40	9.8	11	22	17	39
2022–2024 Average (Phase 1 Implementation)	0.44	0.38	2.8	8	11	1	12

* Elevated phosphorus loads due to blockage of the Pond 105 inlet
Source: (BlueCycle Canada, Inc., 2026)

Model results indicate a fundamental shift in phosphorus dynamics in Swan Lake following Phase 1 implementation. In 2021, internal phosphorus loading was reduced following the August PAC treatment. Since 2022, internal loading has declined substantially and is negligible under current conditions, with predicted phosphorus concentrations closely matching observed values based on external inputs alone.

External phosphorus loading has also decreased in recent years following resolution of the Pond 105 inlet blockage and continued waterfowl management. Under current conditions, external loading is dominated by geese and runoff-derived sources, with atmospheric deposition and local uncontrolled shoreline runoff representing a minor contribution. Interannual variability in total loading is now primarily driven by hydrologic conditions and fluctuations in waterfowl presence.

Overall, Swan Lake has transitioned from a system historically influenced by both internal and external phosphorus sources to one in which water quality is controlled predominantly by external inputs. This shift reflects the effectiveness of in-lake chemical treatments and supporting watershed management measures and is consistent with recent observed improvements in water quality.

4.4 Chloride Budget

De-icing materials used for winter maintenance of roads, parking lots and walkways are the primary sources of chloride in urban lakes. Other common sources of chloride in urban centres include dust suppressants and water treatment salt (for water softening). Salt from water softening would not be expected to enter surface water systems, but rather discharge to wastewater collection systems.

Chloride in salting materials is readily dissolved in water, and transported overland by runoff or infiltrated into soils, contaminating groundwater and surface water. Dry salt can also be transported as wind-blown dust and re-deposited on land or water. As a result, salt loading to lakes occurs primarily in winter and spring during melt conditions, but continues through the summer and fall via discharge of impacted groundwater, dry deposition of dust to the lake surface, non-point source runoff washing dry salt from land surfaces, and flushing of stormwater ponds.

Winter maintenance of 1 km (15%) of the catchment roads and sidewalks is completed by the City of Markham. The City prescribes and tracks the quantity of salt distributed to the City roadways based upon current and future forecast models and temperatures to determine the required action and material usages in compliance with the desired service level of service and O.Reg 239/02 requirements (O. Reg. 239/02, 2013, amended 2018). Using the average salt usage rate, the City has used an average of 3,100 kg of salt per year over the past two years (R. O'Hara, personal communication, June 18, 2021). The remaining 5.5 km of roads, as well as about 3600 m^2 of parking areas, are serviced privately, and information on the level of service and quantities are not available at this time.

The amount of salt and hence chloride draining to the Lake depends on environmental variables and de-icing/snow removal operations.

A preliminary mass balance indicated that the average chloride load to Swan Lake increase by more than 50% between the periods of 2013-2014 and 2018-2020. Subsequent investigation in 2021 identified a blockage at the East Pond (Pond 105) inlet, which resulted in increased stormwater flows with elevated chloride concentrations entering the lake. This condition largely explains the observed increase in chloride loading and in-lake concentrations during this period. Removal of the blockage restored more typical flow conditions and contributed to the subsequent decline in chloride loads and concentrations after 2021.

The chloride budget for the Lake was updated in 2025 using an updated water balance model, together with recent information on salt usage and chloride concentrations in stormwater runoff (City of Markham, April 2026).

Average total chloride loading to Swan Lake (2022-2024) is estimated to be on the order of approximately 3 tonnes per year, half of which is from the three OGSs (no chloride treatment or water retention), about one ton from the East pond and about a half ton from the North pond. This represents a substantial reduction from the elevated loading observed between 2018 and 2021, when a blockage at the East Pond inlet resulted in increased conveyance of high-chloride runoff to the lake. Shoreline runoff contributes minimally to overall chloride loading (<0.1 t/year).

Flow diversion scenarios evaluated (AECOM, May 2025) indicate that targeted redirection of OGS flows and/or stormwater inputs could reduce chloride loading to the lake by approximately 20% to 60%.

depending on the extent of diversion and system modifications. However, these reductions must be considered in the context of system constraints, potential downstream impacts, and implementation feasibility and uncertainty regarding the role of groundwater contributions to the overall water balance and chloride loading to the lake.

4.5 Sediment Quality

In preparation for a chemical treatment, Swan Lake sediment was retrieved from five sites in October 2020. Three to four cores were taken per site, separated into two depth layers (0-5 cm and 5-10 cm), and pooled for each site. Samples were sent to Institut Dr. Nowak in Germany for analysis, including speciation, to determine the releasable phosphorus in the sediment.

Phosphorus concentrations averaged 700 mg/kg dry weight (DW), ranging from 420 mg/kg DW up to 1050 mg/kg DW. Phosphorus concentrations seem to be correlated to loss of ignition (LOI), which stands for the proportion of organic matter. The largest proportion of phosphorus was present in non-bioavailable, mineral fractions (Al/Fe-oxide bound, base releasable and residual phosphorus). The concentration of potentially bio-available phosphorus was about 40 mg/kg DW (Institut Dr. Nowak, December 2020). In general, the surface (0-5) cm layer indicated more polluted and slightly more organically-enriched sediments that are more prone to phosphorus release than the lower sampled layer (Freshwater Research, January 2021).

5. Phase 1 Projects and Initiatives (2021-2025)

During 2021-2025, Core measures from Phase 1 and some Complementary and Alternative measures from Phase 2 and Phase 3 of the Plan were implemented in an adaptive manner to improve the Lake water quality.

Core and Complementary activities completed 2025 included water quality (and biologic) monitoring, enhanced geese management, fish management, chemical treatment, management of aquatic vegetation and algae, and chloride management.

Details of water quality monitoring are provided in annual water quality reports. Other management measures are described in this section.

5.1 Fish Management

One of the findings of the 2020 water quality management study (Freshwater Research, July 2020) was that the control of bottom-dwelling fish (carp and goldfish) is necessary to ensure high efficiency of the chemical treatment.

Through a meeting with the MNRF staff, they were supportive of the non-native/invasive fish removal as well as the relocation of the bottom-dwelling Brown Bullhead. MNRF staff advised against the relocation of Brown Bullhead in later years due to the risk of contamination.

Since 2021, the City has hired TRCA to complete fish inventory, relocation, and removal efforts. Fish are captured using electrofishing and fyke netting, and removal efforts focus on invasive and benthic species that may contribute to sediment disturbance and internal nutrient cycling. Initial work in spring 2021 confirmed a simplified and disturbance-tolerant fish community dominated by Common Carp (non-native), Brown Bullhead (native, benthic), and Fathead Minnow. Efforts in subsequent years (2022–2025) continued to identify a limited number of species, including Brown Bullhead, Fathead Minnow, Goldfish, and hybrid Carp/Goldfish, with Common Carp notably absent in 2025. Over this period, Common Carp were largely eliminated, Goldfish and Common Carp/Goldfish hybrids emerged as the primary invasive species of concern, and Brown Bullhead remained the dominant native benthic species.

A summary of fish species captured since 2021 is provided in Table 8.

Table 8: Fish Species Collected from Swan Lake Since 2021

Date	Method	Brown Bullhead	Common Carp	Fathead Minnow	Goldfish	Common Carp x Goldfish	Emerald Shiner
April-21	3 days electrofishing + 2 days nets	210	7	>10,000	-	-	-
August-22	1 day electrofishing, 1 day nets	80	20	875	-	-	-
August-23	1 day electrofishing	84	103	14	2	-	-
April-24	1 day electrofishing, 1 day net	193	1	1521	13	59	1
April-25	1 day electrofishing, 1 day net	391	-	3586	354	1	-

In May 2025, 500 juvenile largemouth bass were introduced to the lake by a private contractor (Hidden Lane Fisheries, Smithville, ON), following consultation with TRCA and the MNRF. Fish stocking was identified as a complementary measure in the 2021 Plan to help improve trophic structure and support development of a more balanced fish community. Alternative stocking options, including Bluegill, were considered but not pursued due to their potential to reduce zooplankton populations and indirectly promote algal growth.

The 2021 Plan recommended monitoring and removal of benthic fish for five years. Following the 2025 work, TRCA advised that fish monitoring should continue annually and that invasive species should continue to be removed. They have recommended that in 2026 consideration should be given to returning some/all the Brown Bullhead to the lake (rather than removal) since they are a native fish, and it is important to have some benthic feeders in a lake ecosystem. In addition, monitoring of the stocked largemouth bass population and evidence of spawning activity is recommended, along with public education measures (e.g., signage) to discourage the release of pet fish into the lake.

5.2 Geese Management

Active geese management started in 2014, focusing on resident geese and extended to the management of migratory geese in 2016. The frequent geese chasing would encourage the geese to relocate to a quieter place and reduce the number of resident geese at Swan Lake.

Additional measures were implemented in 2021 when the City hired the TRCA to remove existing nests and eggs and to relocate resident geese from Swan Lake.

From 2021 through 2023, the geese management program included a combination of hazing (using trained border collies), nest and egg management, relocation of resident geese, and deterrent measures (strobe lights). In 2024 and 2025, additional deterrent techniques were introduced, including laser emitters, avian distress calls, and limited use of pyrotechnics. Monitoring was conducted by contractors, City staff, and community volunteers, supported by a geese tracking application (ArcGIS Survey123), allowing for improved scheduling and targeting of management activities.

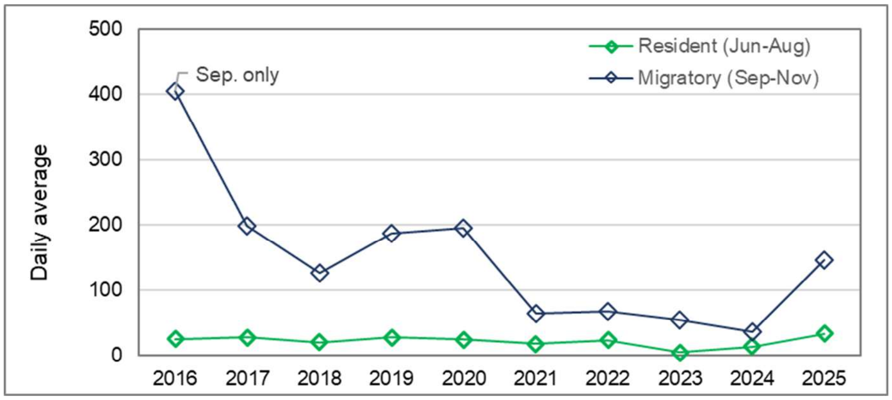
Overall, these measures have been effective in reducing both resident and migratory geese presence at the lake, particularly during peak migration periods in the fall (Figure 13).

At the request of FOSLP, and upon Council approval (City of Markham, September 2020), nine strobe lights were also purchased and installed on the Lake and the two adjacent stormwater management ponds between 2020 and 2025. Strobe lights work by using a solar-powered LED light that flashes every two seconds and is intended to disrupt the geese's sleep patterns and discourage them from staying on the Lake. While the strobe lights were implemented, no consistent measurable effect on geese counts was observed. In contrast, active management measures (hazing, nest control, and relocation) have been the primary drivers of reduced geese presence at the lake.

Enhanced hazing programs, especially when implemented during late summer and fall migration periods, consistently resulted in reductions in daily geese counts. Nest and egg management also contributed to limiting local population growth, with annual nest counts generally ranging from approximately six to nine nests and 28 to 68 eggs managed per year. Relocation efforts further reduced the number of resident geese, with annual removals ranging from approximately 14 to over 40 birds in recent years.

Despite ongoing regional increases in Canada Goose populations, the sustained management program at Swan Lake has effectively controlled local geese numbers over time, particularly when compared to pre-management conditions. However, geese counts increased somewhat in 2025, likely reflecting natural population variability and the temporary removal of laser deterrent systems for product improvement.

Figure 12: Historical Geese Counts at Swan Lake (2016–2025)



5.3 Chemical Treatment

The quantification of different phosphorus sources in 2020 indicated that the effects of internal sources outpaced those from external sources. The phosphorus released from internal sources was believed to be highly bioavailable and quickly become incorporated into phytoplankton and bacteria. An in-lake treatment was therefore recommended as the most immediate and effective solution.

Freshwater Research reviewed various physical and chemical methods of internal load abatement and identified the methods that are limnologically feasible for Swan Lake as a chemical treatment with Phoslock or Poly Aluminum Chloride (PAC). A treatment with Phoslock was completed in 2013. This treatment had provided at least two growing periods of improved water quality and successfully controlled sediment phosphorus release according to the mass balance analysis. There was no obvious negative effect from the previous treatment (Freshwater Research, July 2020).

In order to secure an alternative treatment, the City also initiated a conversation with the Ministry of Environment, Conservation, and Parks (MECP) to explore the feasibility of a PAC treatment. Information on the Lake conditions and the effectiveness and application history of PAC was provided to the Ministry ((City of Markham, November 2019) and (City of Markham, December 2019)). The MECP reviewed this information and agreed that if "after implementing source controls, the City determines that an aluminum-based treatment is necessary, the City should ensure that all measures are taken to monitor water quality and prevent any adverse effect from the application" (MECP, January 2020).

Specialized sediment collection and analysis were completed in the fall of 2020 in support of chemical treatment. Sediment analytical results were used to determine the appropriate Phoslock dosage for each area of the Lake (Freshwater Research, January 2021). A contractor procurement process was initiated in late 2020. However, the Phoslock supplier informed the City that Phoslock needed to undergo a new approval process for use in Canadian lakes, and it would not be available for a 2021 application (N. Trail, personal communication, February 7, 2021).

Following this revelation, at the request of the City, Freshwater Research conducted a feasibility assessment of an aluminum-based treatment (Freshwater Research, March 2021). While PAC was acknowledged as an effective solution, this review noted that the resulting flocculent gelatinous precipitate (aluminum hydroxide) would be chemically stable up to a pH of ~8.8 (pH in Swan Lake water is around 8-9; higher measurements in 2020 were a result of device malfunction). Aluminum would also be toxic to aquatic biota in acidic, poorly buffered waters (pH<7). It was therefore recommended to stagger the application over several days to prevent shocks of toxicity.

In order to determine the optimum dosage and duration for a safe application, the City hired AECOM Canada to develop a PAC treatment plan. This plan provided information on different PAC materials, PAC dosing (including jar test with Lake water) and application methods, and other special provisions for tendering purposes (AECOM, July 2021). A contractor was hired to implement this plan, which was fulfilled in August 2021.

In 2024, a second application of PAC was completed using a reduced dosage based on the updated treatment plan (AECOM, March 2024). Approximately nine tonnes of PAC were applied over two application events in late June, with each event separated by one to two days to allow for floc formation and environmental monitoring.

The reduced dosage reflects improved lake conditions following the 2021 treatment, including lower in-lake phosphorus concentrations and reduced sediment phosphorus accumulation over the intervening period. As a result, the estimated available sediment phosphorus for 2024 was approximately 38% lower than in 2021, and the total available phosphorus was approximately 20% lower, representing an overall reduction of about 30% in the mass of phosphorus requiring inactivation.

5.4 Aquatic Vegetation Management

Despite successful reductions in both internal and external nutrient loading in recent years, resulting in total phosphorus concentrations below target levels, Swan Lake has remained dominated by phytoplankton, and improvements in water clarity have been modest. This condition is likely influenced by warmer climatic conditions and the absence of submerged aquatic vegetation (SAV), which has historically been limited by elevated phosphorus concentrations. In the absence of SAV, phytoplankton remain the primary competitor for available nutrients and light, reinforcing a turbid, algae-dominated state.

Submerged aquatic vegetation plays a key role in maintaining clear-water conditions by stabilizing sediments, reducing resuspension, competing with phytoplankton for nutrients, and providing habitat for zooplankton and fish communities. The establishment of SAV is therefore considered an important mechanism for shifting the lake toward a more stable, clear-water condition.

The 2021 Plan identified the introduction of native SAV as a Phase 2 action. However, following review of 2022 water quality data, this measure was advanced to Phase 1 to support ongoing water quality improvements and complement existing management activities.

In 2023 and 2024, the City hired TRCA to implement a pilot SAV planting program along the north shore of the lake. In June 2023, approximately 1,500 stems of wild celery (*Vallisneria americana*) were planted within four fenced enclosures at depths of approximately 0.3 to 1.0 m. Monitoring in 2024 indicated variable establishment, with an overall survival rate of approximately 30% and improved growth observed in shallower areas (~0.2 m depth). In response, an additional 1,500 stems were planted in 2024 at shallower depths (approximately 0.2 to 0.4 m) to improve establishment success Naturally occurring aquatic vegetation was also observed to be abundant in 2024. However, the rate of establishment for planted wild celery was overall very low in 2025.

During the second PAC application in 2024, significant amounts of SAV, comprised primarily of small pondweed (*Potamogeton pusillus*), were observed and at times hindered the movement of the application boat. This represented the first observation of substantial SAV in the lake.

In July 2025, a comprehensive survey was conducted in accordance with a survey plan developed by AECOM to characterize the existing aquatic plant community. The survey found that SAV was abundant throughout the lake, with generally moderate to high cover at depths less than 2 m, and variable cover ranging from high to absent at depths greater than 2 m. The community was dominated by native species, including muskgrass (*Chara* spp.) and Canada waterweed (*Elodea canadensis*), with lower abundances of small pondweed and curly-leaved pondweed (*Potamogeton crispus*). The establishment of this SAV community is consistent with improved water clarity and reduced algal biomass observed in recent years (BlueCycle Canada, April 2026).

Given the poor establishment of planted wild celery and the successful natural colonization of submerged aquatic vegetation, further planting is not warranted at this time.

5.5 Algae Management

Following the successful use of ultrasound technology to control algae blooms in a stormwater management pond in Markham, two similar units were installed at Swan Lake in 2025 to reduce phytoplankton and further improve water clarity.

Ultrasound is a low-cost and durable method commonly used to control algae growth in water-holding facilities, including drinking water reservoirs. When deployed, the ultrasound device generates vibrations that rupture gas vacuoles within algae cells (structures that control buoyancy) causing the algae to sink to deeper, lower-light areas of the pond where they become inactive. The low-power ultrasound waves used have no impact on aquatic animals, birds, or humans.

The system selected for Swan Lake consisted of two Water IQ Pulsar 3000 units powered by a land-based solar panel. This is the same equipment used in the Markham stormwater pond, allowing staff to benefit from familiarity with installation, operation, and demonstrated performance. The transducers were anchored to cinder blocks and strategically positioned in the lake to maintain direct line-of-sight coverage of all areas where algae had been observed. One limitation encountered was the 100-metre cable length between the solar panel and each unit, which constrained placement options. Evaluation of this technology for its effectiveness in Swan Lake is ongoing.

5.6 Removal of Invasive Plants

As part of the Parks Refresh program for Swan Lake, herbicides were used on the Phragmites/common reeds in Swan Lake and the two stormwater management ponds, followed by physical removal by an amphibious vehicle in 2022. The herbicide application, which was carried out by licensed contractors working on behalf of the TRCA, was repeated in the spring of 2023.

5.7 Chloride Management

Chloride was identified as a key issue in the 2021 Plan due to increasing concentrations in Swan Lake that exceeded applicable water quality guidelines. In urban watersheds such as Swan Lake, chloride loading is primarily associated with winter maintenance activities (e.g., road salt application), as well as contributions from stormwater infrastructure and potential groundwater pathways.

Chloride is a conservative contaminant that accumulates in aquatic systems and is not readily removed through natural processes or conventional in-lake treatments. As a result, chloride management is fundamentally constrained to source control and reduction of inputs, rather than in-lake remediation.

Given these constraints, the City's approach to chloride management has focused on improving understanding of sources and pathways, monitoring trends, and evaluating practical measures to reduce chloride loading to the lake. Management activities since 2021 have included:

- Monitoring and Data Collection

The City has continued to implement a monitoring program to characterize chloride concentrations in Swan Lake and key inflows, including stormwater management ponds and oil-grit separators (OGSs). This monitoring provides the basis for evaluating temporal trends, identifying potential sources, and supporting model development and management decision-making.

- Operations, Maintenance, and Inspection

Routine inspection and maintenance of stormwater infrastructure (e.g., ponds and OGS units) has been undertaken to ensure proper system function and to support water quality objectives. While these activities are not designed specifically for chloride removal, they are important for maintaining hydraulic performance and supporting overall watershed management.

- Water and Chloride Budget Development and Mass Balance Modeling

A comprehensive water and chloride budget was developed to quantify inflows, outflows, and chloride loading to the lake (City of Markham, April 2026). This work provides a foundational understanding of the relative importance of different sources and pathways and supports evaluation of potential management strategies.

A monthly chloride mass balance model was also developed to simulate lake chloride concentrations based on inflows, outflows, and estimated chloride loads (BlueCycle Canada, April 2026). The model was used to evaluate the relationship between external loading and observed lake concentrations and to assess the relative importance of different loading estimates. Overall, the model is considered a planning-level diagnostic tool, useful for understanding system behaviour, identifying key uncertainties, and supporting future refinement as additional monitoring data become available.

- Flow Diversion Study

Evaluation of source control through structural modification was included in Phase 3 of the Plan, to be pursued if other management measures were not sufficient. In 2022, and at the request of FOSLP, Council directed staff to bring forward this evaluation to Phase 1. In 2023, the City retained AECOM Canada to develop a dual drainage hydraulic model using InfoWorks ICM to assess the feasibility of diverting stormwater runoff from Swan Lake (AECOM, May 2025). The analysis focused on evaluating whether stormwater flows could be redirected without increasing flood risk within the study area or at downstream locations. A range of diversion scenarios was evaluated, including redirection of stormwater flows from key inflow points, capture and diversion of higher-strength “first flush” runoff, modification of existing flow control structures, expansion of upstream storage capacity, and implementation of combined or integrated approaches. The analysis estimated reductions in stormwater flows ranging from 6% to 46% for the scenarios evaluated.

- Research and Emerging Treatment Technologies

Evaluation of new technologies for chloride treatment was included in Phase 2 of the Plan. At the request and based on a proposal solicited by FOSLP, Council directed staff to support a research initiative by York University to evaluate potential treatment approaches for chloride removal from water using biochar filtration systems. Initial results indicate that the biochar materials tested to date are not effective for chloride removal under typical lake conditions, with increases in chloride observed in low-concentration samples and only limited reductions at higher concentrations. York University is currently testing alternative materials (e.g., eggshell-based media and polymers). This research scope agreed-upon by the City is expected to be completed by the end of 2026.

5.8 Evaluation of Management Outcomes (2021-2025)

Management activities implemented since 2021 have focused on reducing internal and external phosphorus loading, controlling waterfowl inputs, managing fish populations, and improving overall ecological function in Swan Lake. Monitoring data and updated modelling indicate that water quality improvements have met or exceeded the interim targets established in the 2021 Plan and are consistent with predicted responses described in FWR (2020) (Table 9).

Table 9: Evaluation of Management Outcomes Relative to 2021 LMP Targets

Parameter	2021 LMP Baseline	Interim Target (2021 LMP)	2022–2024 Observed	Status
Total Phosphorus (µg/L)	>200	50–100	~20–30	Exceeded
Secchi Transparency (m)	<0.5	0.6–0.8	~0.6–0.8	Achieved
Chloride (mg/L)	~700	400–500	~200	Exceeded
Frequency of Algal Blooms	Annual	Every 3 years	No significant surface blooms; minor localized accumulations	Achieved
Internal P Load (kg/yr)	~53	0–25	~0	Exceeded
External P Load (kg/yr)	~30	~15	~9–11 (typical)	Achieved

Total phosphorus concentrations declined from historically eutrophic conditions (>200 µg/L) to approximately 20–30 µg/L, substantially exceeding the interim target of 50–100 µg/L. This response is consistent with FWR (2020) predictions that control of internal phosphorus loading would be the primary driver of improved water quality. Mass balance modelling confirms that internal phosphorus loading, previously a dominant source (~50 kg/year), has been effectively eliminated and remains negligible through 2024 (BlueCycle Canada, April 2026). As a result, Swan Lake has transitioned from an internally driven system to one in which external inputs govern water quality.

External phosphorus loading has declined to approximately 9–11 kg/year under recent conditions, achieving the interim target and reflecting the combined effects of watershed management measures and improved stormwater system performance (BlueCycle Canada, April 2026). Continued control of external inputs is now the primary factor influencing future water quality.

Water clarity improved from less than 0.5 m to approximately 0.6–0.8 m, meeting the target range. While gains in Secchi depth are more moderate relative to phosphorus reductions, this response is consistent with shallow lake conditions where sediment resuspension and non-algal turbidity continue to influence clarity.

Reductions in algal bloom occurrence have been significant, with no widespread or persistent surface accumulations observed in recent years. Minor, localized accumulations have occasionally been observed along shoreline areas but do not represent whole-lake bloom conditions. Based on the FWR (2020) definition of bloom conditions in terms of aerial extent and persistence, the interim target has been achieved. The additional PAC treatment applied in 2024 is expected to further support control of internal phosphorus release and help maintain these conditions.

Dissolved oxygen conditions have improved substantially as predicted by FWR (2020) with reduced phytoplankton biomass following internal and external phosphorus management. Historically, anoxic conditions near the sediment–water interface were significant, promoting internal phosphorus release and contributing to poor water quality. Recent monitoring indicates that low oxygen conditions are now limited in both extent and duration, generally confined to deeper portions of the lake, as would be expected for a shallow, warm-water, urban lake. Dissolved oxygen levels meet Provincial Water Quality Objectives for the protection of aquatic life, and anoxia during the open water season is no longer a significant concern that would require active management.

A key ecological response has been the establishment of submerged aquatic vegetation (SAV) in 2024–2025, representing a major shift from historically phytoplankton-dominated conditions. This development reflects improved light availability and reduced nutrient concentrations and is expected to contribute to long-term stabilization through sediment stabilization, nutrient uptake, and increased resistance to algal dominance.

Chloride concentrations have declined substantially from approximately 700 mg/L under pre-2021 conditions to approximately 200 mg/L in recent years, exceeding the interim target range of 400–500 mg/L. This improvement is attributed primarily to stormwater system maintenance, including removal of flow constraints (Pond 105 inlet blockage). Despite these gains, chloride remains a conservative parameter controlled by external loading associated with road salt application and watershed processes. As a result, further reductions may be limited under current conditions, and continued emphasis on source control and monitoring if it is shown that current concentrations are a detriment to aquatic habitat improvement.

5.9 Summary and Costs

Management actions implemented since 2021 have been highly effective, with all primary interim targets achieved or exceeded. Observed responses align closely with FWR (2020) predictions, particularly with respect to the dominant role of internal phosphorus loading and the effectiveness of chemical treatment. Improvements in dissolved oxygen conditions and the establishment of SAV further confirm that internal loading has been effectively controlled and that key ecological feedbacks are now supporting improved lake function.

Swan Lake has transitioned from a highly eutrophic, internally driven system to a more stable condition in which water quality is governed primarily by external inputs. Continued monitoring and adaptive management will be required to sustain these improvements, with a focus on controlling external nutrient inputs, maintaining internal nutrient control through periodic chemical treatments, maintaining stormwater system performance, and supporting long-term ecological stability.

Total cost for the implementation of Phase 1 measures was about $1,000,000 for water quality improvement (through the Environmental Services department), with additional expenses for shoreline management through the Operations department. Details are shown in Section 8 (Table 12).

5.10 Stakeholder Engagement and Education

5.10.1 Resident Initiatives and Public Consultation

The residents of Swan Lake Village have been very involved in making observations about the Lake conditions and the natural and built environment around it.

In 2010, Professor Jon Van Loon sent an email to Councillor John Webster asking for data regarding water quality in Swan Lake. He subsequently reviewed the reports provided and sent an email to all members of Markham Council asking for action to clean up the Lake. After the Phoslock treatment and for several years, he was actively following the initiatives and studies completed at Swan Lake.

In 2019, the newly formed resident group, Friends of Swan Lake Park (FOSLP), contacted the City to report their observations of the Lake, and to request available technical reports and drawings. Over the past seven years, FOSLP has been actively pursuing a number of initiatives and provided the City with several reports and presentations, which have been considered in the development of this Plan.

In March 2024, the City held a community meeting at Markham Museum for the members of the public interested in the Swan Lake water quality improvement program. The meeting was attended by more than 100 residents, and a presentation was delivered on the program details.

Extensive consultations with FOSLP and their external advisors were conducted in 2026, through which staff reviewed and held meetings with report authors to discuss these submissions. Appendix A provides the submissions, staff feedback, and meeting presentations and minutes.

5.10.2 Engagement and Education

The City maintains a website to share information and document activities and outcomes, including City Council directions related to Swan Lake (www.markham.ca/swanlake).

In 2020, algae signs were installed at multiple locations around Swan Lake to warn the public about the potential presence of toxic algae and against water contact for humans and pets.

Staff developed educational signs in 2021 to remind residents of the environmental impact of geese and to encourage them to submit geese observations through an online App, which has been used by a number of residents. Since 2023, staff have also been collaborating with researchers from Trent University, who are studying the bioaccumulation of Rare Earth Elements (REE) in aquatic biota. Swan Lake was chosen as a study site due to the presence of lanthanum, an REE used in the manufacturing of Phoslock.

6. Policy Direction and Goal Statement

6.1 Federal and Provincial Regulations

Based on a communication from the DFO, no review pursuant to the Fisheries Act or the Species at Risk Act is required for "artificial water bodies that aren't connected to a water body that contains fish at any time during any given year, such as quarries and aggregate pits" (Fisheries and Ocean Canada, 2021).

The MNDMNRF would be involved in the approval process of any undertaking on Crown Land. The bed of Swan Lake "is not designated as Crown Land, and as such activities affecting the bed of Swan Lake would not be subject to approvals under the Public Lands Act" (Ministry of Natural Resources, 2013).

The MECP has been involved in the approval of a chemical treatment for Swan Lake both in 2013 (Phoslock) and 2021 (PAC), and will need to be consulted for any future undertakings.

All new or retrofit stormwater management systems are regulated by the MECP through an Environmental Compliance Application (ECA) Section 53 of the Ontario Water Resources Act.

Through the Rouge River Watershed Plan, the TRCA supports "a healthy aquatic system that supports a diversity of native habitats and communities and provides sustainable public use opportunities" for the Rouge watershed (Toronto and Region Conservation Authority, 2007)

The TRCA regulates any proposed development, interference, or alteration within a Regulated Area ((O. Reg. 166/06, 1990), which does not apply to Swan Lake.

6.2 Markham Strategies and Bylaws

The City of Markham launched a strategic plan in 2008 called Building Markham's Future Together, which has been updated periodically. One of the goals of this plan is to build a safe, sustainable, and complete community through protecting and enhancing the natural environment and built form, among other approaches (City of Markham, 2019).

The City also launched a Greenprint plan in 2011 (City of Markham, 2011) to improve the natural environment and enhance the quality of life in Markham. The Greenprint is a 50 plus year plan with a bold vision and a strong leadership commitment to make Markham one of the most livable and sustainable communities in North America.

The City of Markham Official Plan (2014) provides land use policy direction to guide future growth and development in the City. The Markham OP includes policies for environmental protection, natural heritage conservation, water resource planning and the management of natural hazards. In accordance with the Planning Act, the City of Markham is undertaking a review of the City of Markham Official Plan (2014) to determine updates necessary to bring the plan into conformity with provincial policies and plans, integrate relevant direction from the York Region Official Plan (2022) and address local priorities and planning needs.

6.3 Goal Statement and Level of Service

Based on the review of applicable policies and strategies, as well as input received from stakeholders, a narrative was developed as a goal statement for water quality management in Swan Lake, as follows:

To improve the overall health of Swan Lake, which will provide opportunities for no-contact activities for the enjoyment of the community.

Numerical water quality targets for Phase 1 of the Plan were initially developed in 2019 (Freshwater Research, July 2020) and subsequently refined through evaluation of treatment scenarios (Freshwater Research, August 2021). For Phase 2 (2026-2030), these targets have been further reviewed and updated based on:

- Recent monitoring data and model results
- Lake and watershed characteristics
- Observed response to Phase 1 management measures
- Practical achievability under current conditions.

The proposed updated targets represent interim (adaptive) levels of service that reflect current achievable water quality conditions following implementation of Phase 1 management measures. While substantial improvements have been realized, Swan Lake remains in a transitional state, with ongoing ecological adjustment and variability in external inputs. These targets are considered appropriate for Phase 2 implementation and are intended to guide management over the next five years, after which they will be reviewed and updated based on monitoring results and continued improved understanding of system processes.

Table 10 presents the proposed interim (adaptive) targets for Swan Lake. Detailed descriptions of the targets and their rationale are described in Swan Lake Management Targets Update (BlueCycle Canada, Inc., 2026)

Table 10: Proposed Interim Targets for Swan Lake for the next five years (2026-2030)

Parameter	Current Values*	Interim Target*	Objective and Rationale
Total phosphorus (µg/L)	<20	≤20 (<30 for single events)	Aligns with the Provincial Water Quality Objective (20 µg/L) as a benchmark and reflects current observed conditions. The target is intended to maintain current conditions, recognizing that only modest further reductions may be achievable or warranted.
Secchi Transparency (m)	~0.6–0.8	≥0.6	Represents sufficient light availability to support establishment and persistence of submerged aquatic vegetation (SAV). At current nutrient levels, Secchi is influenced by multiple factors and is no longer a reliable surrogate for phosphorus.
Chloride Concentration (mg/L)	~200 (2024–2025 average)	200–400	Reflects substantial improvement from historical conditions (>700 mg/L). Target maintains concentrations below levels associated with increased ecological risk while recognizing constraints from ongoing road salt use, background concentrations, and potential groundwater inputs.
Frequency of Cyanobacteria blooms	Periodic blooms; densities near guideline thresholds	Reduced frequency, duration, and severity; generally, ≤50,000 cells/mL	Based on Health Canada recreational guidance for primary contact use. Target supports reduced health risk and improved conditions while recognizing that blooms may still occur under certain conditions. Focus is on long-term system response rather than elimination.
Internal phosphorus load (kg/yr)	~0	≈0 (negligible)	Internal loading has been effectively controlled following treatment and is no longer a dominant source. Maintaining negligible internal loading is critical to sustaining current lake conditions.
External phosphorus load (kg/yr)	9–17	≤12–15	External inputs now control lake phosphorus concentrations. Target reflects recent post-treatment conditions with an allowance for variability in flow. Continued BMP implementation is required to maintain gains and limit increases during higher-flow years.

*Unless otherwise indicated, targets represent open water season (April–November) average conditions.

7. Analysis and Discussion of Lake Management Measures

Through a review of the history and the current state of the Lake (Sections 2 to 5), and based on the proposed lake management objectives (Section 6), a number of issues and opportunities were identified for lake management for Phase 2 (2026-2030), including:

- Swan Lake is not a natural feature, and water does not enter and exit the system like in most natural systems. Contaminants that enter the system build up over time, leading to poor water quality.
- The land use surrounding Swan Lake has changed significantly over the past 30 years. Starting as farmlands, it has changed to a residential community, including a gated community and senior housing development. Major land use types include community/ infrastructure (75 %) open water, including the Lake (15%) and tree canopy or parks (10 %).
- Average contributions from different sources of water to the Lake include direct precipitation (47%), direct runoff (4%), and controlled runoff (49%). Due to scarcity of data, and intrinsic challenges with measurement in a shallow urban environment groundwater has not been quantified independently and rather calculated as the balance of other measured or estimated inflows and outflows.
- Two stormwater ponds and three oil and grit separators (OGS) collect and treat runoff from 80% of the catchment.
- The City owns most of the Lake except for a small portion in the south.
- The two stormwater ponds and two OGS units are owned and maintained by the developers. Storm sewer lines within the catchment are owned by the City and the private condominium corporation. The Region of York owns the 16th Avenue sewer line.
- Winter maintenance of 1 km (15%) of the catchment roads and sidewalks is completed by the City of Markham, and the remaining roads, as well as about 3600 m^2 of parking areas, are serviced privately.
- Internal phosphorus loading, historically the dominant source of nutrients to the lake, has been effectively controlled following in-lake treatment and is now negligible.
- External phosphorus inputs, including contributions from stormwater runoff and waterfowl, now represent the primary sources influencing lake water quality.
- Dissolved oxygen conditions have improved substantially, meeting guidelines for aquatic life and limiting internal phosphorus release potential from sediments.
- Submerged aquatic vegetation (SAV) has become established under recent conditions, representing a significant ecological shift toward a more stable, clear-water state.
- While water quality has improved significantly, the lake remains sensitive to external inputs and ongoing watershed influences.
- Chloride concentrations have declined substantially from historical levels but remain governed by external loading associated with road salt use and watershed processes.
- Groundwater contributions to water and chloride balance remain uncertain and may influence long-term system response.
- Stormwater infrastructure performance and maintenance continue to play an important role in controlling water and contaminant inputs to the lake.
- Climate variability, including warmer temperatures and altered runoff patterns, may influence future nutrient and chloride dynamics and water quality.

- The fish community remains simplified, and ongoing management is required to support ecological balance.
- Swan Lake continues to provide important recreational, aesthetic, and ecological value, with strong community interest in maintaining and improving lake conditions.

Multiple management measures were developed in consultation with stakeholders and evaluated to address these issues and opportunities, as described here. Each measure was evaluated for technical feasibility and effectiveness (water quality), maintenance and operation needs, terrestrial and aquatic environment, construction impacts, public safety, the cost to the City, and community benefits/impacts.

7.1 Measures to Control Internal Nutrient Load

7.1.1 Chemical Treatment for Phosphorus Control

Chemical treatment with Phoslock or Poly Aluminum Chloride (PAC) has been identified as the most effective and immediate method of controlling internal phosphorus load in Swan Lake (Freshwater Research, July 2020). Recent chemical treatments using PAC have effectively controlled internal phosphorus loads and should be continued in Phase 2 at a modified dosage and frequency. Prior to the next application, a targeted sediment survey following the approach used by Freshwater Research (January 2021) is recommended to confirm dosage requirements. Pending the results of the survey and observed lake phosphorus concentrations, the treatment may be postponed by more than three years following the last application.

A modified application of chemical treatment (PAC) to Swan Lake costs about $132,000 or $44,000 per year for a three-year cycle. A sediment survey costs about $15,000 (only one is required).

7.1.2 Bottom-Dwelling Fish Management

Bottom-dwelling fish (carp and goldfish), while not a significant source of phosphorus, contribute to the disturbance of lake sediment and thus the release of internal load. One study concluded that the presence of large carp contributed 23% to summer internal loading (Kelton & Chow-Fraser, 2005). Therefore, fish management is recommended as a method for internal load control.

Removal of bottom-dwelling fish cost about $10,000 annually.

7.1.3 Nitrogen Control

Targeted nitrogen control is not warranted for Swan Lake. Monitoring and prior studies confirm that phosphorus is the limiting nutrient in the system, and that reductions in phosphorus loading are the primary driver of water quality improvement. Nitrogen concentrations have declined in response to reduced productivity following phosphorus control, and additional reductions are expected through ongoing management measures, including geese management. In addition, cyanobacteria are less responsive to N-limitation, and low inorganic concentrations of nitrogen may give cyanobacteria a competitive advantage over other algae (Freshwater Research, August 2021).

Staff and City consultant previously reviewed a number of proposals brought forward by FOSLP to further decrease nitrogen load, including water circulation with pre-treatment, bioswales, and manufactured floating treatment wetlands, and recommended against them.

7.2 Measures to Control External Nutrient Load

7.2.1 Geese Management

Geese defecation contributed to more than 68% of the external phosphorus load in Swan Lake (2022-2024 average), and is thus an important load to manage. Geese management is therefore recommended to continue, including existing programs (hazing, nest and egg management, and relocation), as well as exploring new methods to deter migratory geese. As the strobe light have not been effective, these should be removed from the program.

The annual cost for the enhanced geese management programs at Swan Lake (and Toogood Pond) is about \$50,000. Additional measures completed in 2021 cost about \$8,500 (including extended hazing, nest management and geese relocation). Funds will be required for new methods such as nighttime hazing (at an estimated cost of \$31,500 annually).

7.2.2 Stormwater Management Facilities Maintenance

Stormwater ponds and OGS's contribute to about 18% and 7% of the external load, respectively (assuming that the facilities are working as per design). Proper maintenance, including sediment removal and inlet and outlet cleaning, are essential in controlling the flow of nutrients to the Lake.

Currently, all these facilities are owned and operated by the developers. Once all existing underground and aboveground deficiencies are rectified, the City will proceed with the process of Acceptance for Maintenance of the two stormwater management ponds, followed by Assumption (transfer of ownership). Once Swan Lake Boulevard is assumed, the City will own and maintain sewer infrastructure and OGS assets on Swan Lake Boulevard.

The annual cost for the maintenance of the two stormwater ponds, including any future cleanout, will be through the City's pond maintenance program. Maintenance costs are in the order of a few thousand dollars for occasional repairs and about \$500,000 per pond for cleanout and retrofit, occurring at an approximate frequency of every 15 years.

7.2.3 Shoreline Planting and Access

It is estimated that the shoreline runoff contributes to about 18% of the external load. This might be a conservatively high estimate given that phosphorus-based fertilizers are not used in the Park, and geese contribution has been included in the mass balance separately. Nonetheless, it will still be helpful to use Best Management Practices (BMP's) in the Park, including controlled lakeshore access via boardwalks and plantings around the lakeshore, to adsorb pollutants and prevent geese from accessing the Lake.

The Parks Department worked with the TRCA to develop a plan for shoreline planting/improvements. Design consultation for shoreline improvements was identified as one initiative through the Swan Lake Park, Parks Operations and Parks Refresh Draft Plan presented to Council on November 2, 2020. This work is ongoing and included the installation of geese exclusion posts and fencing with wire mesh, and shoreline planting. The list of plants selected was modeled from the TRCA - recommended riparian shoreline restoration initiatives, and include Serviceberry, Common Buttonbush, Red Osier Dogwood, Smooth Sumac and Common Elderberry.

7.2.4 Groundwater and Historic Dumping

Due to the lack of data, the nutrient budget for Swan Lake does not include any potential contribution of groundwater and the historic dumping in the surrounding area to the south and west of the Lake. This dumping site was operational from 1983 to 1999 and received household waste, and so leaching of nutrients from the site is likely (Freshwater Research, January 2017).

Information on groundwater is scarce, and extensive site investigations and a detailed groundwater model will be required to quantify groundwater contribution.

Site investigation of the historic dumping areas will require participation of the developers and private owners, and given the minimal contribution of internal sources, this measure is therefore given lower priority.

7.3 Measures to Improve Oxygen Level

Historical monitoring indicated that Swan Lake experienced periods of oxygen depletion during summer stratification, which contributed to internal phosphorus release from sediments and degraded aquatic habitat conditions. As a result, various artificial oxygenation approaches, including mechanical aeration and chemical oxygen release methods, were previously considered.

Monitoring results since 2021 indicate that dissolved oxygen conditions have improved substantially. The extent and duration of low-oxygen conditions have been significantly reduced, and anoxia is no longer a dominant driver of internal phosphorus loading or water quality impairment in the lake.

Based on current conditions, active oxygenation measures are not recommended. Such measures would provide limited additional benefit and, in the case of mechanical aeration, could result in unintended adverse effects, including sediment disturbance and increased nutrient release. Chemical oxygenation approaches remain experimental and are not warranted given the observed improvements in dissolved oxygen conditions.

Ongoing monitoring will be used to confirm that current conditions are maintained; however, additional oxygen management measures are not warranted at this time.

7.4 Measures to Control Chloride Concentration

7.4.1 Winter Maintenance on Private Land

About 85% of the roads (5.5 km), as well as 3600 m^2 of parking areas in the catchment, are serviced privately. Salt reduction on private lands is, therefore, an important component of a chloride reduction strategy. This could be achieved through engaging the developers and private owners within the community on the rate and frequency of salt applications and chloride alternatives to prevent excessive salt application while keeping the appropriate level of service. Reduction of chloride load to the Lake could also be achieved through more frequent snow removal and disposal (rather than letting snowmelt find its way to the Lake).

It would be beneficial that winter operators are trained through the 'Smart About Salt' program to understand the impact of chloride on the environment and the importance of complying with recommended salting rates, the operation of the salting equipment at a higher threshold, and the merits of using low chloride products. The logistics of this measure will need to be discussed as the majority of winter maintenance is undertaken by private contractors for private landowners.

7.4.2 Physical or Biological Treatment

A number of methods were reviewed for removing dissolved chloride from the Lake water, including adsorption on media (e.g., , biochar), solar still, and biological treatment by chloride-tolerant plants (Fleming College, February 2021).

A research initiative is ongoing by York University to evaluate potential treatment approaches for chloride removal from water using biochar filtration systems. Initial results indicate that the biochar materials tested to date are not effective for chloride removal under typical lake conditions, with increases in chloride observed in low-concentration samples and only limited reductions at higher concentrations.

The use of salt-tolerant vegetation (halophytes) is an emerging, nature-based approach for managing chloride in urban environments. These plant species are adapted to saline conditions and may help to intercept, uptake, or retain chloride in soils before it is transported to receiving waters. However, successful chloride depletion in receiving waters by biological treatment or alien chloride-tolerant plants is questionable, and case studies with quantitative results are not reported in the scientific literature (Freshwater Research, April 2021).

A pilot-scale phytoremediation project is currently underway at Lake Wilcox (Richmond Hill), led by the Toronto and Region Conservation Authority (TRCA), York Region, Toronto Metropolitan University, and the Royal Military College. The project is evaluating the effectiveness of halophytes in reducing chloride concentrations through several applications, including roadside seed mixes, targeted plug plantings in salt-impacted soils, and integration with urban tree plantings to improve soil conditions and vegetation health. Monitoring of vegetation performance, soil chemistry, and associated environmental conditions is expected to provide insight into the feasibility and effectiveness of this approach.

At this time, application of halophytes in the Swan Lake watershed is considered a measure for future consideration, pending results from ongoing studies and evaluation of site-specific feasibility. The City will continue to monitor developments in this area, including outcomes from the Lake Wilcox project, to determine whether similar approaches could be incorporated into future chloride management strategies.

7.4.3 Redirecting Stormwater

In 2023, a feasibility study was completed for diverting stormwater runoff from Swan Lake (AECOM, May 2025) to identify scenarios where stormwater flows could be redirected without increasing flood risk within the study area or at downstream locations, and reduce chloride load to the Lake. The analysis estimated reductions in stormwater flows ranging from 6% to 46% for the scenarios evaluated, ranging in cost from $125,000 to $7,000,000. While these strategies may have nominal benefits in terms of chloride input, given that chloride concentration have decrease significantly since the initiation of this study, even the highest-ranking scenario are not recommended at this point. Structural measures for reducing chloride concentration may be considered in Phase 3 if other efforts for improving aquatic habitat are not successful due to chloride concentration.

7.5 Measures to Improve Natural Heritage Features

7.5.1 Shoreline Planting

See section 7.2.3.

7.5.2 Planting and Evaluation of Submerged Water Plants

Planting of submerged aquatic plants (SAV) was recommended in the 2021 plan once phosphorus was controlled to consistent concentrations below 0.100 mg/L and transparency improved. SAV has since colonized naturally in response to improved light conditions in the lake. SAV plantings, therefore, are no longer recommended as a management action.

Future efforts should focus on monitoring the developing plant community, with consideration of targeted plantings to introduce additional species (e.g., floating-leaved vegetation) to increase habitat diversity and ecological function.

A repeat comprehensive aquatic vegetation survey is recommended in approximately five years, unless earlier changes in lake conditions warrant reassessment. This timing would allow evaluation of the persistence, expansion, and composition of the naturally established plant community and help inform whether any additional vegetation management is needed. Estimated cost for this activity is $10,000.

7.5.3 Fish Stocking

Now that phosphorus concentrations in water are reduced, dissolved oxygen levels and water clarity have improved, and SAV has established, the water quality and habitat of Swan Lake could be suitable for additional fish species, and at which point a Fish Management Plan will be completed. The plan will include discussions with the TRCA and MNRF regarding suitable species and the potential of stocking, and will consider the success of the 2025 stocking program (overwintering survival). While habitat conditions in the open water season may support stocking, winter conditions under ice may not be favourable for overwintering of stocked fish due to the shallow conditions of the lake with little deep-water refugia and potential under-ice anoxia. The plan will also consider the installation of submerged woody habitat (e.g., logs) to increase structural complexity and enhance fish habitat.

The MNRF has indicated that they would support elevating Swan Lake as a potential candidate for a pilot project with Fish Culture, given the City allows public angler access to the Lake. Through this program, the Ministry will raise largemouth bass and bluegill sunfish in their hatcheries for stocking in stressed urban waterbodies not suitable for the typical stocking of trout or walleye. Public angler access, however, is key for any government-supported stocking (W. Wegman, personal communication, August 5, 2021).

8. Proposed Strategy

8.1 Summary of Evaluation of Lake Management Measures

Table 11 provides a summary of measures evaluated in Section 7 for feasibility, effectiveness, and costs over 25 years.

Table 11: Evaluation of Lake Management Measures

Issue	Measure No.	Description	Technical Feasibility and Effectiveness	Unit Cost
Internal Load	IL1	Chemical Treatment for Phosphorus Control	Feasible; lowers nutrient input from the most significant and bioavailable source and hence the most immediate and effective solution.	$132,000 per modified application (three-year intervals) $15,000 sediment survey
	IL2	Bottom-Dwelling Fish Management	Feasible; lowers internal load release.	$10,000 annually
	IL3	Nitrogen Control (by pumping & treatment or artificial wetlands)	Not recommended- Nitrogen does not control algae growth in Swan Lake	N/A
External Load	EL1	Geese Management (including Toogood Pond)	Feasible; lowers nutrient input from the most significant external source.	Enhanced measures: $50,000 annually
	EL2	Stormwater Management Ponds Maintenance (2 wet ponds)	Feasible; lowers nutrient input; currently maintained by the developers and, once ponds are assumed, by the City.	$1500 annually $500,000 cleanout ($33,000 annualized)
	EL3	Shoreline Planting/ Improvements	Feasible; lowers nutrient input by blocking geese access to the Lake, intercepts nutrient runoff	Funded
	EL4	Groundwater and historic dumping areas	Not recommended except for flow and chloride measurements	$10,000
Algae Blooms	AB1	Ultrasound Treatment	Feasible; potentially reduces phytoplankton biomass preventing surface blooms. Effectiveness for Swan Lake is still being evaluated.	Funded
Oxygen Level	OL1	Mechanical or chemical oxygenation	Not recommended- Oxygen levels are within water quality objectives and no management (mechanical or chemical) is needed.	N/A
Chloride Level	CL1	Winter Maintenance on Private Land	Stakeholder engagement for snow and salt management will help reduce chloride concentration.	Privately funded
	CL2	Physical or Biological Treatment	Review of chloride uptake by plants	Internal
	CL3	Redirecting Stormwater	Not recommended in Phase 2	$125K to $7M
Natural Features	NF1	Shoreline Planting/ Improvements	Feasible; will provide fish habitat	See EL3
	NF2	Planting and Evaluation of Submerged Water Plants	Not recommended. Natural colonization has occurred.	$10,000 (Survey every five years)
	NF3	Fish Management Plan and Fish Stocking	Feasible; pending outcomes of the 2025 stocking. Includes addition of submerged logs or other habitat structure	$10,000

8.2 Recommended Strategy

Based on monitoring, modelling, and evaluation of management outcomes for the 2021–2025 period, the core measures implemented in Phase 1 have been highly effective in achieving intended water quality improvements. Key targets for chloride, phosphorus, water clarity, algal bloom frequency, and internal loading have been met or exceeded, and the lake has transitioned from an internally driven system to one primarily influenced by external inputs.

Accordingly, the recommended strategy has been updated for Phase 2 and Phase 3 to focus on maintaining current conditions, optimizing management measures, and supporting long-term ecological stability through adaptive management, rather than expanding to more intensive or higher-cost interventions.

The plan relies on a set of "Core" measures established in Phase 1 that are deemed technically reliable and cost-effective. Additional "Complementary" measures are introduced in Phase 2 based on the review of Phase 1. Annual reporting and reporting at the end of each phase would be used to identify the need for additional measures to be considered in subsequent phases, and to refine the frequency and dosage of chemical treatment, based on monitoring and water quality results achieved. Further "Alternative" measures may also be considered in later phases (see items u) and v) but are expected to have a high cost, have challenges for implementation (e.g., activities on private lands) and may not be technically required to meet the proposed water quality goals.

The phased approach includes the following recommended measures:

Phase 1 (2021-2025): Core Measures - Completed:

a) Continue water quality monitoring and report on quality annually through Markham Subcommittee
b) Continue geese management and explore enhanced methods
c) Remove benthic-dwelling fish
d) Maintenance of stormwater management facilities (by developers then City)
e) Community engagement in reducing nutrient and chloride, data sharing, as well as progress reviews and plan updates
f) Chemical treatment in 2021 and 2024
g) Shoreline planting/improvements
h) Chemical oxygenation pilot project (by research institute) – not pursued
i) Evaluate Phase 1 measures

In Phase 1, several Complementary and Core measures that were identified for Phase 2 and Phase 3 were advanced, including:

- Fish stocking
- Planting of submerged plants
- New technologies for chloride (biochar research by York U)
- Flow diversion assessment

In Phase 1, several additional Complementary Measures were identified and implemented including:

- Ultrasound for algae control
- Water and chloride budget
- Submerged aquatic plant survey

Phase 2 (2026-2030): Adapted Core Measures and Complementary Measures:

j) Items a) to e) in Phase 1
k) Chemical treatment with adjusted frequency and dosage
l) Fish management plan and fish stocking
m) New technologies for chloride treatment (complete research by York U and evaluate chloride uptake by halophytes)
n) Lake sediment survey
o) Targeted groundwater flow and chloride monitoring
p) Shoreline plantings/improvements
q) Submerged aquatic plant survey
r) Ultrasound for algae control
s) Evaluate Phase 2 measures

Phase 3 (post 2030): Adapted Core Measures with or without Alternative Measures

t) Items j) to k) in Phase 2 with modifications if required
u) Investigate contribution from groundwater, if required
v) Evaluate/design structural modifications such as lake water recirculation and stormwater redirection, if required

At the end of Phase 2, a 5-year summary report will be completed, summarizing the effectiveness of the Adapted Core measures and evaluating additional Complementary measures to consider in Phase 3. Additional Complementary measures will be advanced based on needs to further improve water quality and considering the technical feasibility and cost-effectiveness of additional measures.

Table 12 provides a cost estimate for the 25-year life cycle based on the proposed phased approach. Cost estimate for some future measures is provided as an order of magnitude and for perspective.

The total cost for implementing Core and Complementary measures for the next 25 years as per the recommended plan, is about $5,584,000 (including pond cleanout), funded from the Environmental Services lifecycle. Implementing all measures, including the Alternative Measures, would cost about 8.7 to 2.6 million dollars (depending on the flow diversion scenario, and the extent of groundwater remediation work).

Table 12: Life-Cycle Cost Estimate

Measure	Phase 1 Plan	Phase 1 Actual	Phase 2 (2026-2030)	Phase 3 (2031-2050)	Total (Phases 2 and 3)	Current Life-Cycle (2021)	Increase Over Current Life-Cycle
Continue water quality monitoring	$149,000	$140,000	$168,000	$866,000	$1,034,000	$919,000	$115,000
Continue geese management and enhanced methods (including Toogood)	$275,000	$210,000	$419,000	$2,160,000	$2,579,000	$2,280,000	$299,000
Remove benthic-dwelling fish	$39,000	$50,000					
Fish management plan and fish stocking	$20,000	$10,000					
Planting of submerged plants	$20,000	$49,000					
Maintenance of stormwater management facilities	$2,000	$-	$6,000	$538,000	$544,000	$537,000	$7,000
Chemical treatment with adjusted frequency and dosage	$309,000	$331,000	$287,000	$1,040,000	$1,327,000	$1,380,000	$(53,000)
New technologies for chloride treatment	$50,000	$50,000	$-	$-	$-	$50,000	$(50,000)
Investigate dumping areas	$-	$-	$-	$20,000	$20,000	$-	$20,000
Investigate groundwater	$-	$-	$10,000	$-	$10,000	$-	$10,000
Evaluate structural modifications	$-	$120,000	$-	$-	$-	$120,000	$(120,000)
Other measures	$-	$15,000	$-	$-	$-	$-	$-
Evaluate measures	$25,000	$25,000	$28,000	$72,000	$100,000	$-	$100,000
Total	$889,000	$1,000,000	$908,000	$4,676,000	$5,584,000	$5,286,000	$298,000

Notes:
Phase 3 extended five years (20 years duration) to match 25-year life-cycle. Future life-cycle includes Phase 2 and Phase 3
Assumed pond cleanout/retrofit during the period.

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