MARKHAM

Report to: Markham Subcommittee Meeting Date: November 16, 2021

SUBJECT: Swan Lake Water Quality Management Plan

PREPARED BY: Robert Muir, Environmental Services, Ext. 2357
Zahra Parhizgari, Environronnemental Services, Ext. 2867

RECOMMENDATION:

1. THAT the report entitled "Swan Lake Water Quality Management Plan" be received;
2. AND THAT Staff implement the Plan presented as Option 1 including proposed Core and new Complementary measures beginning in 2023;
3. AND THAT an additional $2.35M over 25 years be reflected in the 2022 Lifecycle Reserve Update;
4. AND THAT Staff report back annually on water quality results and evaluation of adapted Core and Complementary measures for consideration in Phase 2 of the strategy through the Markham Sub-Committee with the participation of the Friends of Swan Lake Park;
5. AND THAT Staff be authorized and directed to do all things necessary to give effect to this resolution.

PURPOSE:

The purpose of this report is to present a Long-Term Management Plan for Swan Lake (the Lake) and to provide recommendations on how to improve and maintain Swan Lake's water quality in a sustainable manner.

BACKGROUND:

In 2011, the City initiated a study, including monitoring of the Lake, and found that high levels of nutrients were leading to the growth of algae and poor water quality in the Lake.

In 2013, Council approved a chemical treatment, called Phoslock®, to be applied to the Lake to capture nutrients in the water and lock them into the sediment at the bottom of the Lake.

Link to 2013 Council Report on Phoslock application

Active geese management started in 2014, focusing on resident geese at the beginning and extended to the management of migratory geese in 2016. The program aimed at reducing waterfowl loading of nutrients into the Lake. A monitoring program was also set up to measure changes in the system.

The Phoslock treatment improved water quality from hyper-eutrophic (excessive levels of nutrients and algae concentration) to eutrophic conditions (high levels of nutrients and algae) for two years; however, by 2016, water quality was as low as or lower than in the pre-treatment year.

In 2019, the City initiated a study to define a short-term and a long-term strategy for water quality management in Swan Lake. On June 15, 2020, General Committee received the presentation *Swan Lake, Water Quality Improvement Program*, including recommendations for long-term quality management defined as “as balanced approach in maintaining water quality at an acceptable level during typical weather conditions”. The Swan Lake Water Quality Program was approved and staff was directed to implement the following elements:

i) Continued annual monitoring,
ii) Continued annual geese control with review of additional options related to vegetation and strobe lights,
iii) Sediment analysis to guide the frequency and dosing of chemical treatment and to provide direction on level of service and future treatments,
iv) Chemical treatment commencing in 2021 to address internal loading, and
v) A new fish management program.

Link to June 2020 Presentation to General Committee - “Swan Lake, Water Quality Improvement Program”

Staff were also directed to “report back in 2021 with an overall water quality (with service levels) and park improvement program that will be sustainable into the future”. Reporting back on this matter to General Committee was recommended through the Markham Sub-Committee with the participation of the Friends of Swan Lake Park.

Link to June 2020 Council Resolutions

Options for geese management were subsequently presented to General Committee on September 21, 2020 in *Geese Management at Swan Lake, Overview of Options and Path Forward*. Council approved the recommendations, including geese relocation by TRCA in 2021, the installation of strobe lights, and modification of habitat to deter geese through the Park Refresh Plan.

Link to September 2020 Presentation to General Committee - “Geese Management at Swan Lake, Overview of Options and Path Forward”

Link to September 2020 Council Resolutions

The Park Refresh Plan was presented to General Committee on November 2, 2020 in *Swan Lake Park – Parks Operations and Parks Refresh Draft Plan*. Council approved Parks Refresh Initiatives including shoreline improvements/habitat modifications to reduce resident geese populations. The scope of these improvements would include the one-time removal of invasive species and the use a combination of fencing/planting and natural stone to reduce geese population access.

Link to November 2020 Presentation to General Committee – "Swan Lake Park – Parks Operations and Parks Refresh Draft Plan"

Link to November 2020 Council Resolutions

Following the above Swan Lake Water Quality Improvement Plan, Geese Management at Swan Lake, and Parks Refresh Draft Plan, the following projects have been completed or are underway:

- Annual monitoring
- Enhanced geese management (relocation 2021), and strobe light installation (2020/2021)
- Sediment sampling (Fall 2020) and future dosing analysis
- Fish management (inventory, relocation, removal – Spring 2021)
- Treatment planning and 2021 water treatment (August 2021)
- Scenario analysis for level of service and future treatments (see Attachment B)
- Stakeholder engagement and education (Communication with Friends of Swan Lake Park and other residents, developers, researchers)
- Engagement of the TRCA to study the current state and make recommendations regarding a scope of work for shoreline modifications Fall 2021-Spring 2022

Geese management is currently being supported by community volunteers including geese counts, coordinated through Friends of Swan Lake Park.

As measures to manage Swan Lake water quality have expanded over time, funding allocated through the Environmental Services lifecycle planning and budgeting process has increased. The 25-year lifecycle budget for water quality monitoring and geese control of $0.89M in 2018 has increased to $2.87M in 2021 due to expanded monitoring and geese control measures and the addition of fish management and regular chemical treatment.

OPTIONS/ DISCUSSION:

Issues and opportunities for lake management were identified, and several lake management measures were developed with input from stakeholders. The Swan Lake Long-Term Management Plan (Attachment A) provides a detailed description and evaluation of each measure. Some measures considered and proposed by stakeholders have not been advanced due to significant cost and uncertain benefits, and potential impacts. This includes optional measures such as withdrawal and treatment of water in a bioswale and aeration, previously assessed and not recommended in the June 2020 presentation to General Committee. These measures have been further assessed and screened from further considerations as described in Attachments A and B.

Option 1 – Expanded Core and Complementary Measures

Based on the evaluation of all identified measures, a phased approach is recommended for the Swan Lake water quality improvement. The recommended Option 1 includes a range of measures that represent an overall water quality program related to a sustained improved service level, requested in June 2020. The program defined in Option 1 is intended to reach targets identified in Attachment A, including a low eutrophic condition after treatment, increasing to eutrophic in the third year. Water clarity would be increased relative to existing conditions and algae bloom frequency would be reduced from annually to every three years.

This strategy and its program measures 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: Core Measures for the first five years:

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)
i) Evaluate Phase 1 measures

In Phase 1, the following measures are currently funded in the Environmental Services lifecycle:

- Water quality monitoring
- Geese Management
- Fish removal
- Chemical (e.g., Phoslock or PAC) treatment

The following Phase 1 measures are new/expanded projects that require additional funding/resources:

- Enhanced geese management
- Shoreline planting/improvements

In Phase 1, new measures that would be advanced and that would not require additional funding/resources include:

- Community engagement
- Chemical oxygenation pilot project (by research institute)

Phase 2: Adapted Core Measures and Complementary Measures for years five to ten:

j) Items a) to e) in Phase 1
k) Chemical treatment with adjusted frequency and dosage
l) Fish management plan and fish stocking (through Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF))
m) Planting of submerged plants

n) Evaluate new technologies for chloride treatment
o) Evaluate Phase 2 measures

Phase 3: Adapted Core Measures with or without Alternative Measures past year ten

p) Items a) to e) in Phase 1
q) Chemical treatment with adjusted frequency and dosage (considering climate change impacts)
r) Investigate groundwater and dumping areas contribution if required
s) Evaluate/design structural modifications such as lake water recirculation and stormwater redirection

At the end of Phase 1 in 2026, a 5-year summary report will be completed, summarizing the effectiveness of Core measures and evaluating additional Complementary measures to consider in Phase 2. 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. Similarly, following Phase 2, a summary report will be completed identifying any Alternative measures can be advanced. The 25-year lifecycle cost for the recommended Option 1 is $5.22M, excluding any future measures identified as part of the adaptive management process. A breakdown of the current program costs totaling $2.87M in the 2021 Lifecycle Update, and the incremental cost of $2.35M for Option 1 is included as Attachment C.

Based on results of past chemical treatment efforts, including initial monitoring results from the 2021 treatment, and proposed measures to control the largest external phosphorus loads, Staff has a high level of confidence that the recommended option will meet the proposed water quality targets. The recommended plan has been reviewed and accepted by the City's limnology specialist consultant. The proposed adaptive management approach including regular monitoring and reporting will allow the effectiveness of the plan to be evaluated with management measures to be adjusted over time, as required. For example, Complementary measures identified in Phase 2, such as fish management planning or planting of submerged plants may be advanced to the end of Phase 1, depending on water quality conditions achieved after the second chemical treatment.

Option 2 – Expanded Core, Accelerated Complementary and Alternative Measures

Option 2 is similar to Option 1 with the acceleration of items l), m) and n) from Phase 2 into Phase 1, and the acceleration of items r) and s) from Phase 3 into Phase 2. The cost of studies to investigate groundwater contributions (item r)) and to assess structural modifications (item s)) are estimated at $0.42M. The cost of implementing controls on groundwater contributions, and on structural modifications are expected to be high and would be determined following future studies. Pre-concept, nominal budgets for these later items are estimated at $2-10M and $5M, respectively. The 25-year lifecycle cost for Option 2 is $12.67-20.67M. A breakdown of the incremental cost of $9.8-17.80M for Option 2 is included as Attachment C.

Option 2 is not recommended due to cost considerations and given that Alternative measures may not be necessary to achieve the proposed water quality targets. That is, other Core and Complementary measures recommended under Option 1 are expected to reach the proposed target without the cost of complicated additional measures. Also, fish stocking and planting of submerged plants (i.e., items l) and m)) would be more appropriate, and have a higher degree of success after improved water quality conditions are first established following implementation of Option 1's Phase 1 measures. The need for studies to assess groundwater contributions to lake water quality and to then pursue potentially costly management measures in item r) in Option 2 is considered premature until other core measures are first assessed in Option 1 as part of the first Phase of an adaptive management approach. Similarly, the need for structural measures in item s) is also considered to be premature, and in addition the feasibility of stormwater redirection of private storm sewer works is uncertain.

FINANCIAL CONSIDERATIONS:

A total of $220,000 has been spent to date on chemical treatment, fish removal, geese management and monitoring in 2021. The total cost for implementing the recommended Option 1 water quality plan is $5.22M over the 25-year lifecycle period and will be funded through the Environmental Services lifecycle. This represents an increase of $2.35M over the existing 2021 budget, and would begin in 2023. In addition to the above, $35,000 has been allocated for parks design identified in November 2020, and expected shoreline planting/improvements with an estimated implementation cost of $0.125M has been submitted for 2022 capital budget consideration.

HUMAN RESOURCES CONSIDERATIONS:

Not applicable.

ALIGNMENT WITH STRATEGIC PRIORITIES:

This report aligns with the areas of strategic focus as follows:

- Safe, Sustainable, & Complete Community: the proposed strategy will support the enhancement of the natural environment and built form through sustainable integrated planning, infrastructure management and services.
- Stewardship of Money & Resources: the strategy proposed will provide a reasonable cost-effective level of service.

BUSINESS UNITS CONSULTED AND AFFECTED:

This report has been circulated to the Operations and Finance Departments for their input.

RECOMMENDED BY:

Eddy Wu,
Director, Environmental Services

Morgan Jones,
Commissioner, Community Services

ATTACHMENTS:

Attachment A- Swan Lake Long-Term Management Plan

Attachment B- Freshwater Research Memo

Attachment C- Life-Cycle Cost Estimate

Swan Lake Long-Term Management Plan

November 2021

MARKHAM

Environmental Services

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Executive Summary

Background

A gravel pit in the 1960s and 1970s, and used as a dumping area for construction waste in the early 1980s, Swan Lake was formed once the operation stopped dewatering when the gravel pit ceased operations. The newly formed lake was considered an asset in the environmental master plan prepared by Swan Lake Limited in 1993, in which potential beneficial uses were outlined. Since then, many studies have been completed with respect to the Lake's water quality, and potential rehabilitation options have been discussed over time.

Several issues were discovered in 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. There was concern at the time that blooms of blue-green algae (also known as cyanobacteria) could be present, which can release toxins into the water.

A chemical treatment was administered in 2013 using Phoslock to reduce the phosphorus levels and algal blooms. This treatment improved water quality from hyper-eutrophic to eutrophic conditions for two years; however, by 2016, water quality had deteriorated to pre-treatment conditions.

In 2019, the City of Markham conducted a study to define a water quality management strategy for Swan Lake based on the current state of the Lake, factors affecting water quality and management goals, and objectives. The strategy was received by City Council in June 2020, which directed staff to implement the report's recommendations on continued water quality monitoring and geese control, and introduce a fish removal and chemical treatment program.

The measures proposed in 2020 were implemented in the spring and summer of 2021. The present report has been developed to provide a long-term plan for water quality improvement in Swan Lake as an important step in ensuring the long-term sustainability of Swan Lake as a valued recreational and ecological asset for the community.

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, 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 (32%), direct runoff (21%), and controlled runoff (47%). 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 88% of the catchment.

- High phosphorus levels have been found to cause significant algal blooms, low oxygen levels, and degraded fish habitats in Swan Lake.
- The annual load of total phosphorus was estimated at 84 kg/yr over the last ten years. Sources of phosphorus to the Lake include internal load from sediment (63.4%), geese dropping (20.1%), inflow from stormwater ponds (7%), inflow from OGS's (2%) uncontrolled runoff from the shoreline (6.5%), and atmospheric deposition (1%).
- Internal phosphorus is highly biologically available, and with its release being elevated at summer water temperature, it severely affects the lake water quality in summer and fall.
- Geese dropping are the main source of external phosphorus load. Uncontrolled shoreline runoff and stormwater management facilities contribute approximately the same amount of phosphorus to the Lake. The control of runoff is emphasized through the implementation of site-based stormwater approaches and directions to protect or enhance the natural environment.
- Chloride concentrations in the Lake have increased sharply in recent years from about 400 mg/L in 2016 to above 700 mg/L. Currently, there is no feasible way of treating existing chloride in the Lake.
- 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. 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.
- Climate models predict warmer winter temperatures, which can lead to more precipitation falling as rain instead of snow, and increase in the number of winter runoff events from melting snow and ice. Phosphorus concentrations in the Lake could also increase with changing climate conditions.
- Swan Lake is home to a diverse community of terrestrial species. A review of recent fish survey data for Swan Lake indicated that fish species diversity is very low.
- Swan Lake and Park are well-used amenities and nature-based recreation facilities. The community has expressed strong support for a long-term plan that involves investment in sustainable solutions and restoration of the aquatic and land-based habitat. The community recognizes the value of the Lake as an important natural heritage feature and the importance of local access to services and amenities.

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 considered in the development 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, as follows:

Parameter	Current Values	Interim Target	Objective and Rationale
Total phosphorus (µg/L)	>200	50-100	A low eutrophic condition in the first year after treatment increasing to eutrophic in year three
Secchi Transparency (m)	<0.5 m	0.8 m	Correlates with the phosphorus target. Secchi is also a substitute for Chlorophyll a.
Chloride Concentration (mg/L)	700	400-500	Chronic guideline for the protection of aquatic life (120 mg/L) is not achievable at this time. To remain below acute guideline (640 mg/L) and close to 2013-2014 values
Frequency of algae blooms	Annual	Every three years	Trigger for treatment every three years
Internal phosphorus load (kg/yr)	53	0 - 25	To achieve the lake concentration target (see above)
External phosphorus load (kg/yr)	30	15	

Recommended Strategy

Based on the evaluation of all identified optional 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: Core Measures for the first five years:

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)
h) Shoreline planting/ improvements

i) Chemical oxygenation pilot project (by research institute)
j) Evaluate Phase 1 measures

In Phase 1, the following measures are currently funded in the Environmental Services lifecycle:

- Water quality monitoring
- Geese Management
- Fish removal
- Chemical (e.g., Phoslock or PAC) treatment

The following Phase 1 measures are new projects that require additional funding/resources:

- Enhanced geese management
- Shoreline planting/improvements

In Phase 1, new measures that would be advanced and that would not require additional funding/resources include:

- Community Engagement
- Chemical oxygenation pilot project (by research institute)

Phase 2: Adapted Core Measures and Complementary Measures for years five to ten:

k) Items a) to e) in Phase 1
l) Chemical treatment with adjusted frequency and dosage
m) Fish management plan and fish stocking (through MNDMNRF)
n) Planting of submerged plants
o) New technologies for chloride treatment
p) Evaluate Phase 2 measures

Phase 3: Adapted Core Measures with or without Alternative Measures past year ten

q) Items a) to e) in Phase 1
r) Chemical treatment with adjusted frequency and dosage (considering climate change impacts)
s) Investigate contribution from groundwater and/or dumping areas, if required
t) Evaluate/design structural modifications such as lake water recirculation and stormwater redirection

At the end of Phase 1, a 5-year summary report will be completed, summarizing the effectiveness of Core measures and evaluating additional Complementary measures to consider in Phase 2. 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. Similarly, following Phase 2, a summary report will be completed identifying any Alternative measures.

The total cost for implementing Core and Complementary measures for 25 years, the recommended plan, is about $5,220,000 (including pond cleanout), funded from the Environmental Services lifecycle. Implementing all measures, including the Alternative Measures would cost about $20,670,000.

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
DW	Dry Weight
ECA	Environmental Compliance Application
FDC	Foundation Drain Collection
FOSLP	Friends of Swan Lake Park
GLISA	Great Lakes Integrated Sciences + Assessments
LED	Light Emitting Diode
LOI	Loss of Ignition
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
PAC	Poly Aluminum Chloride
REE	Rare Earth Elements
TBD	To be Determined
TP	Total Phosphorus
TRCA	Toronto and Region Conservation Authority
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

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Figures

1. Introduction

1.1 Background

A gravel pit in the 1960s and 1970s, and used as a dumping areas for construction waste in the early 1980s, Swan Lake was formed when pumping for the gravel pit ceased operations. The newly formed lake was considered an asset in the environmental master plan prepared by Swan Lake Limited in 1993, through which potential beneficial uses were outlined. Since then, several studies have been completed with respect to the Lake's water quality, and potential rehabilitation options have been discussed over time.

Several issues were discovered in 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. There was concern at the time that blooms of blue-green algae (also known as cyanobacteria) could be present, which could result in the release of toxins into the water.

A chemical treatment was administered in 2013 using Phoslock to reduce the phosphorus levels and algal blooms in Swan Lake. This treatment improved water quality from hyper-eutrophic to eutrophic conditions for two years; however, by 2016, water quality was as low as or lower than in the pre-treatment year.

In 2019, the City of Markham conducted a study to define a water quality management strategy for Swan Lake based on the current state of the Lake, factors affecting water quality and management goals, and possible objectives. The strategy was received by City Council in June 2020, which directed staff to implement the report's recommendations on continued water quality monitoring, geese control, fish removal, and chemical treatment. Staff was directed to report back in 2021 with overall water quality (and Park) improvement programs. A draft Park Refresh Plan was presented to the Council in November 2020.

1.2 Purpose

This report provides a long-term plan for water quality improvement in Swan Lake. 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. The main objective of the report is to provide an understanding of the opportunities and constraints and to develop recommendations for water quality management in the next five-year period.

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 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 853.5 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 45 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: private storm sewer lines not shown on the map.
OGS: Oil and Grit Separator

2.2 Lake Morphometry and Hydrology

2.2.1 Morphometry

Swan Lake has an approximate area of 5.4 ha and a maximum water depth of 4.5 m (from the deepest point at 204.5 m to the Lake edges at 209 m).

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

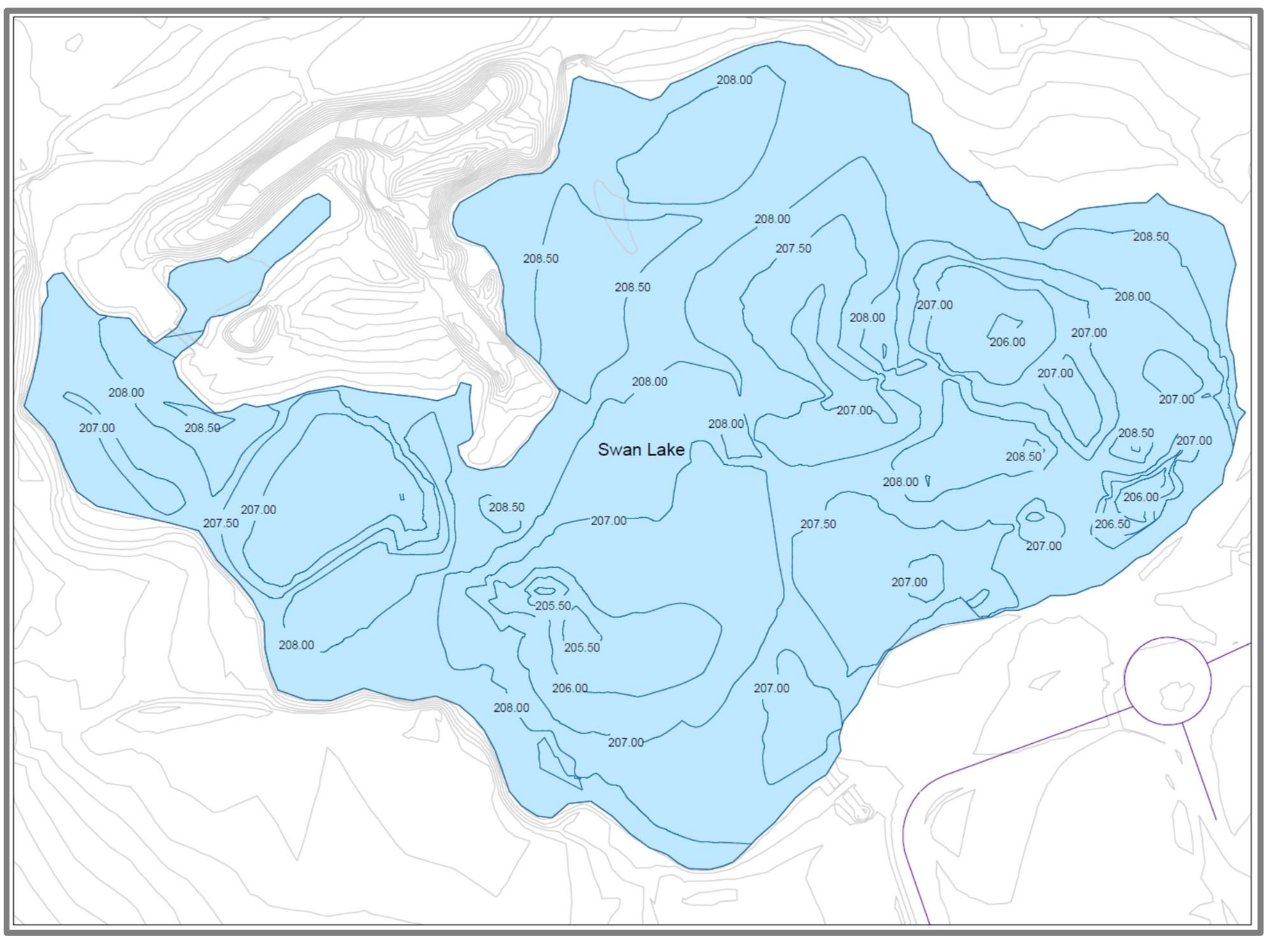
Table 1: Hypsometry of Swan Lake (2016 Survey Date)

Elevation (m)	Depth (m)	Volume of Layer (m^3)	Volume below (m^3)	Area of Layer (m^2)
209	0	27,000	112,000	54,000
208.5	0.5	25,000	85,000	50,000
208	1	23,000	74,480	46,000
207.5	1.5	17,000	60,000	34,000
207	2	10,000	37,000	20,000
206.5	2.5	6,000	20,000	12,000
206	3	2,900	10,000	5,800
205.5	3.5	940	4,000	1,880
205	4	160	1,100	320
204.5	4.5	0	0	0

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	5.4
Volume (1000 m^3) at 209 m	112
Mean depth (m)	2.0
Maximum depth (m)	4.5

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



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 (4.71 ha). Two wet extended detention ponds (#104- North Pond and #105-East Pond) attenuate the stormwater runoff generated from the controlled catchment (31.44 ha). Three Oil and Grit Separators (OGS) treat runoff from a combined area of 1.87 ha before discharging to the Lake.

The North and East Ponds have one and two inlets, respectively. A flow splitter immediately upstream of each pond outfall directs up to 25 mm storm runoff to the pond. Weirs within the flow splitters direct the additional runoff to the Lake for flood control attenuation.

The normal water level elevation within the ponds and the Lake is coincident with the adjacent groundwater elevation. All stormwater inflows to the ponds drain to the Foundation Drain Collection (FDC) system, which ultimately drains to the storm sewer south of 16th Ave.

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 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) have 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, including resident and migratory Canada Geese and other waterfowl and Trumpeter swans. The Village of Swan Lake also brings in a pair of Mute swans to the Lake each year, and a team of residents cares 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 the spring of 2021, the City hired the Toronto and Region Conservation Authority (TRCA) to complete a fish inventory, relocation, and removal. Swan Lake fish were captured using an electrofishing boat and Fyke nets over five events from late April to late May. Only three fish species were caught in the lake with intensive effort: seven Common Carp (non-native), 210 Brown Bullhead, and more than 10,000 Fathead Minnow. All three 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 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".

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 88% of the catchment are owned and maintained by the developers. Currently, the developers responsible for the stormwater ponds are arranging contractors to rectify all underground and aboveground deficiencies. At this point, the City will proceed with the process of Acceptance for Maintenance of the stormwater management ponds (K. Poon, personal communication, August 20, 2021). 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.

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 2019

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 (2010-2020)

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 has been monitored at the deepest point (main or central station) and more recently at two shoreline sites, the Dock and the Bridge. The water depth at the dock is approximately 2.5-3 meters, 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 any trends. The following summary is from the 2020 annual report (City of Markham, 2020).

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 has been found to be the main reason for low water quality in Swan Lake.

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 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.

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 with anoxia, 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 analysable 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 the 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

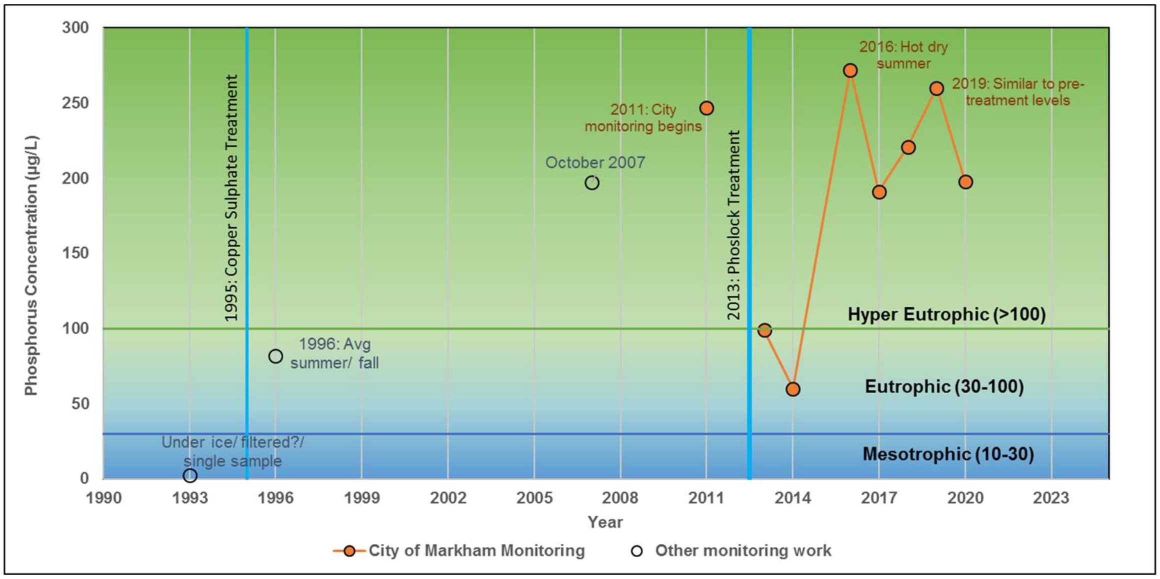
Note: The Anoxic Factor is a measure of anoxia and is defined as the number of days per year that a sediment area equal to the lake surface area is covered by anoxic water.

Average growing period (May - October) TP concentrations indicate hyper-eutrophic conditions in all monitored years except for the two post-treatment years, 2013 and 2014. (2015 was not monitored.) 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).

Total nitrogen concentration over the growing period has always been above the 1.2 mg/L threshold for a hyper-eutrophic condition, except in the post-treatment year, 2014. Nitrogen is, however, not believed to be the limiting nutrient for eutrophication in Swan Lake. Nonetheless, inorganic nitrogen compounds (NO_2, NO_3, and NH_3) have often been below detection limits, indicating relatively low levels of bioavailable nitrogen concentrations (Freshwater Research, July 2020).

Figure 4 provides a summary of phosphorus concentrations for all the years with available data. Based on these values, the Lake has been hyper-eutrophic since 2016.

Figure 4: Trophic State Classification for Swan Lake based on Mixed Layer Growing Period Average Phosphorus Concentration



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 all below 1 m, except in 2014.

Algae Bloom and Cyanotoxins

Table 4 provides a summary of the observed algae blooms in the Lake over the years. It also shows any tests conducted to measure toxins (mainly in terms of microcystin concentration) in the Lake water.

For cyanotoxins, the Health Canada guideline for recreational activities is 20 µg/L (Health Canada, 2012).

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

Bacterial Contamination

Animal droppings in and around the Lake may result in elevated levels of E-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 in support of the 2019 water quality management report. The model was updated in 2020 in support of the Swan Lake chemical treatment planning and scenario analysis using a more refined catchment delineation and extended analysis period to the end of 2020.

Water enters Swan Lake through direct precipitation on the Lake, as well as controlled or uncontrolled stormwater runoff from the surrounding subdivisions. Outflows from the Lake include evaporation and flow through an outlet pipe that discharges to the Lake's southeast towards 16th Ave.

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 modelled for the 2010 to 2020 period using the PCSWMM model for both minor and major systems.

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.

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 (2017-2020) were extrapolated to the previous years by correlating water level with rainfall and evapotranspiration, and outflows were estimated accordingly (Figure 5).

Table 5 provides a summary of the annual water balance established for Swan Lake and used in the nutrient budget (City of Markham, March 2021).

Figure 5: Measured or Estimated Monthly Water Level

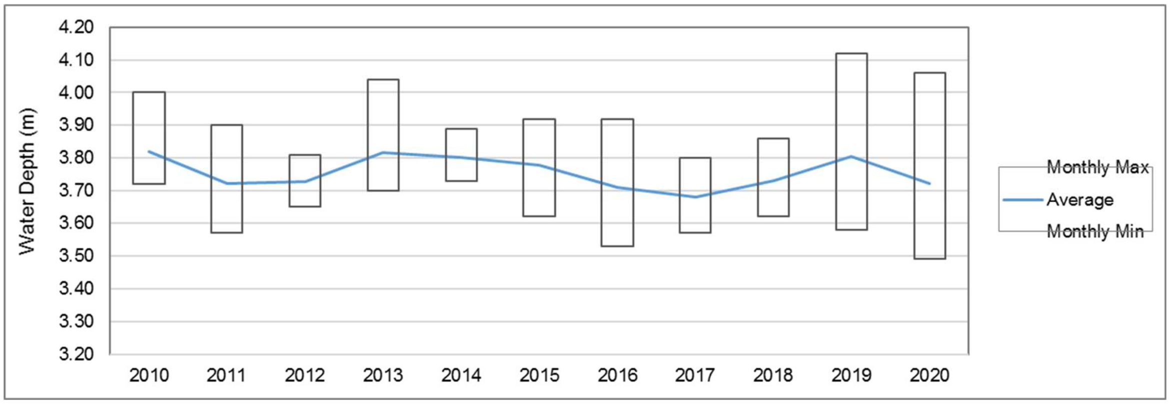


Table 5: Swan Lake Annual Water Balance (m^3)

Year	Precipitation on Lake	Evapotranspiration from Lake	Inflow from Pond 104	Inflow from Pond105	Shoreline Runoff	Inflow from OGSs	Outflow	Balance or groundwater impact
2010	37,191	(52,772)	25,952	14,985	21,573	5,955	(7,230)	(45,654)
2011	28,784	(51,616)	24,114	12,083	18,717	4,786	(5,398)	(31,470)
2012	42,088	(55,015)	35,277	17,864	27,123	7,438	(4,457)	(70,318)
2013	41,021	(51,240)	37,090	17,083	31,950	7,549	(6,383)	(77,070)
2014	40,922	(49,292)	33,838	17,269	29,074	7,236	(8,653)	(70,394)
2015	36,103	(52,951)	28,707	14,822	20,430	5,891	(6,791)	(46,211)
2016	32,064	(54,960)	28,403	12,983	15,819	4,870	(5,766)	(33,413)
2017	40,466	(56,396)	32,745	16,364	22,895	6,735	(4,582)	(58,227)
2018	50,729	(53,740)	42,467	21,982	37,616	9,634	(2,291)	(106,397)
2019	50,337	(51,927)	43,503	20,092	25,624	14,030	(8,416)	(93,243)
2020	42,684	(56,975)	40,662	19,642	31,018	13,823	(6,819)	(84,035)

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 will affect the most efficient management options. Phosphorus sources are external (including stormwater, precipitation, and geese) and internal (including diffusion from bottom sediments and resuspension).

The mass balance analysis conducted previously (Freshwater Research, July 2020) was updated with monitoring data collected in the recent years of 2019 and 2020 and revised hydrological and morphometric input.

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). Annual calculated phosphorus loads are shown in Table 7 for various internal and external sources (Freshwater Research, August 2021).

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 since 2016, when management efforts reduced the population to a stable plateau. Currently, there are approximately 20-30 resident geese throughout the year with an increased abundance 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: Phosphorus Concentration in Rain and Runoff

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)

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

Year	Geese	SWM pond 104	SWM pond 105	Shore	Atmospheric deposition	External (total)	Internal Load
2010	8.79	3.02	1.74	5.82	0.80	20.2	55.4
2011	10.12	2.81	1.41	4.97	0.80	20.1	32.6
2012	11.45	4.11	2.08	7.30	0.80	25.7	81.1
2013	12.79	4.32	1.99	8.35	0.80	28.2	26.0
2014	14.12	3.94	2.01	7.67	0.80	28.5	0.0
2015	27.54	3.34	1.72	5.56	0.80	39.0	n/a
2016	40.97	3.31	1.51	4.37	0.80	51.0	20.8
2017	14.28	3.81	1.90	6.26	0.80	27.0	50.5
2018	14.90	4.94	2.56	9.99	0.80	33.2	101.4
2019	15.84	5.06	2.34	8.38	0.80	32.4	112.8
2020	14.69	4.73	2.29	9.48	0.80	32.0	50.6

Source: (Freshwater Research, July 2020)

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. This could be attributable to varied snowfall, snow management practices, or sources other than catchment runoff.

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 DW, ranging from 420 mg/kg dry weight (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 percentage of potentially bio-available 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. Recent Projects and Initiatives (2020-2021)

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 gold fish) is necessary to ensure high efficiency of the chemical treatment.

In 2020, the City hired the TRCA to complete a fish inventory, relocation, and removal. Through a meeting with the MNDMNRF staff, they were supportive of the non-native/invasive fish removal as well as the relocation of the bottom-dwelling Brown Bullhead.

Swan Lake fish were captured using an electrofishing boat and Fyke nets during the months of April and May 2021. Only three fish species were captured in Swan Lake:

- Common Carp – non-native
- Brown Bullhead – native, bottom-dwelling
- Fathead Minnow – native minnow

All three fish species are considered tolerant to environmental perturbation. Seven Common Carp were capture and euthanized. Two hundred and ten Brown Bullhead were transferred to Milne Pond, and more than 10,000 Fathead Minnow were returned to the Lake.

Three fish species in a lake does not constitute a well-balanced community. Healthy fish communities in Toronto Region lakes usually comprise multiple fish species from a variety of trophic levels.

5.2 Geese Management

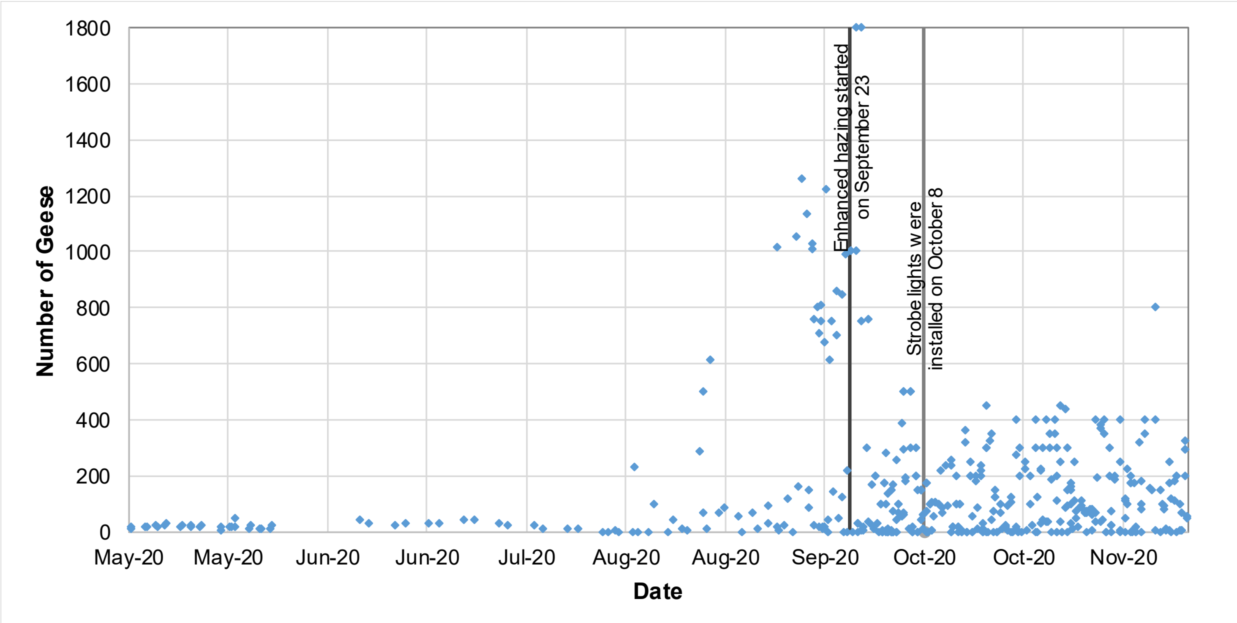
In 2020, an external contractor was hired to chase (i.e., ‘haze’) terrestrial geese by border collies and perform egg oiling. The frequent geese chasing would encourage the geese to relocate to a quieter place and reduce the number of resident geese at Swan Lake.

In an effort to reduce the number of geese further, a thorough investigation of other geese management methods was completed. It was concluded that increasing the hazing frequency will be the most efficient method in the short term, and an enhanced hazing program was completed from late September to the end of November. The increased hazing frequency (starting on September 23) was very effective in reducing the number of geese present at different times of the day (see Figure 6).

At the request of a resident group, Friends of Swan Lake, and upon Council approval (City of Markham, September 2020), nine strobe lights were purchased and installed on the Lake and the two adjacent stormwater management ponds. 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. Any impact that strobe lights might have had on the geese count is not readily evident from the data (see Figure 6).

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. Thirteen nest containing 52 eggs were managed at Swan Lake. Forty Canada Geese were rounded up from Swan Lake, and four adult Canada geese and four goslings were left at Swan Lake (TRCA, 2021).

Figure 6: 2020 Geese Count Results



5.3 Chemical Treatment

The quantification of different phosphorus sources indicated that the effects of internal sources outpace those from external sources. The phosphorus released from internal sources is also highly bioavailable and quickly becomes 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 recommended for 2021. 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.

5.4 Stakeholder Engagement and Education

5.4.1 Resident Initiatives

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 over the years, he has been actively following the initiatives and studies completed at Swan Lake.

In 2019, the newly formed resident group, Friends of Swan Lake Park, contacted the City to report their observations of the Lake, and to request available technical reports and drawings. Over the past two 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.

5.4.2 Engagement and Education

The City has been in communication with the developers regarding the maintenance of stormwater management facilities in the catchment.

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 through an online App, which has been used by a number of residents.

Staff have also been in contact with a researcher from Trent University, who is 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.

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 values were developed as interim targets in 2019 (Freshwater Research, July 2020). The targets are further improved through the recent analysis of treatment scenarios (Freshwater Research, August 2021) and considering the Lake and watershed characteristics and beneficial uses that are practically achievable.

Table 8 lists the proposed interim targets. These targets are proposed to be achieved within the next five years after which the management plan will be reviewed and updated.

Table 8: Proposed Interim Targets for Swan Lake for the next five years

Parameter	Current Values	Interim Target	Objective and Rationale
Total phosphorus (µg/L)	>200	50-100	Current value: the average of growing season TP values in the period since 2016 has been 200. Interim target: will provide a low eutrophic condition in the first year after treatment increasing to eutrophic in year three
Secchi Transparency (m)	<0.5 m	0.6-0.8 m	Based on correlation with the phosphorus target. Secchi is also a substitute for Chlorophyll a.
Chloride Concentration (mg/L)	700	400-500	Chronic guideline for the protection of aquatic life (120 mg/L) is not achievable at this time. Target: to remain below acute guideline (640 mg/L) and close to 2013-2014 values of about 400 mg/L.
Frequency of algae blooms	Annual	Every three years	Trigger for treatment every three years
Internal phosphorus load (kg/yr)	53	0 - 25	Both internal and external loads should be controlled to achieve the lake concentration target (see above)
External phosphorus load (kg/yr)	30	15	

7. Analysis and Discussion of Optional 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, 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 (32%), direct runoff (21%), and controlled runoff (47%). 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 88% of the catchment.
- High phosphorus levels have been found to cause significant algal blooms, low oxygen levels, and degraded fish habitats in Swan Lake.
- The annual load of total phosphorus was estimated at 84 kg/yr over the last ten years. Sources of phosphorus to the Lake include internal load from sediment (63.4%), geese dropping (20.1%), inflow from stormwater ponds (7%), inflow from OGS's (2%) uncontrolled runoff from the shoreline (6.5%), and atmospheric deposition (1%).
- Internal phosphorus is highly biologically available, and with its release being elevated at summer water temperature, it severely affects the lake water quality in summer and fall.
- Geese dropping are the main source of external phosphorus load. Uncontrolled shoreline runoff and stormwater management facilities contribute approximately the same amount of phosphorus to the Lake. The control of runoff is emphasized through the implementation of site-based stormwater approaches and directions to protect or enhance the natural environment.
- Chloride concentrations in the Lake have increased sharply in recent years from about 400 mg/L in 2016 to above 700 mg/L. Currently, there is no feasible way of treating existing chloride in the Lake.
- 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. 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.
- Climate models predict warmer winter temperatures, which can lead to more precipitation falling as rain instead of snow, and increased winter runoff events from melting snow and ice. Phosphorus concentrations in the Lake could also increase with changing climate conditions.
- Swan Lake is home to a diverse community of terrestrial species. A review of recent fish survey data for Swan Lake indicated that fish species diversity is very low.

- Swan Lake and Park are well-used amenities and nature-based recreation facilities. The community has expressed strong support for a long-term plan that involves investment in sustainable solutions and restoration of the aquatic and land-based habitat. The community recognizes the value of the Lake as an important natural heritage feature and the importance of local access to services and amenities.

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 has been identified as the most effective and immediate method of controlling internal phosphorus load in Swan Lake (Freshwater Research, July 2020).

In order to determine the optimum treatment frequency, Freshwater Research modeled a number of scenarios to quantify expected changes in lake phosphorus and lake response, including climate change impact (Freshwater Research, August 2021).

Based on this modelling effort, internal load in the growing period immediately after a treatment is expected to decrease by at least 25%, depending on the time of application (earlier treatment would increase the benefit in the growing period). In the second growing period after a chemical application, internal load could be expected to be successfully intercepted to result in zero sediment release. It is likely that the following year (i.e., the third growing period) still includes a 50% benefit resembling the first-year effect. According to this analysis, an application every third year has been recommended.

To address climate change impacts, scenarios with increased stormwater events and extreme heat were modeled, considering the impact of water temperature on sediment release. Under such scenarios, the internal load was conservatively assumed to increase by 50%. The impact on phosphorus concentration and lake response was assumed proportional.

A full application of chemical treatment (Phoslock or PAC) to Swan Lake costs about $150,000 or $50,000 per year for a three-year cycle.

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 in 2020 cost about $20,000. It is estimated that annual removal activities in the future can be more limited and cost about $5,000 annually.

7.1.3 Nitrogen Control

Studies have confirmed that nutrient control in Swan Lake should focus on phosphorus. Some nitrogen reduction will be achieved through decreased productivity resulting from other management measures (e.g., internal phosphorus control resulted in low nitrogen in 2014). Geese management will also reduce nitrogen load. 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 reviewed a number of proposals brought forward to further decrease nitrogen load (Friends of Swan Lake Park, December 2020), as follows:

Water circulation with pre-treatment: based on this proposal, water would be circulated using a pump to increase the hydraulic detention time from about a year to 30 days. The recirculated water would need to pass through a treatment system such as constructed wetlands and bioswales to reduce nutrient levels (Fleming College, February 2021).

Bioswales promote infiltration in water conveyances and decrease suspended sediments and nutrients; however, the pollutant retention depends on water retention time and therefore, the length and slope of the conduit. The flat and built-up area around Swan Lake is not supportive of a large and effective application of bioswales. Standing water shallow enough to be exposed to large temperature increases supports mosquito abundance and is generally avoided in urban areas (Freshwater Research, April 2021). Construction of a bioswale will involve significant disturbances in the area. Capital and operations cost associated with the construction of a bioswale and the operation of a pump capable of pumping the Lake water would be cost-prohibitive.

Manufactured floating treatment wetlands: these features employ aquatic plants growing on tethered buoyant mats distributed on the lake surface. Plant roots and mat would provide a large surface area for the growth of naturally occurring bacteria and biofilms that assimilate nutrients (Fleming College, February 2021).

Artificial wetlands are not recommended for Swan Lake, as they would provide more nesting opportunities for resident geese. In addition, the stratified lake will enhance the settling of suspended algae and solids beneath the mats and encourages the proliferation of cyanobacteria. Therefore, the benefit of water quality enhancement is small or even negative. Maintenance, especially in the winter, can be problematic (Freshwater Research, April 2021).

7.2 Measures to Control External Nutrient Load

7.2.1 Geese Management

Geese defecation contributed to more than 55% of the external phosphorus load in Swan Lake, 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.

The annual cost for existing geese management programs at Swan Lake is about $13,500. 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 19% and 5% 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, and staff have requested that they resolve any apparent maintenance issues. 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 is currently in exchange 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. The cost of the design plan consultation was estimated at $35,000 and the cost of implementation is to be determined based on the plan.

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 (see Figure 7). 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 cost about $20,000 (assuming five boreholes). It will, however, require participation of the developers and private owners, which may involve cost sharing for expensive rehabilitation, if required. This measure is therefore given lower priority and will be revisited if other more feasible measures do not achieve the desired water quality results.

Figure 7: Location of Historic Dumping Areas

Source: Aerial photo from 1983, reproduced from (Freshwater Research, January 2017)

7.3 Measures to Improve Oxygen Level

Analysis of DO profile at Swan Lake has shown that severe oxygen depletion occurs during the summer-stratified period, which can lead to the dissolution of sedimentary iron compounds and the release of adsorbed phosphorus back to the water. Oxygen depletion is also harmful to aquatic life.

A proposal has been made to improve oxygen levels artificially (Friends of Swan Lake Park, December 2020). Methods discussed include mechanical aeration (e.g., a bottom-based diffuser system, also called laminar flow aeration system), nano-bubbles loaded on the surface of natural minerals (Oxygen Nano-Bubble Modified Mineral), or using granulated calcium peroxide as slow oxygen releasing compound (Fleming College, February 2021).

Oxygen depletion is a consequence of a highly productive environment, and improving the trophic state by nutrient control will reduce anoxia (Freshwater Research, January 2021). Additional aeration may be beneficial for reducing nutrient release from the sediment; however, mechanical aeration is not recommended for Swan Lake, as it will disturb the nutrient-rich bottom sediment, increasing nutrient release and phytoplankton abundance. Calcium peroxide (CaO_2) may increase oxygen concentration without the negative effects of water mixing (Freshwater Research, April 2021). This method is at research state and could be considered as a pilot project through a research institute.

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., charcoal), solar still, and biological treatment by chloride-tolerant plants (Fleming College, February 2021).

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). New technologies may be considered when they are available and proven effective.

7.4.3 Redirecting Stormwater

The resident group FOPS has recently brought forward proposals to undertake major structural changes to redirect stormwater from the Lake to decrease chloride input. This proposal discusses strategies such as re-routing direct drainage areas to the stormwater management facilities, reducing stormwater flows, bypassing the ponds, and restoring the Lake level (Friends of Swan Lake Park, June 2021). In August 2021, Staff and the local Councillor had a site visit with members of FOSLP to discuss proposed strategies.

While these strategies may have nominal benefits in terms of chloride input, any structural changes to the drainage system, especially when they involve private landowners and/or crossing jurisdictions (i.e., York Region owns the16th Ave. sewer), the changes will require lengthy, comprehensive studies. Such studies would need to assess downstream impacts, such as in the Markham Village flood control Phase 2 flood cluster. That Phase 2 area currently has storm sewer capacity deficiencies that are not planned for upgrades until 2027-2028.

In addition, while chloride concentrations are above the long-term guideline, as of spring 2021, there were a few carp, several Brown Bullhead (*Ameiurus nebulosus*), and many minnows were observed in the Lake, indicating that Swan Lake could potentially support suitable fish species despite high chloride concentrations (Freshwater Research, August 2021). Therefore, expensive, complex measures for reducing chloride concentration are considered a low priority to be considered if other efforts for improving aquatic habitat are not successful due to high chloride concentration.

7.5 Measures to Improve Natural Heritage Features

7.5.1 Shoreline Planting

The Parks Department is currently in exchange with the TRCA to develop a plan for shoreline planting/improvements. In addition to reducing the nutrient load to the Lake, natural water plants, especially cattails, will provide habitat for fish and their prey. Design consultation for shoreline improvements was identified as one initiative through the Swan Lake Park, Parks Operations and Parks Refresh Draft Plan noted above, with design plan consultation cost estimate of $35,000 and implementation cost to be determined.

7.5.2 Planting of Submerged Water Plants

Once phosphorus is controlled to consistent concentrations below 0.100 mg/L and transparency has improved, the planting of native submersed plants will help solidify the sediment and provide fish habitat. A study on 20 gravel pit lakes, including some similar to Swan Lake, determined that improvement in the littoral plant habitat (addition of diverse structures and variability of habitat type) can promote the abundance of most gravel pit lake fish species (Freshwater Research, August 2021).

A nominal cost of $20,000 was considered for this measure.

7.5.3 Fish Stocking

Once phosphorus concentrations in water are reduced, the water quality 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 MNDMNRF regarding suitable species and the potential of stocking.

The MNDMNRF 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 (beginning in 2022) 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 Optional Measures

Table 9 provides a summary of measures evaluated in Section 7 for feasibility, effectiveness, and costs over 25 years. Costs include projects completed in 2021.

Table 9: Evaluation of Optional 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.	$150,000 per full application (three-year intervals)
	IL2	Bottom-Dwelling Fish Management	Feasible; lowers internal load release.	$18,000 initial $5000 annually
	IL3	Nitrogen Control (by pumping & treatment or artificial wetlands)	Water pumping and treatment will result in increased water temperature, and significant disturbance of the area. Artificial wetlands provide geese habitat and promote settling of solids beneath the mats. Nitrogen will be controlled by lowering productivity through other management measures, and does not need targeted treatment.	Significant
External Load	EL1	Geese Management (including Toogood Pond)	Feasible; lowers nutrient input from the most significant external source.	Existing measures: $27,000 annually New measures: $40,000 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	$35,000 design $125,000 implementation
	EL4	Groundwater and historic dumping areas	Groundwater requires extensive investigation. A study of the dumping areas will involve the developers and private owners; low priority	Significant
Oxygen Level	OL1	Mechanical or chemical oxygenation	Mechanical circulation will have negative impacts because of sediment disturbance and nutrient release. Calcium peroxide may be used in a pilot project.	Pilot project TBD through a research institute
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	Existing methods are not very effective; New technologies may be considered when proven effective.	TBD
	CL3	Redirecting Stormwater	Involves private landowners and York Region and detailed study to assess impacts/feasibility, and chloride levels may not impact desired aquatic biota; low priority.	Significant
Natural Features	NF1	Shoreline Planting/ Improvements	Feasible; will provide fish habitat	See EL3
	NF2	Planting of Submerged Water Plants	Feasible; will help solidify sediment and provide fish habitat	TBD
	NF3	Fish Management Plan and Fish Stocking	Feasible; once water quality improves.	TBD for the Plan MNDMNRF for Fish Culture program

8.2 Recommended Strategy

Based on the evaluation of all identified optional measures, a phased approach is recommended for Swan Lake. This plan follows an adaptive management approach, through which management activities will be adjusted to maximize benefits and minimize impacts.

The recommended plan includes a range of measures that represent an overall water quality program related to a sustained improved service level, requested in June 2020. This long-term program is intended to reach targets identified in Section 6.3, including a low eutrophic condition after treatment, increasing to eutrophic in the third year. Water clarity would be increased relative to existing conditions and algae bloom frequency would be reduced from annually to every three years.

The plan relies on a set of "Core" measures in the first phase of implementations (first 5 years beginning in 2021) that are deemed technically reliable and cost-effective. Additional "Complementary" measures would be introduced in Phase 2. 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 r) and s)) 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: Core Measures for the first five years:

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)
i) Evaluate Phase 1 measures

In Phase 1, the following measures are currently funded in the Environmental Services lifecycle:

- Water quality monitoring
- Geese Management
- Fish removal
- Chemical (e.g., Phoslock or PAC) treatment

The following Phase 1 measures are new projects that require additional funding/resources:

- Enhanced geese management
- Shoreline planting/improvements

In Phase 1, new measures that would be advanced and that would not require additional funding/resources include:

- Community Engagement
- Chemical oxygenation pilot project (by research institute)

Phase 2: Adapted Core Measures and Complementary Measures for years five to ten:

j) Items a) to e) in Phase 1
k) Chemical treatment with adjusted frequency and dosage
l) Fish management plan and fish stocking (through MNDMNRF)
m) Planting of submerged plants
n) New technologies for chloride treatment
o) Evaluate Phase 2 measures

Phase 3: Adapted Core Measures with or without Alternative Measures past year ten

p) Items a) to e) in Phase 1
q) Chemical treatment with adjusted frequency and dosage (considering climate change impacts)
r) Investigate contribution from groundwater and dumping areas, if required
s) Evaluate/design structural modifications such as lake water recirculation and stormwater redirection

At the end of Phase 1, a 5-year summary report will be completed, summarizing the effectiveness of Core measures and evaluating additional Complementary measures to consider in Phase 2. 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. Similarly, following Phase 2, a summary report will be completed identifying any Alternative measures.

Table 10 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 25 years, the recommended plan, is about $5,220,000 (including pond cleanout), funded from the Environmental Services lifecycle. Implementing all measures, including the Alternative Measures, would cost about 12 to 20 million dollars (depending on the extent of groundwater remediation work).

Table 10: Life-Cycle Cost Estimate (Assuming 2% Annual Inflation)

Some future costs are included as nominal values for perspective- see footnotes.

	Measure	Phase 1	Phase 2	Phase 3	Total	Current Life-Cycle (2021)	Increase Over Current Life-Cycle
	Continue water quality monitoring	$149,356	$ 164,901	$ 605,013	$ 919,270	$ 87,095	$ 832,175
Core	Continue geese management and enhanced	$275,037	$ 383,582	$ 1,407,339	$ 2,065,958		
	Remove benthic-dwelling fish	$ 38,608	$ 28,165	$ 103,336	$ 170,109	$1,017,325	$ 1,218,742
	Maintenance of stormwater management	$ 4,591	$ 8,284	$ 528,374	$ 541,249	$ -	$ 541,249
	Chemical treatment with adjusted frequency	$309,181	$ 261,141	$ 806,227	$ 1,376,549	$ 1,763,350	$ (386,801)
	Fish management plan and fish stocking **	$ -	$ 20,000	$ -	$ 20,000	$ -	$ 20,000
Complementary	Planting of submerged plants **	$ -	$ 20,000	$ -	$ 20,000	$ -	$ 20,000
	New technologies for chloride treatment **	$ -	$ 50,000	$ -	$ 50,000	$ -	$ 50,000
	Investigate dumping areas	$ -	$ -	$ 20,000	$ 20,000	$ -	$ 20,000
	Investigate groundwater **	$ -	$ -	$ 200,000	$ 200,000	$ -	$ 200,000
Alternative	Control groundwater loading**	$ -	$ -	$ 2,000,000 to $10,000,000	$ 2,000,000 to $10,000,000	$ - $ -	$ 2,000,000 to $10,000,000
	Evaluate structural modifications **	$ -	$ -	$ 200,000	$ 200,000	$ -	$ 200,000
	Implement structural modifications **	$ -	$ -	$ 5,000,000	$ 5,000,000	$ -	$ 5,000,000
	Evaluate measures	$ 25,000	$ 27,602	$ 33,647	$ 86,249	$ -	$ 86,249
	Option 2 - 25-year cost with Alternative Measures	$801,772	$ 963,675	$10,903,936 to $18,903,936	$12,669,383 to $20,669,383	$2,867,770	$ 9,801,613 to $17,801,613
	Recommended Option 1 - 25-year cost without Alternative Measures			$ 3,450,289	**$ 5,215,736**		**$ 2,347,967**

Notes:
* Assumed 25% decrease in five years and 25% in 10 years (not reduced from Phase 2 due to climate change impact).
** Values are order of magnitude and are rough estimates for perspective.
Assume pond cleanout/retrofit during the period.

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Memo

To: Rob Muir & Zahra Parhizgari, City of Markham

From: Gertrud Nürnberg, Freshwater Research

Date: 2021-08-24

Re: Swan Lake Water Management Plan

1 Context

Markham staff described the water quality issues in Swan Lake in the scope of work (City of Markham 2020a): "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. Although the Phoslock treatment improved water quality from hypereutrophic to eutrophic for two years after application, by 2016 water quality was as poor as or poorer than in the pre-treatment year, 2011, and trophic state variables indicated hyper-eutrophic conditions."

A subsequent analysis of the limnological and water quality conditions produced the Swan Lake water quality management strategy (FWR July 2020). Council formally requested further information, especially concerning the bottom derived internal phosphorus loading, which was established before by FWR as the primary and excessive nutrient load to Swan Lake.

This memo addresses one of the objectives of the November scope of work: "Review and determine the differences in cost and expected water quality in performing treatment in 1-5 year intervals moving forward." To accomplish a data supported evaluation, previously collected monitoring data were to be analyzed and updated to include the most recent years (2019 and 2020) and used in scenario modelling. Results were also interpreted in combination with climate and climate change effects.

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2 Water quality variables and relationships with nutrients

2.1 Water quality characteristics in Swan Lake since 2011

Several water quality characteristics, typically employed by lake managers, were determined from monitoring efforts since 2011. (Data from the City of Markham including reports of 2019 and 2020.) These variables include

1. **Secchi** disk depth, a measure of lake water transparency (determined by a black and white disk)
2. **Chlorophyll** concentration, a measure of a green pigment present in all phytoplankton ("real" algae and "bluegreens", i.e., cyanobacteria)
3. **Total phosphorus** (TP) concentration, the most important nutrient in Swan Lake that limits phytoplankton growth.
4. **Total nitrogen** (TN) concentration, an additional nutrient, usually correlated with TP.
5. **Anoxia**, lack of dissolved oxygen. After increased oxygen depletion caused by decaying phytoplankton during warm and quiescent (still) periods, oxygen in the water is completely used up. (Anoxic factor is used as quantification and presents the period of time as if the whole lake area is anoxic at < 2.0 mg/L dissolved oxygen, FWR 2020.)

As is the norm in lake management, averages of these variables for the growing period (May - Sep/Oct) (Table 1) indicate the lake's trophic state, a measure of productivity. Relationships among these variables, especially nutrient-phytoplankton indicators, indicate potential management options. These relationships are examined in the scenario analysis (Section 5.1).

Table 1. Monitored growing period water quality characteristics (at main deep site in 2011-2016, at southern observation dock thereafter, sampled in the surface 0-1.5 m layer).

Year	Secchi Disk Transparency (m)	Chlorophyll *a* (ug/L)	Total phosphorus (mg/L)	Total nitrogen* * (g/L)	Anoxia observed (AF) (days/yr)	Ammonia (mg/L)	Lake Level May-Sep (m)
2011	0.47	32.3	0.247	2.71	49.7		208.21
2012							208.22
2013*	0.43	49.5	0.099	1.64	31.0		208.25
2014*	1.43	12.6	0.060	1.14	32.9		208.26
2015							208.25
2016	0.29	110.9	0.272	4.50	48.4		208.20
2017	0.40	60.9	0.191	2.26	39.7	0.079	208.24
2018	0.53	41.3	0.221	2.55	50.6	0.185	208.24
2019	0.40		0.237	2.81	40.1	0.146	208.23
2020	0.35		0.183	2.56	18.9	0.064	208.18

*Phoslock treatment in April 2013 mostly affected growing periods in 2013 and 2014 and resulted in the better trophic state of "eutrophy" as compared to "hyper-eutrophy" established in all other years.
**Total nitrogen(TN) is mostly total Kjeldahl N because nitrate/nitrite was usually below detection limits.
In empty cells variables were not determined.

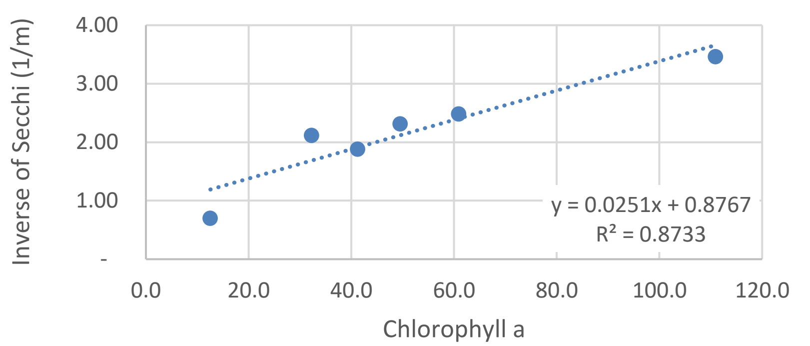
Water quality has been variable with less productive, i.e., less obnoxious phytoplankton biomass and better Secchi transparency in 2 of the 8 monitored years. These "better" years followed a chemical (Phoslock) treatment that diminished the contamination of the lake water by the bottom mud. (Phoslock, is a lanthanum amended-clay that adsorbs phosphate as it is released from highly enriched bottom sediments. Consequently, there is less of the phosphorus nutrient available for phytoplankton to overly produce and to consume a lot of oxygen, creating anoxia during die-off.) Lower TP and less anoxia in both treatment years and lower phytoplankton biomass (lower chlorophyll and higher Secchi transparency) in the second year (i.e., the first full year after the treatment), indicate the importance of phosphorus in the trophic cycle of Swan Lake.

2.2 Secchi disk transparency and relationships with other variables

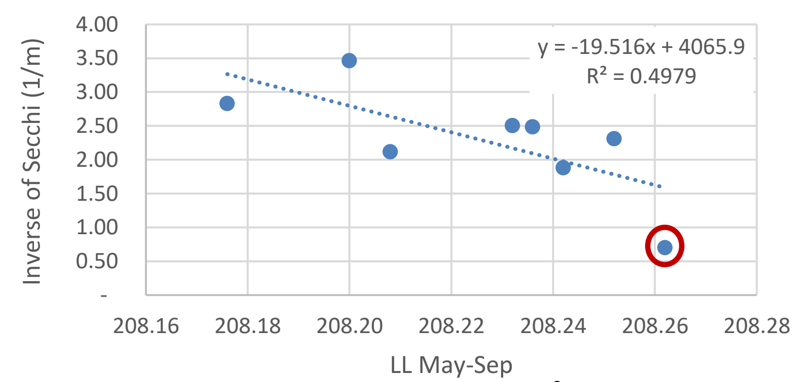
Secchi disk transparency (Secchi) is a visual indicator of lake water clarity. Secchi is controlled by biota, i.e., the phytoplankton pigment chlorophyll *a*, and inorganic suspended material from sediment disturbances due to lake water mixing during dry periods or input from lake shore during rain storm events. Both effects are observed in the long-term data.

Secchi (or its inverse to simplify statistical analysis) is significantly correlated to chlorophyll, the higher chlorophyll the lower Secchi, for available growing period averages 2011-2018 (Figure 1 A). It is also correlated with May-Sep lake level, the lower the level the lower Secchi, possibly indicating the influence of sediment resuspension for available growing period averages 2011-2020 (especially when excluding the post-treatment year 2014 with an exceptional high Secchi caused by the internal load treatment that controlled phytoplankton biomass) (Figure 1 B).

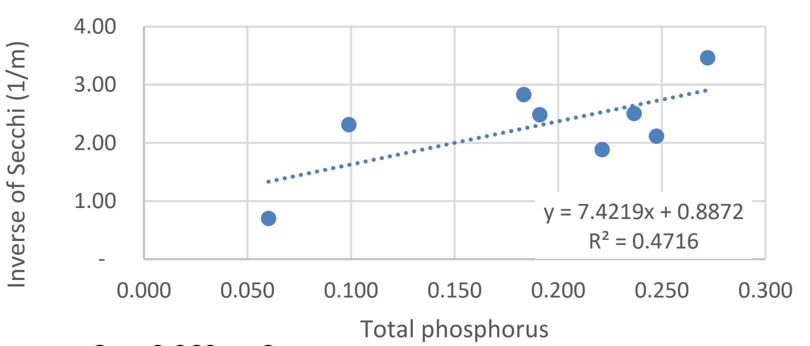
Figure 1. Secchi (inverse) versus chlorophyll (A), lake level (B, with post-treatment year 2014 marked) and total phosphorus (C) for the available growing period averages of Table 1. *(Statistics are provided for additional information)*



A: p=0.006, n=6



B: p=0.051, n=8, (marked 2014, better R^2 when excluded)



C: p=0.060, n=8

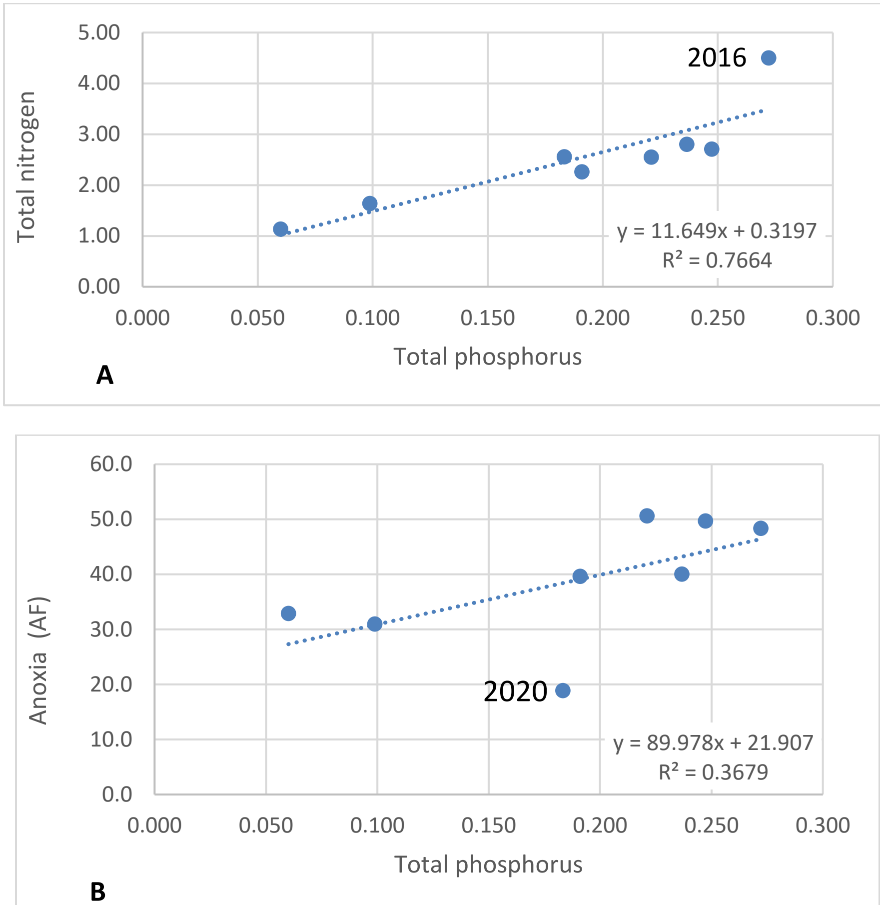
As expected, there is also a correlation between the nutrient, TP, and Secchi (Figure 1 C). Based on growing period averages in 2011-2020 including the post-treatment years, the regression between the inverse of Secchi and TP average is marginally significant (p=0.06, n=8), so that the relationship can be used to provide guidance about TP thresholds. Using the relationship of Figure 1 C, a Secchi of 0.50 m would be reached at a growing period average TP of 0.150 mg/L and of ~0.60 m (exactly 0.614 m) would be reached at TP of 0.100 mg/L, and ~0.70 (exactly 0.693 m) would be reached at TP of 0.075 mg/L.

In a previous analysis (FWR 2018 and Appendix F of 2020) a relationship of individual monitoring dates in years 2011 to 2017 yielded corresponding values of 0.150 mg/L TP and a Secchi depth of 0.45 m. These individual dates-based values are similar to the newly established values of 0.150 mg/L TP and Secchi of 0.50 m (or its inverse of 2.00). Because the last estimate is based on growing period averages that are more robust and includes 3 additional years of observations, these values are preferable for setting growing period water quality thresholds for Swan Lake.

The importance of phosphorus for water quality management is further supported by several relationships with TP and responses to the P treatment:

(1) There is a pattern of Secchi with TP so that decreased TP correlates with increased Secchi transparency (as previously explained for Figure 1 C).
(2) The nutrients TP and TN are significantly correlated, as is often found in lakes (Figure 2A). TN average growing period concentrations were decreased in the years after the P interception treatment. This observation means that P is the driving nutrient in Swan Lake that should be managed, and not N.
(3) There is a pattern of decreased anoxia (expressed as anoxic factor, FWR 2020) with decreased TP (Figure 2B), except when lake level is low and is prone to aeration by mixing (as in 2020, Table 1), further supporting P management to increase water quality in Swan Lake.

Figure 2. Total nitrogen (A) and anoxia, expressed as anoxic factor (B), versus total P for the available growing period averages of Table 1. (Outliers are indicated. 2016 had an extremely high geese population. The 2020 extremely low May-Sep lake level facilitated aeration by mixing.)



3 Nutrient loading estimates

Because phosphorus has been established as the most important variable to control water quality in Swan Lake, the relative contribution from various sources was determined in an attempt to find the most efficient management options. Sources are external, including stormwater, precipitation and geese, and internal, including diffusion from bottom sediments and resuspension.

The mass balance analysis TP conducted previously (FWR 2020 and previous reports) was updated with monitoring data collected in the recent years of 2019 and 2020, and revised hydrological and morphometric input (provided by Staff of the City of Markham). The basic load calculations, the TP model structure, and other component and methods are described in the previous reports. In this memo, results are provided that are relevant to the Swan Lake Water Management Plan.

3.1 External phosphorus load

External P inputs for separate sources were estimated for the last 11 years, 2010-2020. This period includes the increase of the waterfowl population (mainly Canada geese, *Branta canadensis*) until 2016 after which management efforts reduced the population to a stable plateau. (According to enumerations by consultants, city staff, and volunteers there are approximately 20-30 resident geese throughout the year with an increased abundance during migration.) Geese derived loads are substantial compared to the other external TP inputs and are typically larger than the sum of all other remaining estimated external inputs. It was especially high in 2016, before the implementation of geese management (Table 2).

External loads were not specifically addressed by the Phoslock treatment in 2013 that treats sediment derived (internal) load, and, as expected, there is no sign of decreased external load in 2013 and 2014, the post-treatment years with decreased lake water TP concentration. There is an upward trend from smaller loads before the treatment to higher fluctuating loads thereafter (Table 2), caused mainly by the fluctuating geese population and some hydrological variability. The external load has stabilized in the last 3 years (2018-2020) at about 32.5 kg/yr (Table 2). On average, the 2010-2020 average annual external load was highest from waterfowl, next highest from the shoreline, less from the stormwater management (SWM) ponds, and minor from precipitation (Table 3).

Table 2. Annual calculated TP loads for separate flows of several external sources and internal load (kg/yr).

Year	Geese	SWM pond 104	SWM pond 105	Shore	Atmospheric deposition	External (total)	Internal Load	Internal/total TP load
2010	8.79	3.02	1.74	5.82	0.80	20.2	55.4	73%
2011	10.12	2.81	1.41	4.97	0.80	20.1	32.6	62%
2012	11.45	4.11	2.08	7.30	0.80	25.7	81.1	76%
2013	12.79	4.32	1.99	8.35	0.80	28.2	26.0	48%
2014	14.12	3.94	2.01	7.67	0.80	28.5	0.0	0%
2015	27.54	3.34	1.72	5.56	0.80	39.0	na	na
2016	40.97	3.31	1.51	4.37	0.80	51.0	20.8	29%
2017	14.28	3.81	1.90	6.26	0.80	27.0	50.5	65%
2018	14.90	4.94	2.56	9.99	0.80	33.2	101.4	75%
2019	15.84	5.06	2.34	8.38	0.80	32.4	112.8	78%
2020	14.69	4.73	2.29	9.48	0.80	32.0	50.6	61%
Average:								
2010-20	**16.86**	**3.94**	**1.96**	**7.10**	**0.80**	**30.67**	**53.1**	**57%**
2018-20	15.15	4.91	2.39	9.28	0.80	**32.53**	**88.3**	**71%**

Na, No data available

Table 3. Phosphorus contributions from external sources (2010-2020 average), see FWR 2020 for methods

Annual average TP fluxes	**kg/yr**	**%**	**Comments**
Atmospheric deposition	0.80	2.6%	Long-term average wet and dry fallout for South Central Ontario (Ministry of Environment, 2010)
SWM pond 104 SWM pond 105	3.94 1.96	12.9% 6.4%	Based on the average monitored outflow concentration of 0.116 mg/L TP (2011, 2012, n=8)
Immediate lake shore runoff and other untreated runoff	7.1	23.2%	Based on the pro-rated TP concentration in runoff of 0.211 mg/L TP (LaZerte and Nürnberg, 2000).
Geese	16.86	55.0%	Extrapolated from counts
Total external input	**30.67**	**100%**	Sum of above

3.2 Internal phosphorus load

Internal P load is one of the most challenging P sources to quantify in lake and pond eutrophication and restoration. While inputs from external P sources can be estimated from land use, precipitation, and point sources, internal sources cannot be easily quantified. P that originates within a lake from anoxic bottom sediments, macrophytes, or sediment disturbances immediately mixes with the P already present in lake water so that any fluxes or inputs cannot be directly estimated in shallow lakes. But comparison and quantification of the different P sources is needed to establish successful lake management approaches. When the effects of internal sources on water quality outpace those from external sources or for faster remediation effects, an in-lake treatment is recommended.

Internal P loading usually stems from former external inputs which are stored in bottom sediments, and it may originate in nutrient-rich former land fill and recent inputs from water fowl feces in Swan Lake. Because P released from the bottom sediments is highly biologically available, and because its release is elevated at summer water temperature, P release severely affects summer and fall lake water quality. Such internal load is typically a result of oxygen changes at the sediment-water interface. Anoxia leads to the dissolution of iron compounds (iron oxy-hydroxides) in the sediments and the release of adsorbed P (i.e., P attached to the iron surfaces) to adjacent lake water. P may also be released from organic compounds, poly-phosphates, and recently added feces.

Annual internal loads for Swan Lake (Table 2, last 2 columns) were estimated from monitoring data in a mass balance analysis and confirmed by other methods as described previously (FWR 2020). Internal load was zero in 2014, the first complete year after the chemical treatment. It was consistently higher before (2010-2012) and after the treatment effect had diminished (2017-2020), probably because of the initially unchecked abundance of geese. Consequently, the contribution of the internal to the total TP load (internal plus external) fluctuated between 0 and 78% in Swan Lake and averaged 71% in the last 3 years (Table 2).

The effect of internal P load on the TP concentration is evident when comparing monitored TP concentration of the upper mixed layer to whole lake average water concentration (Table 4). In Swan Lake, usually whole lake TP is higher than upper mixed layer concentration. This higher water column average is due to elevated TP concentrations at deeper depths, closer to the sediments. The Phoslock treatment decreased the water-column average TP concentration from 0.355 mg/L in 2011 to 0.161 mg/L due to a 66% decrease of internal load from the preceding year in 2013 and further to 0.090 mg/L due to a 100% decrease in 2014. A 66% decrease was again estimated for 2016, while internal load approached pre-treatment levels thereafter (Table 2 and Table 4).

Table 4. TP concentration averages of the 0-1.5 m mixed layer for May-Sep compared to approximate whole lake average TP concentration (all year and all volume-weighted depths down to 3.5 m or 0.5 m above sediment).

Year	Upper mixed layer average TP (mg/L)	Whole water column average TP (mg/L)	Upper/ whole lake %
2011	0.247	0.355	70%
2012	Na	0.355	70%
2013*	0.099	0.161	61%
2014*	0.060	0.090	67%
2015	Na	Na	Na
2016	0.272	0.454	60%
2017	0.191	0.306	62%
2018	0.221	0.307	72%
2019	0.237	0.354	67%
2020	0.183	0.226	81%

*Phoslock treatment in April 2013 mostly affected growing periods in 2013 and 2014.
Na, data not available

4 Climate change effects

Climate change has been observed and is predicted for the Markham area as reported for the York Region (York Region Public Health. 2021. York Region Climate Change and Health Vulnerability Assessment):

> "York Region, is located in the Lake Simcoe-Rideau Ecoregion, which is characterized by a mild and moist climate. This Ecoregion has a mean annual temperature range of 4.9°C to 7.8°C, a growing season of 205 to 230 days, mean annual precipitation of 759 to 1,087 mm, and mean summer rainfall of 198 to 281 mm. In recent decades, York Region has experienced increases in average temperature and precipitation. From 1948 to 2016, there was an increase of approximately 1oC and 2oC in the mean daily temperature for summer months and winter months respectively. Total precipitation increased by approximately 10% between 1948 and 2012." In addition, extreme whether events have been recorded, including very hot summers, intense rainfall events leading to flooding, and drought.
>
> Climate predictions for York Region 2050s include:

- 90-100% probability of annual and seasonal temperature increases.
- 90-100% probability of cold temperature decreases.

- 66-100% probability of annual precipitation increases (in the winter and spring) annually but not in summer and fall, except increasing frequency and magnitude of extreme events.
- 66-100% probability of a 30-d extension of growing period from past May 17 – Oct 15.
- Drought would increase because of increased temperature without increased precipitation in the summer.

5 Management options and treatment scenarios

The variables of concern respective water quality are mainly dependent on the phosphorus concentration in Swan Lake (Section 2). These observed dependencies are supported by observations from other lakes and theoretical limnological considerations. Consequently, the control of P sources to decrease P concentration is the most effective management option.

According to the partitioning of the P sources (Table 2), input from water fowl and bottom sediment are the largest loads. Both have been decreased by specific management actions that are also available for future management. The immediate shoreline including the park and walkway and rare inflow from the stormwater ponds are small (Table 3), but further management options examined in FWR (2020) including pet management and plantings around the shore would further decrease their impact.

Water fowl was successfully controlled by disturbance and hazing activities by a professional consultant so that it was decreased by almost 60% (from 2016 to 2017, Table 2). Continued goose management kept the input from geese at that level (2017-2020) and is recommended for the future. Additional recommended activities include enhanced geese hazing, geese relocation, and nest removal, conducted more recently.

Internal load was successfully controlled by a one-time Phoslock application for at least 2 growing periods (2013-2016, Table 2). The resurgence of sediment released P since 2017 (71 % of total load in the recent 3 years 2018-2020, Table 2), made another P adsorption treatment necessary that was completed as poly-aluminum-chloride on August 3 to 19, 2021. (Canadian import regulations have currently prevented the repeated use of the preferred Phoslock treatment.)

5.1 Chemical treatment and frequency scenarios

Scenarios were modelled (Table 5) to quantify expected changes in lake phosphorus concentration and the water quality variables Secchi transparency and (modelled) anoxia in response to specific P management options and climate change predictions (Section 4).

As is obvious from scenarios I4-I6 (Table 5) the abatement of internal loading has the most effect on P concentration, Secchi, and anoxia (Table 6). If only 50% of the long-term average internal load would persist (Scenario I5), Secchi is expected to improve by 0.10 m (from 0.43 m of the Base Scenario to 0.53 m), which is substantial in shallow Swan Lake. Such increase in transparency would improve light conditions so that conditions for the potential planting of submerged water plants would improve as well.

If external sources and geese feces could also be settled to 50% of long-term average contributions, Secchi would improve by almost another 0.10 m, to a predicted depth of 0.62 m as growing period average. In combination with fish and plant management, these activities are expected to accelerate the improvement of Swan Lake's water quality.

The dosage and frequency of the chemical application are the most important factors in the control of P released from the bottom sediments as internal load. In addition, other management options, particularly goose management and options leading to lower external P input will increase the beneficial effects of the chemical treatment. The expected decrease in lake over-productivity will result in less settling of nutrient-enriched particles so that the sediment P content decreases over time. Such a decrease will eventually decrease internal loading from the sediments.

The modelled water quality effects concern the average growing period, avoiding short-term variability due to weather and lake use influences. Model results refer to conditions of steady state. Because Swan Lake has a flushing rate of approximately once per year, the time for changes to be fully established can be expected to be about 1 year. Further, the changes in P loading in response to P management would have to be sustained for a longer period of time (several years) to effectively and continuously control water quality (variables).

In this context, the growing period immediate after a treatment with adequate dosage is expected to decrease internal load to at least 75% of untreated load (Scenario I4 in Table 5, Table 6), depending on the time of application (earlier treatment would increase the benefit in the growing period). The 1st full year after chemical application (2nd growing period) could be expected to successfully intercept all sediment release to result in 0% remaining load (Scenario I6 in Table 5, Table 6, considering the average water renewal time of 1 year and based on the observed internal load in 2014, Table 2). It is likely that in the 2nd year (3rd growing period) still includes a 50% benefit resembling the first-year effect. Thereafter and starting in the 3rd year, a consistent decrease of treatment efficiency is expected (I4). Depending on other P input especially that of water fowl, conditions characteristic of only limited management can be expected to re-occur after the 5th year (Base Scenario in Table 5, Table 6).

According to these scenarios, an application every third late spring (after 2 years without treatment) in conjunction with a 50 % decrease in all other manageable P inputs could provide consistently reasonable water conditions (Scenario E1-3, I6 in Table 5, Table 6). With such an aggressive management, Swan Lake is expected to be classified as borderline meso-eutrophic with respect to mixed layer growing period TP (0.038 mg/L, eutrophy: 0.031 - 0.100 mg/L), but Secchi transparency would still be at hyper-eutrophic levels (0.86 m, hyper-eutrophy: less than 1.0 m). A prevailing, relatively low Secchi transparency is probably related to sediment disturbance in this shallow lake.

To address climate change-related implications for Swan Lakes future water quality, scenarios for extreme-hot conditions with increased stormwater events were included in the analysis and produced lower water quality (Table 5, Scenarios CC1-CC3). Increased water temperature has a direct increasing effect on sediment P release. Increased rain events will increase pollutant from shoreline runoff and the SWM ponds. In a conservative approach, 50% increase of all inputs besides that from water fowl was used to model the base-line climate change scenario (CC1).

When amended by management that keeps only 50% of all manageable P sources under climate change conditions (Table 5, Scenario CC2), water quality would still be expected to be improved over long-term average conditions, almost to those of the 50% scenario that does not consider climate change (I5). Water quality would be improved even more for 0 internal load (Table 5, Scenario CC3). Accordingly, Swan Lake management efforts are expected to be highly effective even in the view of a changing climate that, without lake management, would deteriorate water quality.

Table 5. Scenarios for various management options specific to the reduction of P and climate change. TP load after change.

Scenario	Description	Change	TP Load (kg/yr)					
			Precip	Shore	SWM	Geese	External	Internal
Base	**2011-2020 Average**	0	0.8	7.0	6.0	17.0	**30.8**	**50.0**
	External Load:							
E1	**Shore: 50%**	**0.50**	0.8	3.5	6.0	17.0	**27.3**	**50.0**
E2	**SWM: 50%**	**0.50**	0.8	7.0	3.0	17.0	**27.8**	**50.0**
E3	**Geese: 50%**	**0.50**	0.8	7.0	6.0	8.5	**22.3**	**50.0**
E1-3	**Shore, SWM, Geese**	**0.50**	0.8	3.5	3	8.5	**15.8**	**50.0**
	Internal Load:							
I4		**0.75**	0.8	7.0	6.0	17.0	**30.8**	**37.5**
I5		**0.50**	0.8	7.0	6.0	17.0	**30.8**	**25.0**
I6		**0.00**	0.8	7.0	6.0	17.0	**30.8**	**0.0**
E1-3, I5	**All possible 50%**	**0.50**	0.8	3.5	3.0	8.5	**15.8**	**25.0**
E1-3, I6	**50% external, 0% internal**	**0.50**	0.8	3.5	3.0	8.5	**15.8**	**0.0**
	Climate Change (CC):							
CC1	**Climate change only**	**1.50**	1.2	10.5	9.0	17.0	**37.7**	**75.0**
CC2 (E1-3, I5)	**CC with 50% loads**	**0.75***	1.2	5.3	4.5	8.5	**19.5**	**37.5**
CC3 (E1-3, I6)	**CC with 50% external, 0% internal load**	**0.75***	1.2	5.3	4.5	8.5	**19.5**	**0.0**

*75% (1.5 x 0.5) remains of the long-term load for conditions of climate change (CC1) that increases shaded loads by 150% and management efforts (E1-3, I5) for a 50% decrease.

The P loads were determined as presented in Section 3.

Table 6. Scenarios for various management options specific to the reduction of P and climate change. Response by the water quality variables and description of general water appearance.

Scenario	Description	TP (mg/L)		Secchi (m)	Anoxia	Description and predicted period*
		Column average	Mixed Layer		0.5 x AA (d/period)	
Base	**2011-2020 Average**	**0.277**	**0.194**	**0.43**	42	Hyper-eutrophic with heavy phytoplankton biomass in summer and fall and potentially toxic cyanobacteria
	External Load only:					
E1	**Shore: 50%**	**0.265**	**0.185**	**0.44**	41	Hyper-eutrophic, little visual improvement; slightly lower phytoplankton biomass
E2	**SWM: 50%**	**0.266**	**0.186**	**0.44**	41	
E3	**Geese: 50%**	**0.247**	**0.173**	**0.46**	41	
E1-3	**Shore, SWM, Geese**	**0.225**	**0.158**	**0.49**	40	
	Internal Load only:					
I4	**75%**	**0.234**	**0.164**	**0.48**	40	Hyper-eutrophic, little visual improvement; expected in 4th year AT
I5	**50%**	**0.191**	**0.134**	**0.53**	38	Hyper-eutrophic with slight improvement over "Base"; 2nd - 3rd year AT
I6	**0%**	**0.105**	**0.074**	**0.70**	31	Eutrophic; 1st - 2nd year AT
E1-3, I5	**All possible: 50%**	**0.140**	**0.098**	**0.62**	34	Eutrophic; 2nd - 3rd year AT
E1-3, I6	**50% external, 0% internal**	**0.054**	**0.038**	**0.86**	24	Almost mesotrophic, low phytoplankton biomass; expected in 1st - 2nd year AT
	Climate Change (CC):					
CC1	**Climate change only**	**0.386**	**0.270**	**0.35**	45	Hyper-eutrophic, with further decreased water quality: almost consistent phytoplankton patches in summer and fall and potential cyanotoxins
CC2 (E1-3, 5)	**CC with 50% loads**	**0.195**	**0.136**	**0.53**	38	Slight improvement from "Base"; 2nd - 3rd year AT
CC3 (E1-3, I6)	**CC with 50% external, 0% internal load**	**0.067**	**0.047**	**0.81**	26	Almost mesotrophic, low phytoplankton biomass; expected in 1st - 2nd year AT

Footnote to Table 6
***AT**: after chemical treatment to control internal P loading; the indicated year AT is based on previous experience with a Phoslock application in 2013 and provides an approximation only. Responses to external load and climate change (CC) consider long-term (after at least 1 year) conditions. The predictions are imprecise as they are associated with variability from weather-related and other factors.

Trophic state evaluates the water quality of a lake during the growing period, where oligotrophy is only achieved in pristine lakes (e.g., in the "Cottage Country"), mesotrophy represents an acceptable state with little phytoplankton biomass, eutrophy has usually impaired water quality with potentially toxic phytoplankton and hyper-eutrophy describes a seriously polluted water with consistent phytoplankton biomass and low transparency (Secchi).

The **period of 2011-2020** was modelled to include years with available monitoring data and some management activities. Mixed (surface) layer TP concentration is responsible for the description of trophic state and is used in the modelling of Secchi and Anoxia. Whole water column TP is higher than mixed layer TP because it includes the deep layer with elevated TP from sediment release and settled geese feces.

Secchi transparency was modelled from the equations presented in Figure 1C. Anoxia is based on the model described in FWR 2020, Appendix A, but adjusted by 0.5 to present a more realistic observed factor (to account for aeration from mixing). – All modelling results have uncertainty attached to them but provide evidence on expected proportional changes and trends.

5.2 Additional management options

5.2.1 Eutrophication, anoxia, nitrogen

While the control of phosphorus as presented in Section 5.1 is a long-term solution that addresses the causes, there are several short-lived options available that mainly address the symptoms of over-enrichment and **eutrophication**. Such options were presented in detail in FWR (2020) and are not repeated here as they are not recommended. They include treatment approaches for the decrease of phytoplankton by algaecides and treatment of internal load by aeration and destratification, which would only increase the movement of P from the sediment to the illuminated water layer.

Anoxia and oxygen depletion is a consequence of a highly productive environment with a high trophic state. Reducing the trophic state, e.g., by nutrient control (both of internal and external sources) will reduce anoxia. Therefore, the most effective treatment against anoxia is efficient nutrient control. Nonetheless, there is a chemical treatment, calcium peroxide (CaO_2), that may increase the water oxygen concentration without the negative effects of water mixing. However, this method is at research state without any known case studies and is not recommended as a ready-for-use approach for Swan Lake. (More information is provided in a Memo by FWR and a literature review by Siembida-Lösch, 2021).

The nutrient, **nitrogen**, is correlated with TP and was reduced when the chemical P abatement treatment was applied in 2013 (Section 2.1). Nitrogen will be reduced as a result of decreased productivity after phosphorus and goose management, and its direct management is not recommended. In general, nitrogen is not usually controlled because low inorganic concentrations may give cyanobacteria (blue-green, potentially toxic, phytoplankton) a competitive advantage as they are less responsive to N-limitation than other algae.

Some other options put forward by the Friends of Swan Lake are not recommended and include bioswales and wetlands. **Bioswales** have been used to promote infiltration in water conveyances (ditch, small ephemeral creeks) to decrease sediment and nutrient load in the context of best management practice (BMP) solutions. The pollutant retention depends on water retention time and therefore length of the conduit in combination with slope. The flat and built-up area around Swan Lake is not supportive of a large and effective application of bioswales. Standing water shallow enough to be exposed to large temperature increases, support mosquito abundance and is generally avoided in urban areas. Maintenance would be associated with considerable effort and costs and is not deemed feasible after investigation by City staff.

With respect to **floating treatment wetland**, the settling of suspended algae and solids beneath the mats would be enhanced by stagnancy and stratification of the water layers, which also encourages the proliferation of cyanobacteria. Artificial islands on Swan Lake would provide more nesting opportunities for resident geese (they are already inhabiting and nesting on some existing islands). While islands could provide more natural vistas, the benefit for water quality enhancement is small or even negative. Maintenance, especially in the winter, can also be problematic.

5.2.2 Aquatic biological health (fish and vegetation)

Shallow lakes are known to have **alternate stable states** between clear-water and turbid-water states. At nutrient-over-enrichment, as occurs in Swan Lake, phytoplankton that is distributed throughout the water column, is the main photosynthetic active plant shading out other plant life. Contrarily, in less enriched and clearer lakes, submerged water plants (macrophytes) grow up from lake bottom solidifying the sediment and providing refuge for fish.

Once phosphorus is controlled to consistent concentrations below 0.100 mg/L and transparency has improved, additional treatment suggestions include the planting of native submersed plants to help solidify the sediment and provide fish habitat. A study on 20 gravel pit lakes, including some similar to Swan Lake, determined that improvement in the littoral habitat (addition of diverse structures and variability of habitat type) can promote abundance of most gravel pit lake fish species (Matern et al. 2021).

Bottom-dwelling fish including carp and gold fish increase turbidity and internal load and need to be controlled, if overly abundant. A fish consultant would be able to provide the details for Swan Lake. As of spring 2021, there were a few carp, several brown bull head (*Ameiurus nebulosus*) and many minnows detected by electrofishing and net observations, indicating that Swan Lake could potentially support suitable fish species despite high chloride concentrations (Section 5.2.3).

5.2.3 Chloride

Chloride (Cl) concentration has been increasing in Swan Lake from less than 500 mg/L open water average in 2017 to more than 700 mg/L in 2020. There is no feasible management tool to diminish Cl in the lake and it is best treated at the source. The application of improved de-icing methods would also benefit other areas, i.e., parks and water ways in City of Markham jurisdiction. Successful Cl depletion in receiving waters by floating wetlands is questionable and case studies with quantitative results are not reported in the scientific literature. The introduction of (alien) salt-loving plants is not recommended. Further, it is not clear how such introduction should affect Swan Lake Cl concentration.

Elevated Cl concentration is frequently observed in Ontario urban lakes. We recommend an exchange with the City of Toronto, The Town of Richmond Hill, and the Toronto Region Conservation Authority on possible management approaches in the catchment.

5.2.4 Public health

Public health related potential issues include bacterial contamination and cyanotoxins from cyanobacterial phytoplankton. Bacterial contamination, including elevated counts of e-coli, can be caused from animal sources such as water fowl and pets. Although these sources do not directly present a threat to human health due to limited exposure pathways, the addition of animal feces to Swan Lake water should be minimized to avoid contamination by nutrients (Section 3) and organic compounds, which enhance oxygen depletion.

Toxins from cyanobacteria are not directly related to biomass, but are highest when cyanobacteria proliferate at high nutrient concentrations. The proposed treatment related to phosphorus and waterfowl is expected to diminish cyanobacteria proliferation and hence the threat from their toxins.

6 Summary of recommended actions

Management options and associated effects are presented in Section 5 above and in the more comprehensive report of FWR (2020, Section 6). A synopsis of such options and other suggested ongoing activities is presented below.

- A detailed plan to annually **monitoring water quality** by collecting water samples at 1-3 sites is presented in Appendix G of FWR (2020).
- **Waterfowl management** according to the current goose control and monitoring program should be continued until a maximum of 30 residence geese occupy Swan Lake and its surroundings and migratory geese are rare. It is anticipated that theses activities are needed annually.
- **Shoreline runoff and the stormwater runoff** that bypasses the stormwater management ponds can be improved by best management practices, including education about pet management, controlled lake shore access via boardwalks, and plantings around the lake shore to adsorb pollutants. Markham's Parks department is currently drawing up a plan in exchange with the Toronto Region Conservation Authority (TRCA).
- **Historic dumpsite runoff** is to be investigated if despite several treatments and other proposed measures lake water quality still needs to be improved. If dumpsite runoff is found to be substantial, its impact on the phosphorus budget and lake water quality in conjunction with the recommended actions is to be evaluated. A management plan has to include discussions with the owners of the development on these former dumpsites.
- **Fish management and culturing submerged plants**: Control of bottom dwelling fish (carp and gold fish) is necessary to ensure a high efficiency of the chemical treatment. Plantings of non-invasive plants are recommended to help consolidate the bottom sediments, decrease turbidity and increase Secchi transparency.
- **Chemical applications to treat internal P load**: A treatment at a dosage of every three years may control internal phosphorus load to almost reach a mesotrophic state with respect to phosphorus, in combination with a 50% external load reduction that includes geese control, shoreline best management practices and continued minimal storm water pond outflows. - A chemical treatment every five years could provide acceptable conditions for several

years (but still hyper-eutrophic state in the 4th year), depending on climate-related water quality variability and expectations.

- There is no direct treatment suggested to improve **anoxia** in Swan Lake. The suggested control of external and internal P loading will decrease productivity and therefore decrease the amount of oxygen depleting organic material settling to the sediment. A notorious and often proposed aeration and mixing treatment is not recommended for Swan Lake, because of the nutrient-enriched bottom layer that would fertilize the illuminated surface layers and increase phytoplankton abundance. Instead, a chemical treatment of adding oxygen via calcium peroxide directly to the sediment may be investigated. However, this method is only at a research & development state without any known case studies and is not recommended as a ready-for-use approach for Swan Lake. Its applicability could be investigated in a pilot project in connection with a research facility or university.
- Chloride concentration is not commonly controlled in a lake. Instead, it is controlled by source control in the catchment (Section 5.2.3).

The inherent uncertainty of model predictions, the variability of the weather, and the unavoidable effects of climate change mean that the exact future water quality of Swan Lake is uncertain. Therefore, the concept of ***adaptive management*** is proposed. In this principle, continuous and consistent monitoring of the most important water quality variables can be used to adjust management activities to maximize treatment efficiency.

Lakes in an urban environment have become increasingly important to highly populated regions and are an important landscape feature of cities and suburbs. The high density of development and associated human population in cities creates a primarily artificial surrounding with few natural features. Traditionally, parks with ponds have taken the role to satisfy some quest for nature in these environs. However, urban and suburban stresses can create severely eutrophic conditions with high nutrient concentrations, low oxygen concentration and Secchi disk transparency, and high phytoplankton biomass including cyanobacterial blooms. Consequently, these lakes, not unlike urban stormwater ponds, can present a nuisance rather than a recreational asset to visitors of the park environment.

Accordingly, there are many lakes in the Greater Toronto Area (GTA) with water quality reaching from overly-enriched to almost acceptable (Nürnberg unpublished data, 1994-1997: in 16 lakes TP 0.035 – 0.363 mg/L and 6 lakes of 9 had bottom water anoxia). To avoid a hyper-eutrophic nutrient state with associated water quality deterioration, the City of Markham has invested in monitoring and novel lake management of Swan Lake for almost a decade. (I.e., Swan Lake was the first Canadian lake treated with Phoslock.) The continuous effort in pro-active, adaptive lake management is to ensure the future of a decent water quality in Swan Lake.

6.1 Costs

Swan Lake water quality has been variable as determined by intensive monitoring by the City of Markham since 2011 (Table 1). To ensure acceptable conditions in the future, a long-term lake management plan was assembled for specific items, including importance and annual costs (FWR 2020).

Explanations of the projected costs and the specific recommendations are presented in detail as follows. The most important P sources are external (waterfowl) and internal sediment-derived load. Therefore, we recommend to continue an aggressive year-round goose management and repeated chemical treatment for the sediment.

We propose a chemical treatment to address the mobile sediment P every 3 years (but extendable in the future, see below) to avoid large fluctuations in TP and water clarity (Secchi) for costs as specified in Table 7. We usually recommend a single large dosage application rather than several small dosage treatments but in Swan Lake this strategy is debatable. The variable geese impact and climate-related variation in shore line runoff may add settling material that provides further P from the bottom sediments. In addition, depending on the carp and gold fish abundance, disturbance of the sediment may have to be considered.

Continuous monitoring of water clarity (Secchi), TP, and water column temperature and dissolved oxygen will determine whether the frequency of the chemical treatment is optimal. We envision that Swan Lake will become less eutrophic after several application cycles (e.g., after 2 applications and 6 years) so that either the dosage could be decreased or the period between applications could be increased.

For external load abatement, goose control throughout the year is most important. In addition, naturalization of the shoreline (to manage geese and nutrient runoff) and investigation in the runoff hotspots, potentially from the former dump sites, are recommended for costs as specified in FWR (2020) and to be estimated by Staff.

Annual costs including three different treatment frequencies are presented in Table 8.

Table 7. Estimated treatment and monitoring costs concerning internal load

Item	Cost	Comment	Performed by
Implementation Plan	$10,000	Scenario definition and dosage	Consultant
		Fish management	
Survey	$5,000		Consultant
Removal	$20,000		Consultant
		Chemical treatment	
Material			
Phoslock, 25 tonnes	$80,000	5 tonnes/ha over 5.0 ha ($3,200/t)	Phoslock
PAC, 13 tonnes	$30,400	2.6 tonnes/ha over 5.0 ha ($2,320/t)	Various suppliers
Application			
Phoslock*	$31,000	Based on a 2020 quote	Contractors
PAC	$90,000	Based on a 2021 contract	Contractors
		Monitoring	
Monitoring and Evaluation	$25,000	Sampling from open water and evaluation of success	Consultants

Table 8. Evaluation, implementation, and estimated cost of recommended actions.

Recommended Tasks	Comment	Approximate annual Cost*
Costs depending on chemical treatment frequency:		
Internal Load treatment (Phoslock or PAC)	One application every **3 years** Incl. monitoring, evaluation	$50,000 ($150,000/3 yrs)
	One application every **4 years** Incl. monitoring, evaluation	$37,500 ($150,000/5 yrs)
	One application every **5 years** Incl. monitoring, evaluation	$30,000 ($150,000/3 yrs)
Annual costs:		
Fish management	Survey	$5,000
Water fowl management	Continuous	$13,500
Water quality monitoring	Growing season and winter	$12,000
Shoreline BMPs	Naturalization, education, maintenance and cleaning	Staff of Markham
Investigational costs (R&D):		
Hypoxia	Investigation into novel chemical treatment	tbd

*One chemical treatment is estimated as about $120,000 including material and application (Table 7); an additional 30,000 is budgeted for related expenses including extra monitoring.

6.2 Schedule summary

- Geese management: Geese number should be minimized by continued management efforts throughout every year and by shore line horticulture changes.
- Chemical treatment frequency with Phoslock or PAC: Internal P Load is increased at high temperature related to climate change; decreased after chemical treatment; dependent on bottom-dwelling fish abundance.

  Potential treatment frequency:
  - Annual, every spring: Trophic state would be consistently eutrophic (rather than hyper-eutrophic) with further amelioration after several years of annual treatment. Management costs and disturbance would be high every spring.
  - Every third year: The previous treatment improved water quality for at least 2 years. Therefore, a treatment every third year should suffice to improve water quality consistently while keeping costs to a third of an annual treatment and disturbance in the lake surroundings low.
  - Every fifth year: The previous treatment did not last over 5 years (although it is possible that the lack of goose management decreased the beneficial period of the internal load treatment). More frequent treatment would ensure more acceptable water quality.
  - In the future, chemical treatment frequency and dosage could be decreased, if monitoring results show extended improvements by adaptive management.

  Recommended treatment dosage and frequency:

  The whole lake should be treated including the eutrophic bays at a rate similar to the 2013 application until newer insights become available. There is no problem respective “over-dosing” when using Phoslock, because there is enough phosphorus in Swan Lake water and sediment to bind lanthanum of the suggested dosages.

  When using an aluminum-based treatment (PAC), dosage has to be carefully adjusted to avoid increased pH (that can trigger fish kills from elevated soluble Al) as is possible in the summer during high phytoplankton activity (photosynthesis) (FWR 2021b). Toxicity from decreased pH is unlikely because of the hard-water conditions favoring high pH. No immediate toxic effects nor fish kill were observed in the days following the 2021 PAC treatment.
  - 2021 Chemical treatment
  - 2024 Chemical treatment
  - 2027 or later: Chemical treatment. The exact frequency is to be based on future monitoring results.

- 2030-2046: Because of decreased internal load after the earlier treatments, it is expected that the frequency can be decreased to every 5 – 10 years, according to results from water quality monitoring and visual inspection.

- Continuous implementation of best management practices to address shoreline runoff (education, pet feces ordinance, horticultural improvement with the aim to intercept nutrients). Investigation of leakage from former dumpsites and determination of nutrient export to decide the importance of further management.
- Climate change, including extended warm periods and storm events, likely increases internal load and input from runoff. Scenario modelling predicts negative effects on the water quality of Swan Lake that can be counter-acted by the described management efforts.

7 Acknowledgement

Exchange with various stake holders (Friends of Swan Lake Park (FOSP), Jon Van Loon) informed on expectations and value of Swan Lake as a commodity and is much appreciated. This memo was reviewed by Dr. Bruce D. LaZerte, Freshwater Research.

8 References

8.1 Internal reports

City of Markham. 2019. Swan Lake water quality monitoring, 2019 annual report.

City of Markham. 2020a. Scope of Work for Swan Lake Chemical Treatment Planning and Scenario Analysis. Memo 2020-11-27.

City of Markham. 2020b. Swan Lake water quality monitoring, 2020 annual report.

City of Markham. 2021. Swan Lake chemical treatment planning and scenario analysis - Water balance. Memo 2021-03-08.

FWR (Freshwater Research) 2020. Swan Lake water quality management, Report for the City of Markham, Ontario.

FWR (Freshwater Research) 2021a. Swan Lake sediment quality and suggested dosage of Phoslock based on sediment fractionation data. Memo for the City of Markham 2021-01-12.

FWR (Freshwater Research) 2021b. Swan Lake Feasibility assessment of an aluminum-based treatment. Memo for the City of Markham 2021-03-15.

FWR (Freshwater Research) 2021c. Evaluation of the recommendations by the Friends of Swan Lake Park, as summarized in an e-mail by Markham staff on March 25, 2021. Memo for the City of Markham 2021-04-08

Siembida-Lösch, Barbara. February 2021. Literature Review of Potential Engineering Solutions for the Restoration of Swan Lake. Report prepared for Friends of Swan Lake Park, Fleming College Centre for Advancement of Water and Wastewater Technologies, Lindsay, Ontario.

8.2 Peer-reviewed publications and reports

Matern S, Klefoth T, Wolter C, Arlinghaus R. 2021. Environmental determinants of fish abundance in the littoral zone of gravel pit lakes. Hydrobiologia. 848:2449–2471.

ATTACHMENT C

Life-Cycle Cost Estimate (Assuming 2% Annual Inflation)

Some future costs are included as nominal values for perspective- see footnotes.

	Measure	Phase 1	Phase 2	Phase 3	Total	Current Life-Cycle (2021)	Increase Over Current Life-Cycle
	Continue water quality monitoring	$149,356	$ 164,901	$ 605,013	$ 919,270	$ 87,095	$ 832,175
	Continue geese management and enhanced	$275,037	$ 383,582	$ 1,407,339	$ 2,065,958		
Core	Remove benthic-dwelling fish	$ 38,608	$ 28,165	$ 103,336	$ 170,109	$1,017,325	$ 1,218,742
	Maintenance of stormwater management	$ 4,591	$ 8,284	$ 528,374	$ 541,249	$ -	$ 541,249
	Chemical treatment with adjusted frequency	$309,181	$ 261,141	$ 806,227	$ 1,376,549	$1,763,350	$ (386,801)
	Fish management plan and fish stocking **	$ -	$ 20,000	$ -	$ 20,000	$ -	$ 20,000
Complementary	Planting of submerged plants **	$ -	$ 20,000	$ -	$ 20,000	$ -	$ 20,000
	New technologies for chloride treatment **	$ -	$ 50,000	$ -	$ 50,000	$ -	$ 50,000
	Investigate dumping areas	$ -	$ -	$ 20,000	$ 20,000	$ -	$ 20,000
	Investigate groundwater **	$ -	$ -	$ 200,000	$ 200,000	$ -	$ 200,000
Alternative	Control groundwater loading**	$ -	$ -	$ 2,000,000 to $10,000,000	$ 2,000,000 to $10,000,000	$ - $ -	$ 2,000,000 to $10,000,000
	Evaluate structural modifications **	$ -	$ -	$ 200,000	$ 200,000	$ -	$ 200,000
	Implement structural modifications **	$ -	$ -	$ 5,000,000	$ 5,000,000	$ -	$ 5,000,000
	Evaluate measures	$ 25,000	$ 27,602	$ 33,647	$ 86,249	$ -	$ 86,249
	Option 2 - 25-year cost with Alternative Measures	$801,772	$ 963,675	$10,903,936 to $18,903,936	$12,669,383 to $20,669,383	$2,867,770	$ 9,801,613 to $17,801,613
	Recommended Option 1 - 25-year cost without Alternative Measures			$ 3,450,289	**$ 5,215,736**		**$ 2,347,967**

Notes:

* Assumed 25% decrease in five years and 25% in 10 years (not reduced from Phase 2 due to climate change impact).

** Values are order of magnitude and are rough estimates for perspective. Assume pond cleanout/retrofit during the period.