Swan Lake

Annual Meeting with Markham Subcommittee

May 11, 2023

Environmental Services

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Agenda

- Background and Completed Work
- 2022 Water Quality Results:
  - Nutrients and Eutrophication
  - Chloride Concentration
- Review of Three Research Initiatives:
  - Chemical Oxygenation
  - Chloride Treatment
  - Survey of Lower Level Aquatic Life
- Review of FOSLP *Towards a Comprehensive Restoration Plan for Swan Lake*
- 2023 Plan and Recommendations:
  - Core Measures
  - Submerged Aquatic Vegetation Planting
  - Flow Diversion Feasibility Study
  - Assessment of New Technologies for Chloride Treatment

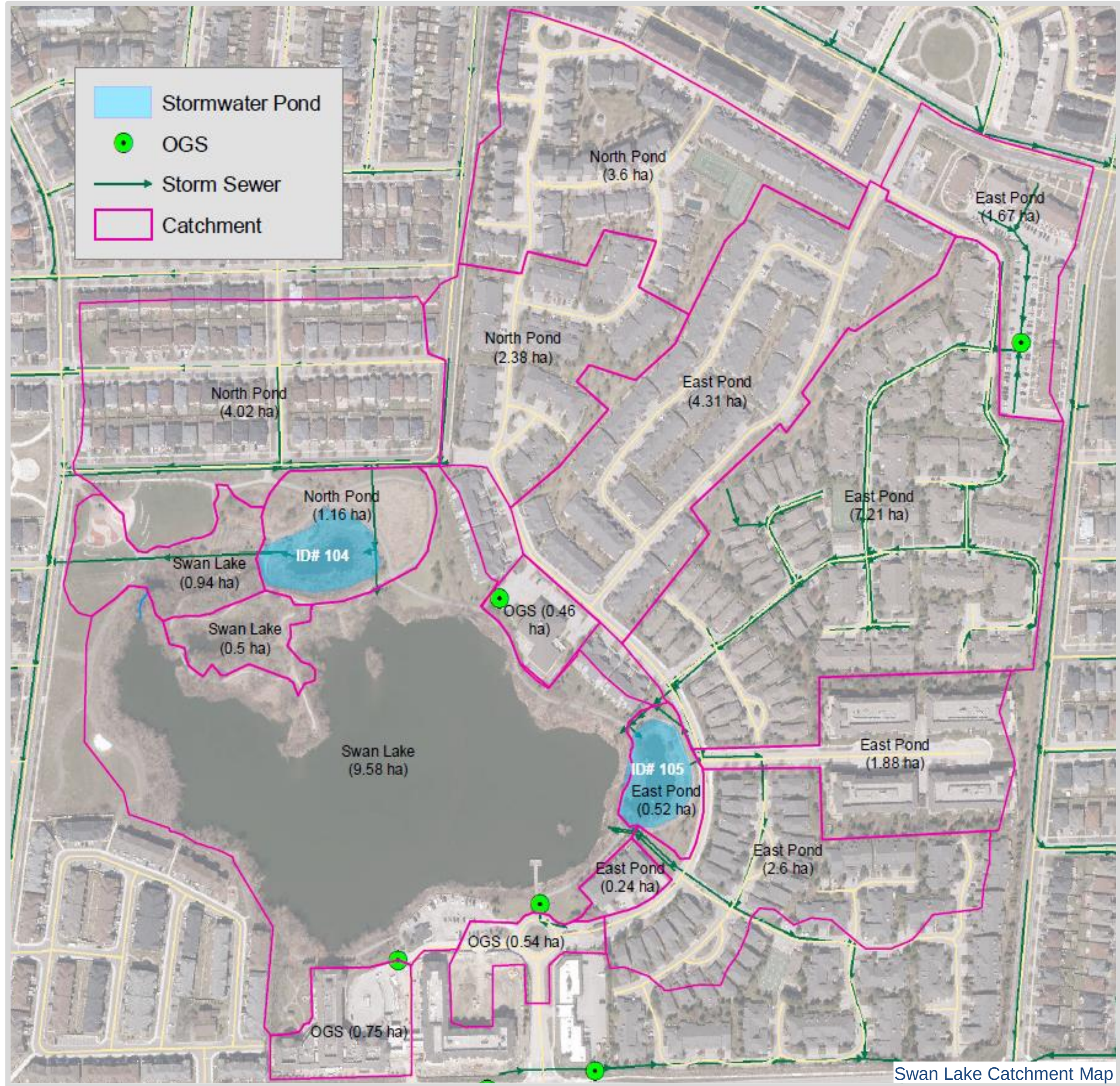
Background and Completed Work

Location and History

- Area: 5 ha, max depth: 3.5m
- Gravel pit in the 1960s and 1970s; construction waste dump in the early 1980s
- Lake formed when pumping for the gravel pit ceased operations
- Environmental Management Study for the Swan Lake Community in 1993 and several studies until 2008
- Water quality issues from 2010 and possibly earlier

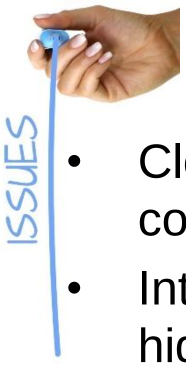
Catchment

- Started as farmlands
- Changed to residential community, including a gated community and senior housing development
- About 45 ha:
  - Community & infrastructure (75 %)
  - Open water including the Lake (15%)
  - Tree canopy or parks (10 %)
- Two stormwater management ponds and three oil and grit separators



Swan Lake Catchment Map

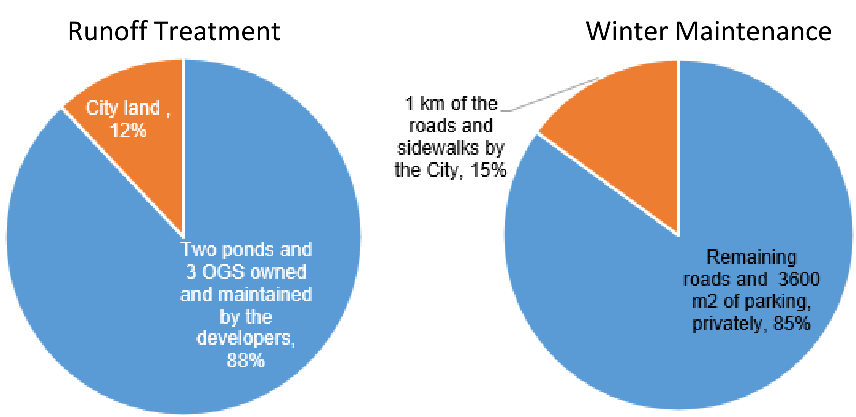
Issues and Opportunities



- Closed system resulting in contaminant build-up
- Internal source of phosphorus highly bio-available
- External source of phosphorus, mainly geese dropping, difficult to control
- High chloride concentration due to winter maintenance activities
- Most of the catchment is privately serviced

- Swan Lake and park are well used amenities with strong community support for sustainable solutions
- Existing stormwater management infrastructure to treat most of runoff

Maintenance responsibility



Management Timeline

2011
Lake at Hyper-eutrophic level
Monitoring started

→

2013
Phoslock application (improved quality)

→

2014
Geese control initiated (hazing/ egg oiling/shoreline planting)

→

2019
Water quality strategy study

→

2021
Long-Term Management Plan
Chemical Treatment
Fish Management

Measures	**Phase 1 (Years 1-5)**	**Phase 2 (Years 6-10)**	**Phase 3 (Years 11-25)**
Core Measures	☑	☑	☑
Complementary Measures		☑	
Alternative Measures			☑
5-yr review	☑	☑	☑

2022 Council Resolutions

MINUTES AND NOTES OF THE SEPTEMBER 6, 2022 MARKHAM SUB-COMMITTEE

1. That the deputation from Fred Peters and the Friends of Swan Lake Park Presentation, "Action Plan For Restoration of Swan Lake and Swan Lake Park" be received; and,
2. That the minutes of the May 11, 2022 Markham Sub-Committee Swan Lake Meeting be received; and,
3. That General Committee endorse the recommendation from the May 11, 2022 Markham Sub-Committee Meeting;
   a. That the Staff report and presentation on the "Swan Lake- 2021 Water Quality Status and Updates" be received; and,
   b. That the FOSLP presentation "Action Plan For Restoration of Swan Lake and Swan Lake Park" and York University presentation on the research it is proposing on the use charcoal filter system to remove nutrients and chloride be received and referred to Staff; and further,
   c. That Markham Sub-Committee request that Staff report back on the feasibility, and implications of designating Swan Lake a natural heritage asset, as part of the Official Plan update; and,
4. That Staff review and report back to Committee on the feasibility and costs of the following research initiatives:
   a. Chloride Removal;
   b. Oxygen Enhancement; and,
   c. Survey of Lower Level Aquatic Life; and,
5. That Council approve a technical analysis of Swan Lake to assess the feasibility of proposed changes to determine if the infrastructure within Swan Lake can support the proposed changes; and,
6. That this recommendation be forwarded to the 2023 Budget Committee for consideration; and further,
7. That Staff be authorized and directed to do all things necessary to give effect to this resolution.

2022 Measures

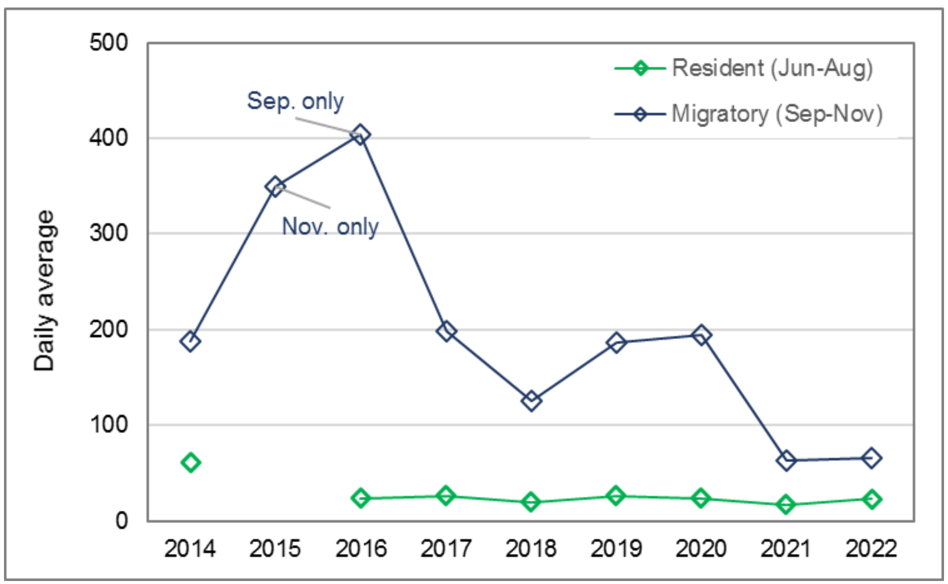
Activity	Phase 1 Core Measures (Years 1-5)
Water quality monitoring and annual reporting to Subcommittee	☑
Enhanced Geese management	☑
Removal of benthic-dwelling fish	☑
Maintenance of stormwater management facilities	☑
Community Engagement	☑
Shoreline planting / Improvements	☑
Chemical oxygenation pilot project	Reviewed
New technologies for chloride treatment *	Reviewed
Fish management plan and fish stocking (by MNDMNRF) *	Pending improved water quality
Planting of submerged plants *	Planning underway
Flow Diversion Feasibility Study **	Planning underway

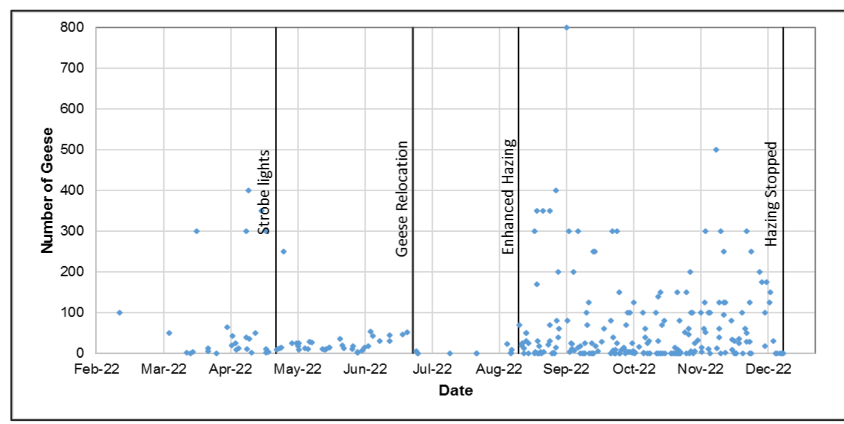
* Originally planned for Phase 2
** Originally planned for Phase 3

Geese Management

- Geese relocation and hazing and egg/nest management
- Increased hazing frequency reduced the number of geese present at different times of the day
- Any impact that strobe lights might have had is not readily evident from the data

Swan Lake Geese Count Survey QR Code





* Some assumptions have been made in calculating the daily average for each year to fill in data gaps.

Fish Management

- Removal of bottom-dwelling fish (to avoid disturbance of sediment)
- Fish inventory (Common Carp, Brown Bullhead, and Fathead Minnow)
- Fish management plan and fish stocking pending improved water quality and planting of submerged aquatic vegetation

Storm System Maintenance

- In November 2021 the East pond inlet was cleared
- Assumption process underway
- Clearing of the blocked outlet from Swan Club OGS has been requested


Clearing of East Pond inlet- Nov 2021

Shoreline Improvement (Parks Department)

- Shoreline improvement: Phragmites removal
- Design and consultation

Phragmites Removal- Oct 2022

Swan Lake Designation (Planning Department)

- Council direction: Review feasibility and implications of designating Swan Lake a natural heritage asset as part of the Official Plan update
- Supporting studies underway:
  - Natural Heritage Inventory and Assessment Study completed in 2021
  - Future phases (2022/2023) will consider the Greenway System across Markham for potential ecological enhancements, costs and priority setting

Community Engagement

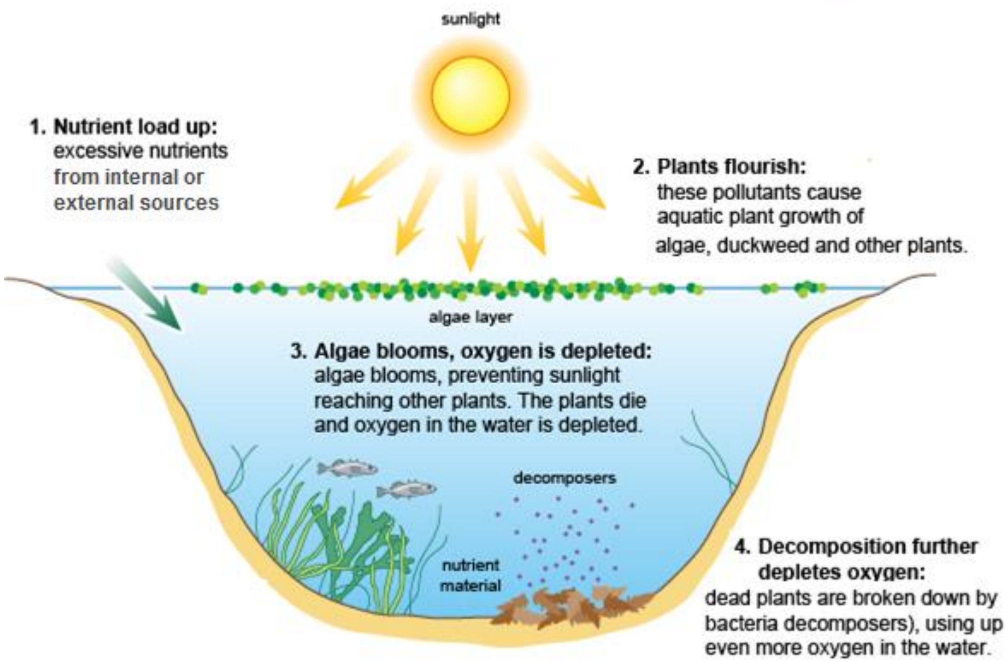
- Ongoing conversation with residents
- Swan Lake Park walkabout
- Markham Lions Club (Adopt a Park Program)
- Discussions with TRCA (geese and fish management, shoreline and submerged planting)
- Met researchers engaged by FOSLP (Fleming College and York University)
- Discussions with Trent University researchers
- Met with FOSLP on April 19, 2023

2022 Water Quality Results
Nutrients and Eutrophication

Lake Processes

- Excessive amount of phosphorus and nitrogen results in algae growth
- As the algae die and decompose, the process consumes dissolved oxygen (DO)
- Low DO concentrations could have lethal or sub-lethal (physiological and behavioral) effects on fish

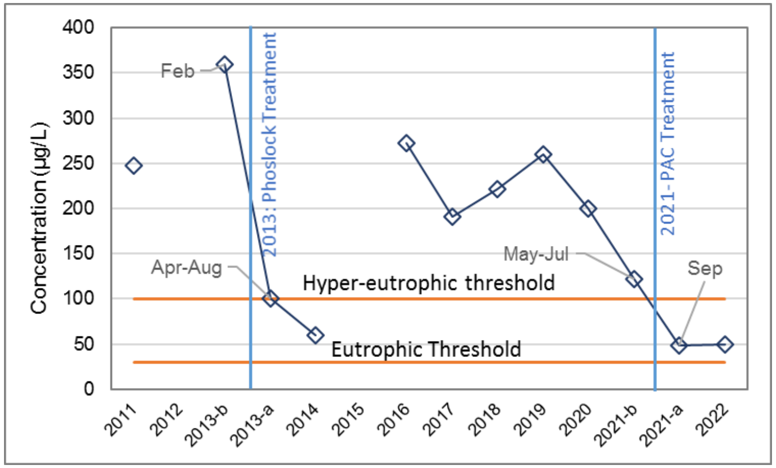
Eutrophic Classifications (based on DO, phosphorus, clarity):
Oligotrophic: pristine
Mesotrophic: clear with some submerged plants
Eutrophic: somewhat unclear, lots of planktonic plant growth
Hypereutrophic: unclear, with frequent algal blooms



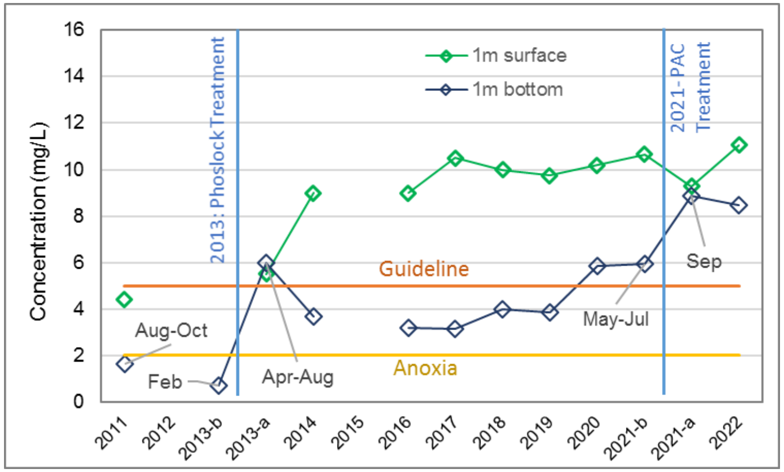
Water Quality- Nutrients and Oxygen

- Total Phosphorus:
  - Average under 50 µg/L during growing season
  - Decreased significantly after each treatment
- Total Nitrogen:
  - Average about 0.6 mg/L during growing season (limit 1.2)
  - Dominant forms not bioavailable
- Dissolved Oxygen:
  - Surface concentration > 9.5mg/L all year
  - Bottom concentration mostly >5mg/L
  - Increased compared to previous years

Total Phosphorus

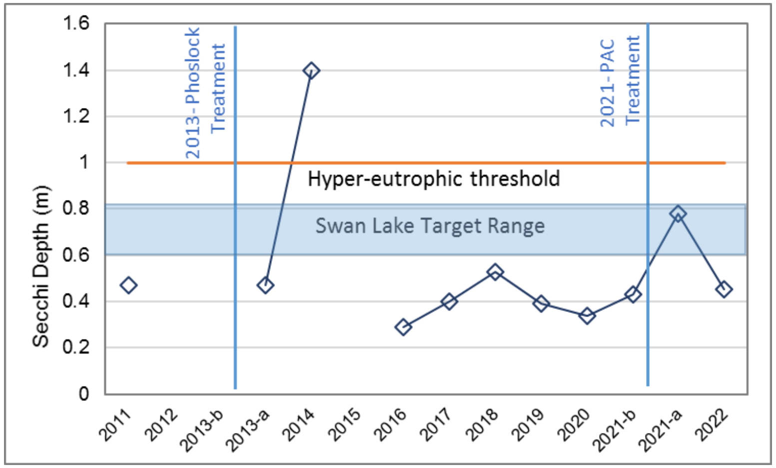


Dissolved Oxygen



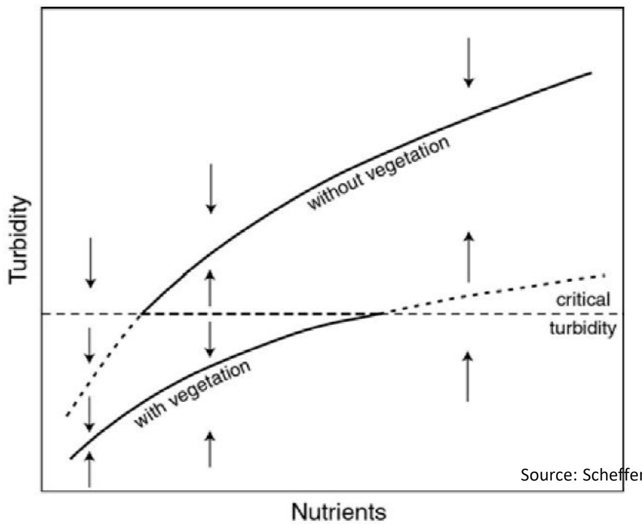
Water Quality- Algae and Clarity

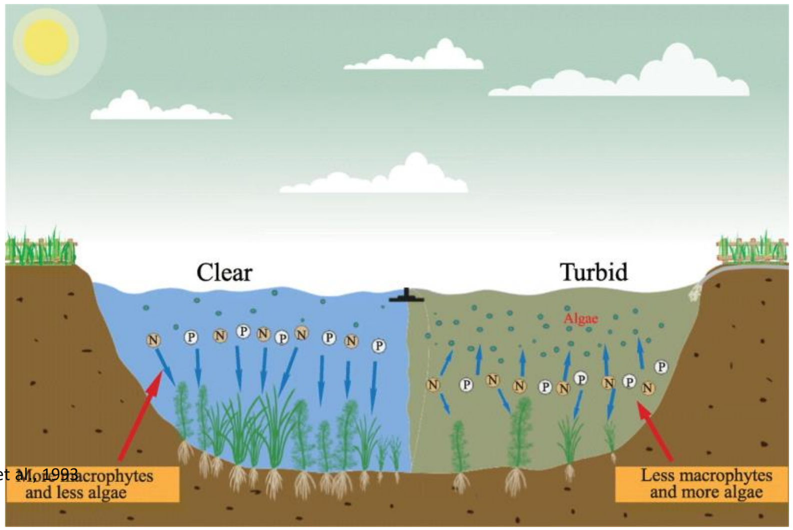
- Algal growth:
  - Peaked in June and September
  - Cell numbers increased from 2021
  - Microcystis measured below the recreational limit; however, it is probable that values were higher in other locations in the Lake
- Clarity:
  - Above >0.5 until June
  - Low clarity after first bloom



Alternative Equilibria in Shallow Lakes

- Generally, water turbidity is directly related to nutrient loading
- However, shallow lakes can have two 'alternative equilibria' for the same nutrient concentrations:
  - A turbid state, dominated by high algal blooms
  - A clear state, dominated by aquatic vegetation
- When a lake is in turbid state, reduction of nutrients alone may not bring it back to the clear state and habitat intervention is required.





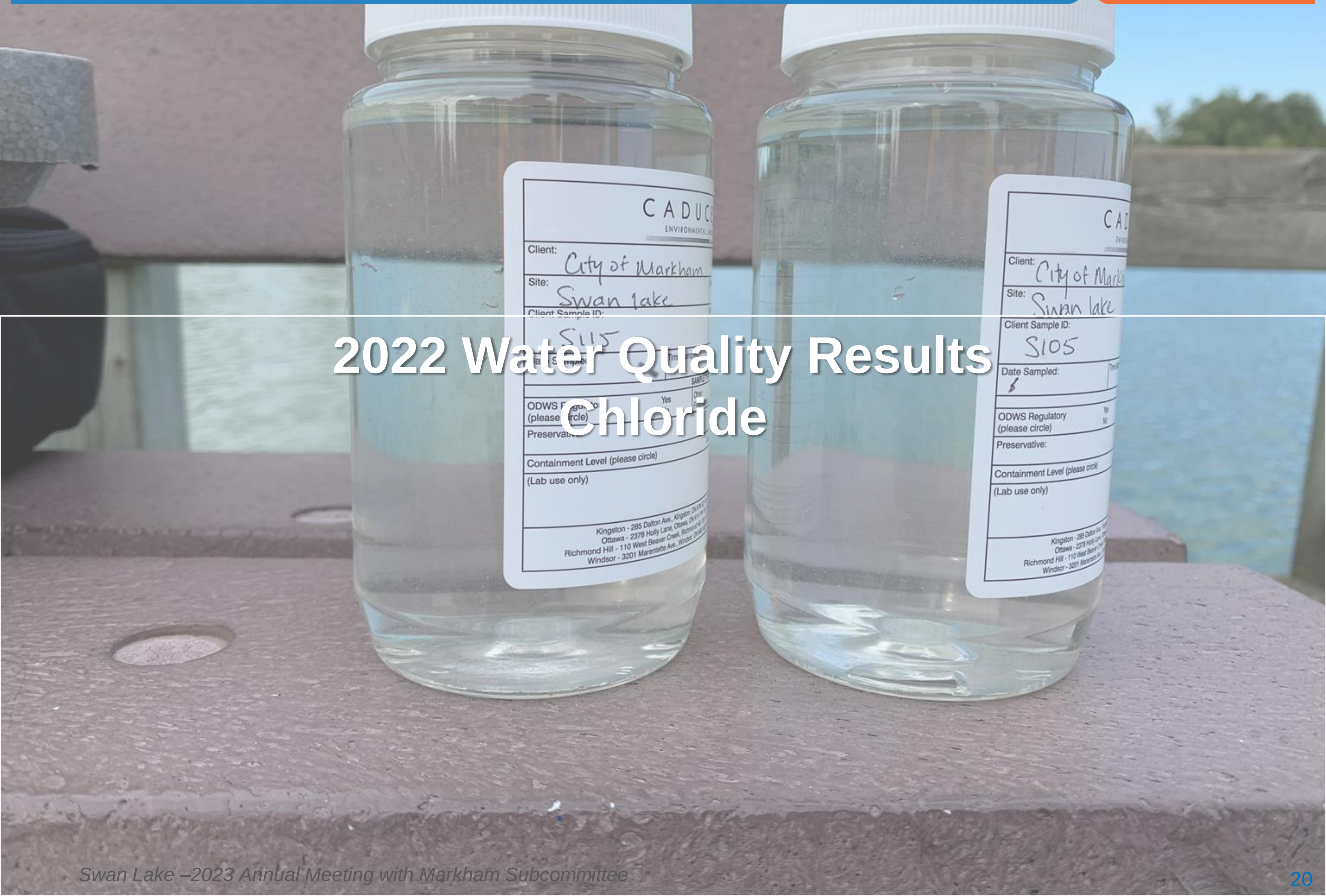
Source: Scheffer et al., 1993

Turbid State in Swan Lake

- Phosphorus and nitrogen concentrations reduced after treatment and geese management
- Low clarity and high algae growth continued
- Planting of submerged aquatic vegetation (SAV) will encourage the change of state
- It will also:
  - Provide habitat for zooplankton, which grazes algae
  - Fix sediment and reduce nutrient release

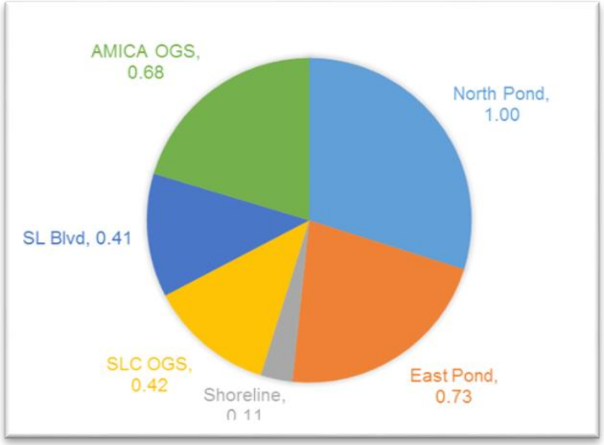

Aquatic vegetation

2022 Water Quality Results
Chloride

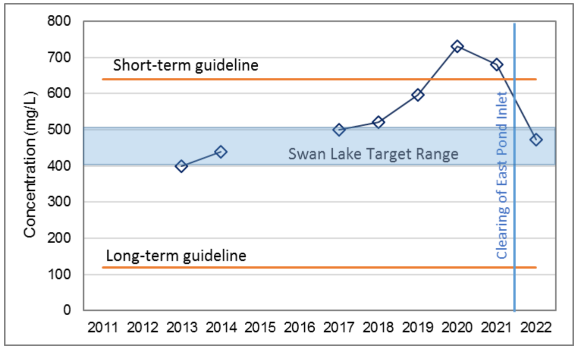


Winter Maintenance and Salt Usage

- Salt Usage:
  - Swan Lake Village Corporation : 14 km road (~ 30 tonnes/yr) & driveways/ walkways/parking (~70 tonnes/yr)
  - City roads: 1.1 km (~3 tonnes/yr)
  - Residents north of the Lake
  - AMICA Corporation to the south
- Chloride Estimates:
  - Runoff sample collections
  - About 3.5 tonnes of chloride contributes to the Lake
  - Contribution higher during ~2018-2021 when the inlet to East pond was blocked.
  - Annual variations depending on the amount of snow and salt application



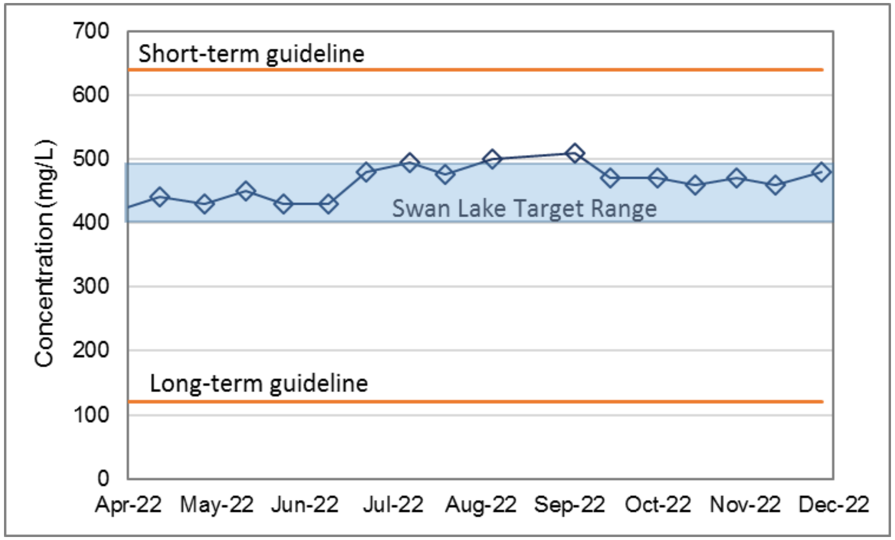
Initial estimate of chloride contribution to the Lake (tonne/yr) from each source based on modeled flows and salt usage data
Values will be refined through the Flow Diversion Study.



Chloride Concentrations

- Chloride concentrations were increasing in Swan Lake, but dropped considerable in 2022, likely due to clearing the blockage at the East Pond inlet.
- Chloride guidelines are for protecting the most sensitive species and may not be suitable targets for the Swan Lake system
- Swan Lake interim target is already being met

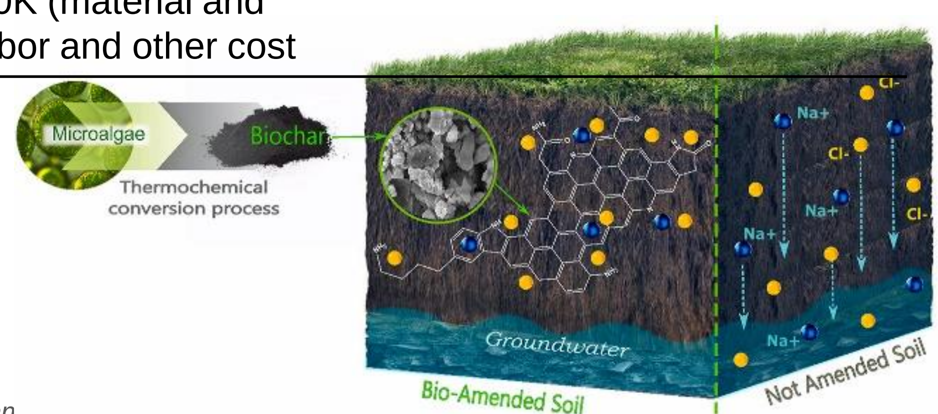

School of minnow in Swan Lake- April 2023



Review of FOSLP Proposals

Chloride Treatment

FOSLP Proposal	Evaluation	City's Plan
Chloride Removal using Biochar * Lab testing for $43.2K * proposed by York University	• Biochar Removal mostly at research stage with few experiments for chloride (mostly nutrients) • Concentration of chloride is already within City interim target range with no apparent effect on biota • MECP recommends source identification and reduction before treatment • Costs: $200-300K (material and equipment) + labor and other cost	• Source control measures on public and private properties will be pursued • Opportunities to reduce loadings will be sought through Flow Diversion Study • Chloride treatment research in 2024 as positive results could be a valuable tool

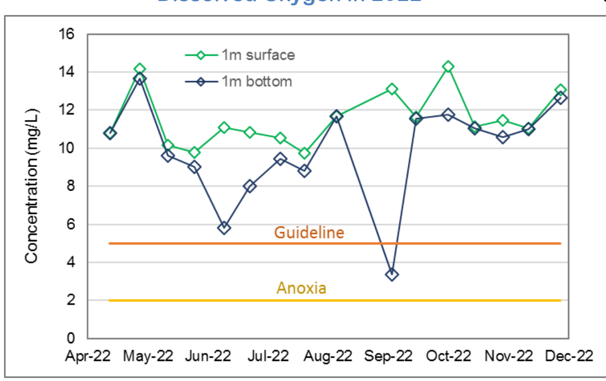


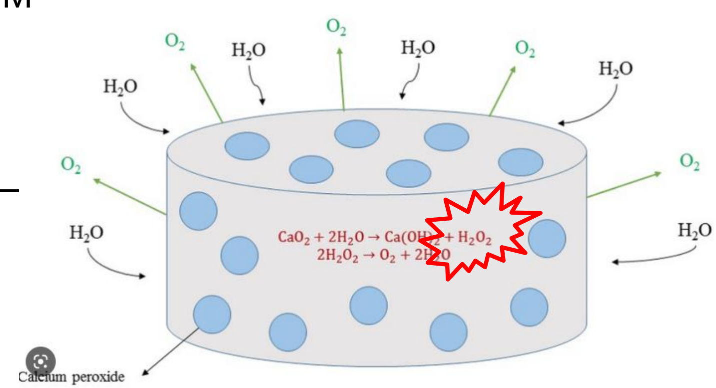
Pahlavan et al 2023

Chemical Oxygenation

FOSLP Proposal	Evaluation	City's Plan
Oxygen Enhancement using Calcium Peroxide * Lab testing for $37K * proposed by Fleming College's Centre for Advancement of Water and Wastewater Technologies	• Potential for aquatic toxicity and interference with chemical treatment • Method at research stage and needs further stages of research to ensure safety • DO is already above guidelines • Costs: $150k to $1,500M (material) + application cost	• Managing the root cause by reducing nutrient loads (internal and external) and improving habitat • Recent measures improved DO significantly; no need for immediate intervention • Will continue to measure DO

Dissolved Oxygen in 2022

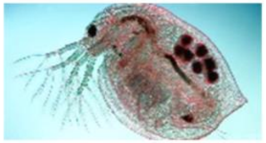




Survey of Lower Level Aquatic Life

FOSLP Proposal	Evaluation	City's Plan
Survey of Lower Level Aquatic Life (Phytoplankton, Zooplankton, Protozoa)	• Phytoplankton identification already done • No benefit in identification of others for the overall health of Swan Lake • Targets not available and results will not be actionable • Ongoing habitat improvement will increase diversity and abundance	• Monitoring parameters already targeted for improvement in Phase 1, including nutrients, oxygen, chloride and phytoplankton • Future opportunity through a research project by Trent U looking at bio-accumulation of rare earth elements (REE's) in biota


Zooplankton sampling net



Drawdown and Sediment Removal

- FOSLP's report Towards a Comprehensive Restoration Plan (Draft Apr. 14, 2023)
- Assumes sediment removal is necessary for water quality improvement
- Draw the Lake down to 207.0 MASL to remove water
- Assumes lake will be refilled with rainfall and groundwater in 1-3 seasons
- Remove exposed sediment
- Storage on site or disposal off-site

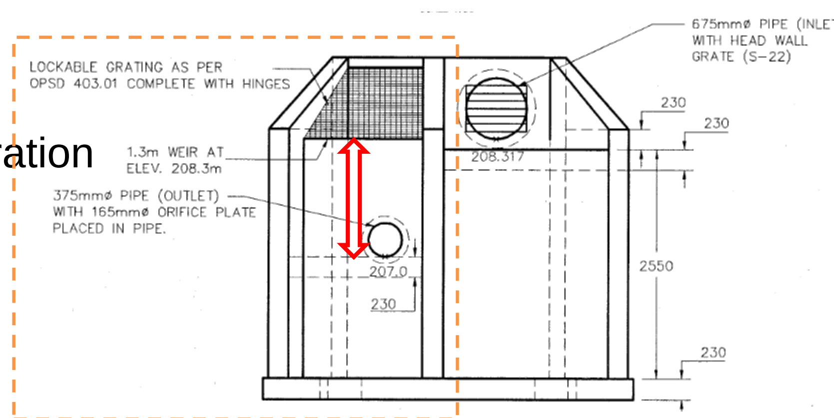

Swan Lake Outlet


Typical pond sediment

Lake Dewatering Implications

- Drawdown feasibility:
  - Excavate a trench 1.3m deep in the Lake
  - Pump water from lower areas
- Refilling calculation:
  - Evaporation not considered (> rainfall)
  - No basis for groundwater flow estimate
- Ecological impacts:
  - On the lake during dewatering
  - On receiving water- regulatory issues (PWQO exceedance, sediment impacts on fisheries if filtration is not applied)


Swan Lake Outlet



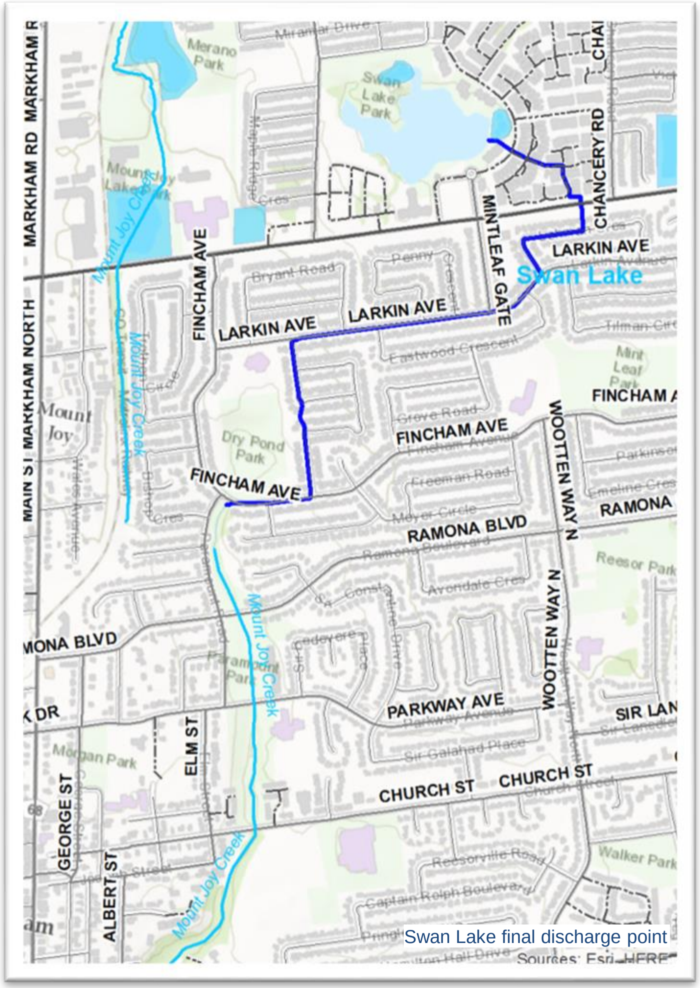

Snapping turtle in Swan Lake
Photo courtesy of Mark Henschel

Regulatory Context for Discharging Downstream

- Ontario water management: policies, guidelines, provincial water quality objectives (PWQO):
  - Policy 1: In areas which have water quality better than the PWQO, water quality shall be maintained at or above the Objectives.
  - Policy 2: Water quality which presently does not meet the PWQO shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the Objectives.

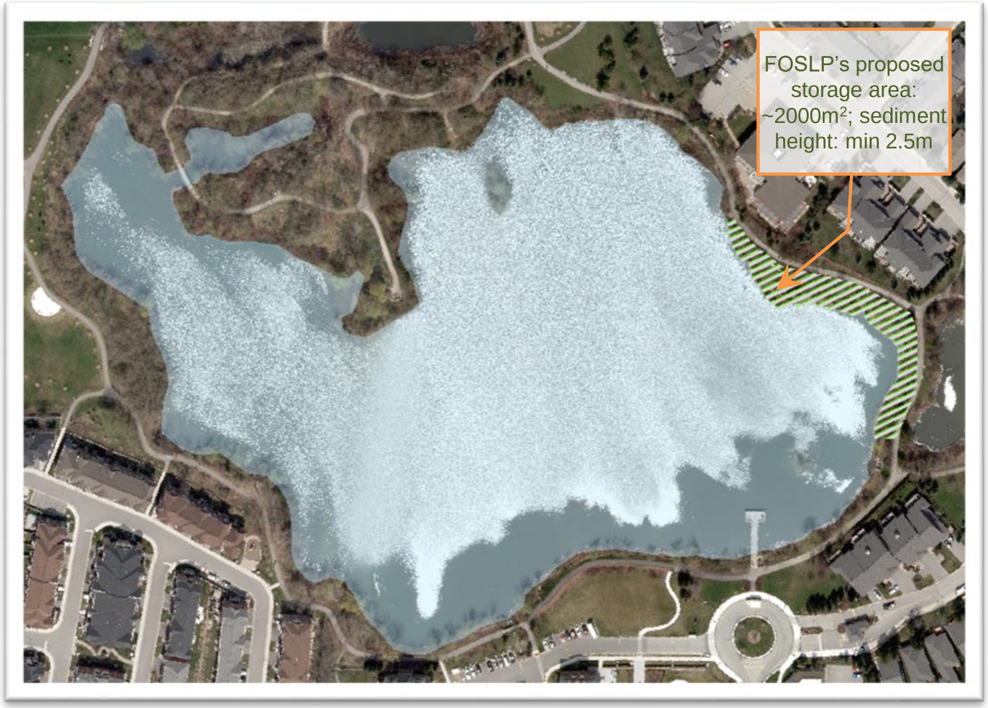
Parameter	PWQO/ CCME	Mt. Joy Creek*	Swan Lake
Total phosphorus	30 µg/L	70 µg/L (policy 2)	>100 µg/L (pre treatment) 50 µg/L (post treatment)
Dissolved chloride	120 mg/L	350 mg/L (policy 2)	~ 500 mg/L in 2022

* Rouge River in Box Grove; average of values for 2014-2018 (latest 5-year of available data)



Sediment Storage or Disposal Issues

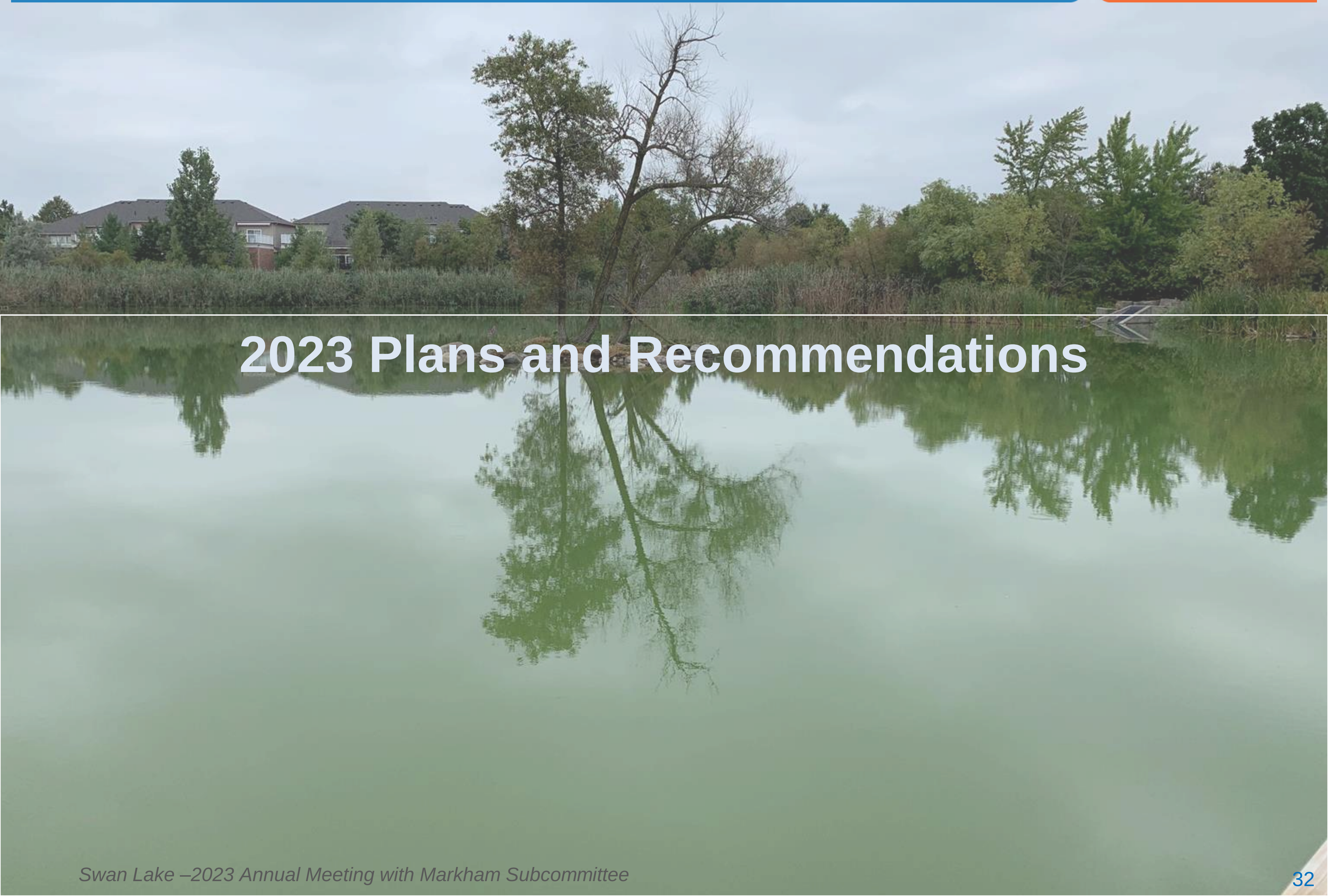
- Several scientific studies and experts have recommended against disturbing sediment in Swan Lake (Gartner Lee Limited, 2006; Freshwater Research 2019; AECOM 2022)
- Extensive long-duration disruption to the park (multiple years)
- Substantive damage to the park on staging and drying areas
- Former dump sites contamination
- Sediment needed in lake to grow aquatic plants
- Other Storage issues:
  - Space for on-site storage not available (5000-8000 m^3)
  - Contaminated leachate from stored sediment
  - Containment (concrete walls) unsightly and not-environmental friendly and costly
- Transport and disposal costly



Other FOSLP Proposals/Statements (April 2023)

FOSLP Proposal/ Statement	Evaluation
• Current programs do not improve nitrogen and Dissolved Oxygen	• Lake processes are interconnected and need to be managed as such • Geese management and chemical treatment using PAC has improved phosphorus, nitrogen and oxygen concentrations as evident in actual measurements in 2021 and 2022
• Further oxygen enhancement is required as the Lake has no surface-level inflow • Proposals include recirculation through the north channel and chemical oxygenation	• Oxygen levels have improved by lowering nutrient levels, and will be further improved through habitat modification (e.g. submerged aquatic vegetation (SAV) planting) • Recirculation with be very disruptive and could increase water temperature (as per FR report); Chemical oxygenation too costly; potential impact on aquatic community • As per the approved Plan, recirculation could be considered in Phase 3 if necessary
• New research on impact of oxygenation on P release • New research on impact of Cl on P/N release • Water quality workshop	• Research could be done independently by others as long as it is not interfering with the City's approved program • The current team (City and consultants) already includes all the skills listed; however, a workshop could be considered after Phase 1 completion (2026)

2023 Plans and Recommendations



2023 / 2024 Planned Activities

CORE MEASURES:

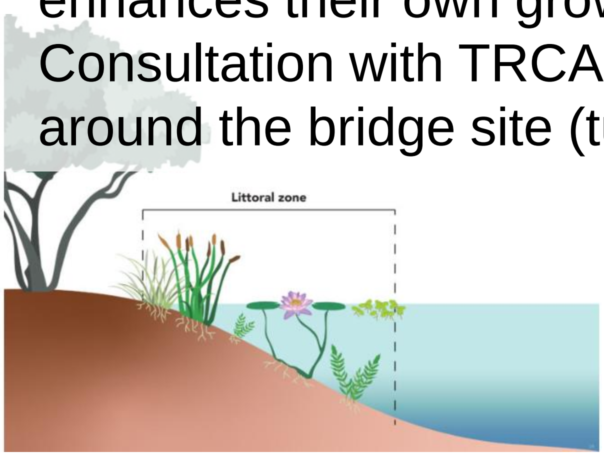
- Water quality monitoring and annual reporting to Subcommittee
- Geese management
- Maintenance of stormwater management facilities
- Community engagement
- Chemical treatment planning for 2024
- Shoreline improvements (Parks)

COMPLEMENTARY AND ALTERNATIVE MEASURES:

- Planting of Submerged Aquatic Vegetation
- Flow Diversion Feasibility Study
- Assessment of New Technologies for Chloride Treatment

Submerged Aquatic Vegetation Planting

- Planned for Phase 2 of the Long-Term Plan to help solidify the sediment and provide fish habitat.
- Moved to Phase 1 after a review of 2022 water quality results by our limnologist consultant
- Submerged aquatic vegetation (macrophytes) can compete with and help mitigate algae (phytoplankton) growth
- Macrophytes will increase water clarity, which in turn, enhances their own growing conditions.
- Consultation with TRCA underway for a pilot project around the bridge site (turtle inlet)



Swan Lake Turtle Inlet- April 2023

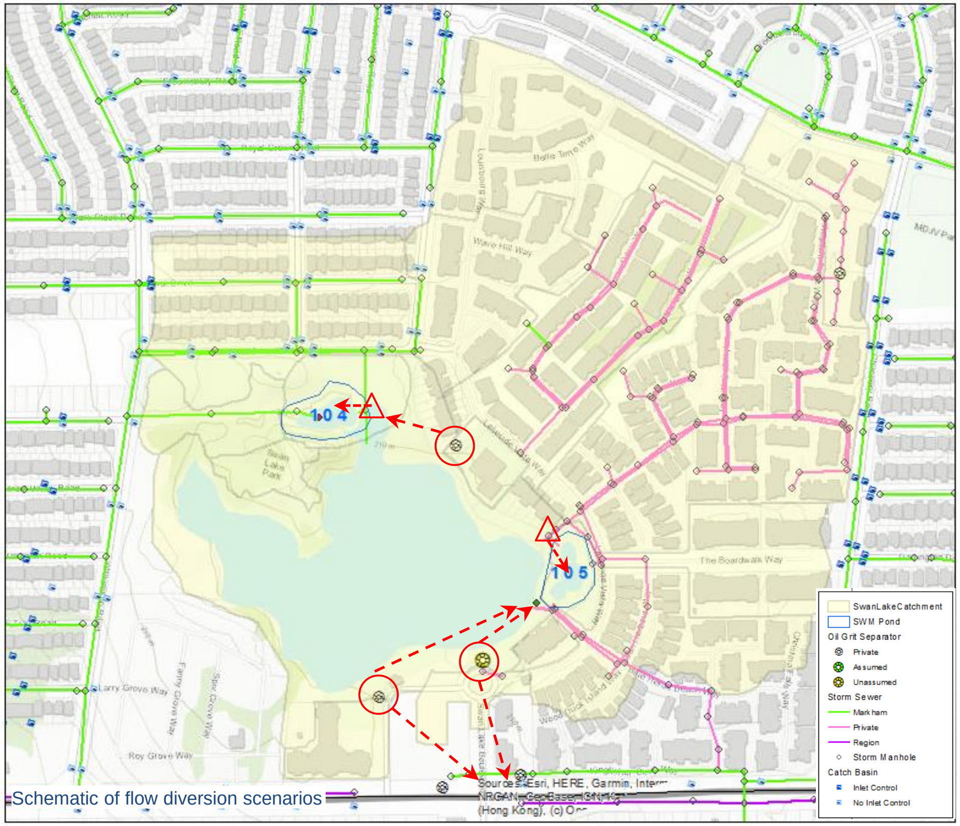
Flow Diversion Feasibility Study

- Alternative measure in Phase 3: evaluate/design structural modifications such as lake water recirculation and stormwater redirection
- FOSLP proposal to reduce Swan Lake's role in the 'local stormwater management regime' by rerouting the flows … in order to control chloride concentrations.
- Flow Diversion Feasibility Study: Technical analysis to assess the feasibility of proposed changes to determine if the infrastructure within Swan Lake can support the proposed changes.
- A consultant will be hired in 2023 for this study following data collection/digitization of private sewer infrastructure.
- If a technically feasible option is found for flow diversion, which is also effective in chloride reduction, a Municipal Class Environmental Assessment may be required to engage all stakeholders (including private landowners and York Region) and identify a preferred alternative.

Flow Diversion Feasibility Study - Scenarios

Source	Scenario
AMICA OGS and Swan Lake Blvd OGS	Redirect flows to 16th Ave sewer
	Redirect flows to Lake Outlet
	Redirect the first-flush (most pollutant-laden runoff) in a small diversion sewer
Swab Lake Club OGS	Redirect flow to North Pond Splitter
East Pond and North Pond	Adjust the flow splitter weir to reduce flow bypass to the Lake
	Expanding the storage capacity to reduce flow bypass to the Lake *
Foundation Drain Collectors	Redirecting flows toward Swan Lake to supply potentially cleaner, cool groundwater
Combination of the above scenarios	

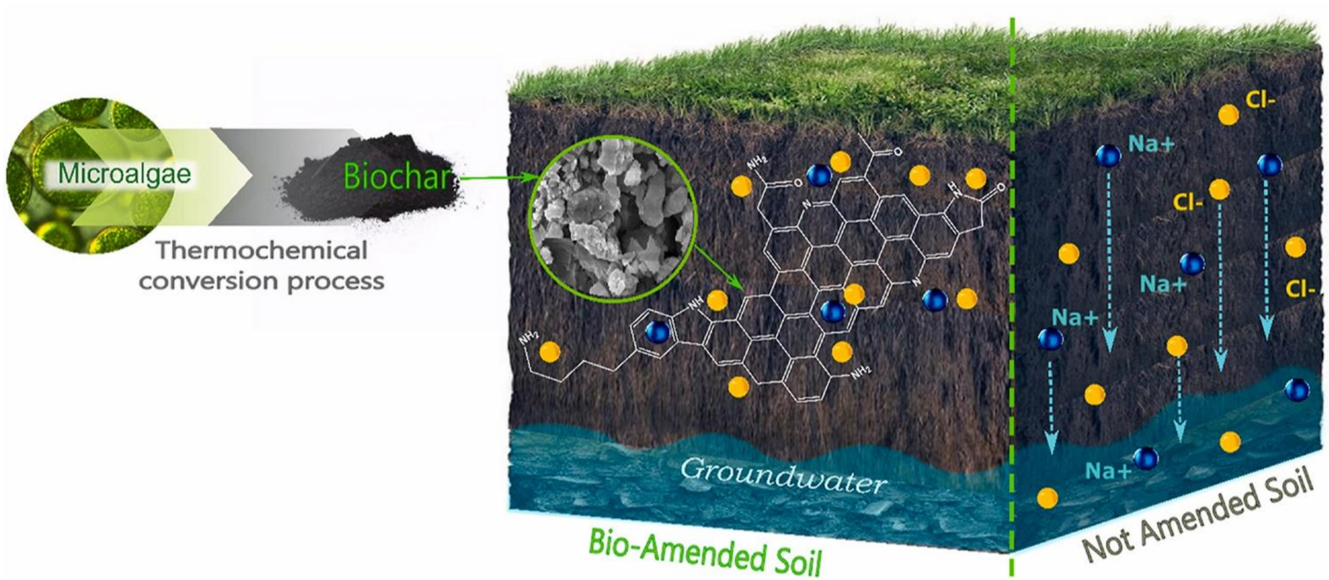
* To consider if the redirecting scenarios increases flood risk and if less costly than any sewer capacity upgrades



Schematic of flow diversion scenarios

Assessment of New Technologies for Chloride Treatment

- Initially planned for 2027 at a cost of 50K
- Advanced to 2024
- Discuss/refine scope of work with researchers
- Lab-scale units to test the biochar efficiency



Pahlavan et al 2023
https://www.sciencedirect.com/science/article/abs/pii/S0045653523004393?via%3Dihub

Evaluation and Plan Summary

Plan	Measure	Allocated Budget	Additional Costs	Assessment	Recommendation
Core measure	Water quality monitoring	30K/yr	-	Required for decision making	Implement annually
	Geese management	70K/yr	-	Proven efficiency	Implement annually
	Chemical treatment	150K/3yrs	-	Proven efficiency	Plan in 2023 Implement in 2024
Complementary measure	Planting Submerged Aquatic Vegetation	20K (pilot)	TBD	Potential for competing with algae and increasing water clarity	Implement in 2023
	Assessment of New Technologies for Chloride Treatment (for Biochar)	50K for initial lab test	200-300K (material/ equipment) + operation (TBD following lab test)	Test as no other feasible technology exists	Research in 2024
	Oxygen Enhancement using Calcium Peroxide	-	37K initial lab testing + $$ for additional testing; 200-1,600K/yr implementation	DO levels high in 2022; Potential impacts on Swan Lake and other treatments; costly	Not recommended
Alternative measure	Flow Diversion Feasibility Study	150K	TBD for implementation (initial estimate 5M)	Informs source reduction strategy for chloride	Implement in 2023/2024
-	Survey of Lower Level Aquatic Life	-	20-50K (nominal)	No tangible benefit	Not recommended
-	Drawdown and Sediment Removal	-	1.5-3.7M (FOSLP estimate for storage option)	Uncertainties and issues re Lake refilling timeline, ecological impacts on the Lake and downstream during dewatering, Sediment quality and, storage space and contamination leachate, disposal cost, park disturbance	Not recommended

Recommendations

1. THAT the report entitled "Swan Lake- 2022 Water Quality Status and Updates" be received;

2. AND THAT Staff continue to implement the Long-term Management Plan for Swan Lake approved by Council in December 2021, including advancement of submerged aquatic vegetation, research into chloride treatment, and flow diversion evaluation (previously in Phases 2 and 3 of the Plan);

3. 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 Plan through the Markham Sub-Committee with the participation of the Friends of Swan Lake Park;

4. AND THAT the next review of the Plan will be in 2026 (after the completion of Phase 1 and other measures as listed under item 2);

5. AND THAT Staff be authorized and directed to do all things necessary to give effect to this resolution.

Questions?

MARKHAM

Report to: Markham Subcommittee Meeting Date: May 11, 2023

SUBJECT: Swan Lake- 2022 Water Quality Status and Updates
PREPARED BY: Robert Muir, Environmental Services, Ext. 2357
Zahra Parhizgari, Environnemental Services, Ext. 2867

RECOMMENDATION:

1. THAT the report entitled "Swan Lake- 2022 Water Quality Status and Updates" be received;
2. AND THAT Staff continue to implement the Long-term Management Plan for Swan Lake approved by Council in December 2021, including advancement of submerged aquatic vegetation, research into chloride treatment, and flow diversion evaluation (previously in Phases 2 and 3 of the Plan);
3. 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 Plan through the Markham Sub-Committee with the participation of the Friends of Swan Lake Park;
4. AND THAT the next review of the Plan will be in 2026 (after the completion of Phase 1 and other measures as listed under item 2);
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:

- 2022 water quality results and implemented measures;
- Review of the feasibility and cost of FOSLP's research initiatives and other proposals; and
- Scope of work for 2023

BACKGROUND:

On November 16, 2021, Staff provided a report and presentation to the Markham Subcommittee titled Swan Lake Water Quality Management Plan, outlining the history of Swan Lake management activities up to that point and a Long-Term Management Plan for Swan Lake Water Quality (the Plan) for the next 25 years. The Plan was developed based on a scientific evaluation of issues and opportunities for lake management and an assessment of several lake management measures designed with input from stakeholders (see here for Meeting Minutes).

The Swan Lake Long-Term Management Plan follows an adaptive management approach, through which management activities would be adjusted to maximize benefits and minimize impacts. The Council endorsed this phased approach on December 14, 2021 (see here for General Committee Meeting Minutes and Council Meeting Minutes).

As per resolutions 7, 8, and 9 of the December 14, 2021 meeting, Staff presented the first annual Subcommittee report on May 11, 2022. This report included the 2021 water quality results and evaluation of the adapted Core and Complementary measures, a High-Level Water Flow Analysis, and the Friends of Swan Lake Park (FOSLP) "Holistic Approach to Realizing Community Goals (see here for Markham Subcommittee Report and Presentation).

The motions that the Subcommittee recommended for consideration at the September 6, 2022 General Committee meeting (see here for Meeting Minutes) included directing Staff to review and report back to the Committee on the feasibility and costs of the following research initiatives (resolution #4):

a. Chloride Removal;
b. Oxygen Enhancement; and,
c. Survey of Lower Level Aquatic Life

That Council also approved a technical analysis of Swan Lake to assess the feasibility of proposed changes to determine if the infrastructure within Swan Lake can support the proposed changes (resolution #5).

That Markham Sub-Committee also requested that [the Planning Department] Staff report back on the feasibility, and implications of designating Swan Lake a natural heritage asset, as part of the Official Plan update (resolution #3c).

The following Discussion presents the 2022 Water Quality Results, a review of three research initiatives to address resolution #4, and a description of the scope of work for the 2023 activities, including a flow diversion study to address resolution #5.

The City hired a senior aquatic scientist from AECOM to review the 2022 results and comment on the feasibility and impact of the proposed research initiatives. This report reflects the feedback received from AECOM.

DISCUSSION:

2022 Water Quality Results and Implemented Core Measures

The Phase 1 Core Measures completed in 2022 include:

- Annual monitoring
- Enhanced geese management
- Fish management

Staff collected water quality data through the Swan Lake monitoring program from January to December 2022. These data provide insight into long-term trends in water quality and help determine the need for and impact of chemical treatment of Swan Lake (see Attachment A for the 2022 Annual Report).

Contractors completed Geese management by chasing ("hazing") geese with border collies, oiling eggs and managing nests, and by relocation of geese in the spring. Hazing frequency was modified in 2021 to focus on the migration seasons. The increased hazing frequency (starting in mid-August) effectively reduced the number of geese present at different times of the day to about 50% of the geese numbers in 2020.

A fish inventory and removal campaign was completed to remove bottom-dwelling fish, which could interfere with the chemical treatment efficacy. Only three fish species were caught in the Lake through this intensive effort: Common Carp (non-native), Brown Bullhead, and Fathead Minnow. Of these, only Fathead Minnow was found in abundant numbers and this main fish species was left in Swan Lake.

The management activities in 2022 focused on the significant nutrient loadings identified in the Long-Term Plan (i.e., fish management to reduce internal loads from the lake bottom and geese management to reduce external loads). While these activities successfully reduced nutrient concentrations, the Lake was dominated by phytoplankton, and water clarity did not improve. This could be partly due to the absence of aquatic vegetation (submerged macrophytes), which has been replaced by phytoplankton (algae) due to low water clarity.

In 2022, chloride levels decreased considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake.

Feasibility and Cost/Benefit of Three Research Initiatives

a. Chloride Removal using Biochar

Chloride concentrations have been increasing in urban lakes due to de-icer application for winter maintenance of roads and walkways. In Swan Lake, chloride concentrations were between 400 and 500 mg/L from 2012 to 2018 but increased sharply between 2018 and 2021 when the inlet to the East Pond was blocked. The concentrations declined to under 500 mg/L after the said blockage was removed. Average chloride concentrations are now below the short-term guidelines for the protection of aquatic life (640 mg/L). However, they are within the interim targets defined for Swan Lake (400-500 mg/L) and can support most aquatic biota.

The City plans to further improve chloride levels by exploring measures to reduce chloride load into the Lake as outlined in the Long-Term Plan. To support these measures, Staff started collecting runoff samples and salt usage data in 2021 to quantify chloride loads and determine the relative contribution of each catchment area. This information will help identify the most efficient strategy for reducing chloride loading to the Lake. In addition, the Plan has provisions for research into chloride removal technologies in Phase 2, if required.

In May 2022, FOSLP shared a proposal from York University for "Research into Removal of Nutrients and Chlorides from Swan Lake", which proposed "lab-scale units to test the biochar efficiency on the removal of selected nutrients" (and chloride) at an estimated cost of $43,200.

FOSLP requested support from the City for this research initiative in Phase 1 of the Plan, and in September 2022, the Council directed Staff to review and report back on the feasibility and cost of chloride removal using this method.

Staff and the City's consultant (AECOM) reviewed this proposal (see Attachment B) and did not find any application of biochar for chloride removal, except for one recent computational study (no experiments involved) demonstrating "the potential of amending soils with algal biochar as a dual-targeting strategy to sequestrate carbon and prevent de-icing salt contaminants from leaching into water bodies"[1]. However, since there is currently no feasible and cost-effective technology for removing chloride from freshwater bodies, using biochar, if successful, will be a valuable lake management tool.

Capital costs for full-scale implementation will vary depending on the application methodology developed. Active treatment will require treatment equipment (pumps, pipes, and installation at a cost of about $200-300k as per the reference[2] used by York U), a building to house the equipment (about $300k for 100 m^2 at $3000/$m^2$)[3], and specialist Staff to operate the system (about $130k)[4]. If passive treatment is deemed feasible (e.g., leaving pales of biochar in water), implementation costs will be much lower.

The application may pose a significant threat as pollutant release (e.g., of heavy metals) or desorption may occur if biochar not used properly[5].

Based on this assessment, Staff recommends that the lab-scale tests proposed by York University be completed, and if the results are promising, pilot or field-scale experiments follow suit in the future. The Swan Lake life-cycle budget has accounted for $50,000 for the assessment of new technologies for chloride treatment in Phase 2 of the Plan (in 2027), and Staff recommend this budget be advanced to Phase 1 (2024).

Full-scale implementation will be assessed based on the results of this experiment, including performance and implementation costs, the Lake's water quality, and aquatic habitat health at the time.

b. Oxygen Enhancement using Calcium Peroxide

On March 24, 2021, FOSLP provided a 'Literature Review of Potential Engineering Solutions for the Restoration of Swan Lake by Fleming College's Centre for Advancement of Water and Wastewater Technologies (CAWT).

Staff and the City's consultant at the time (Freshwater Research) reviewed this document as part of the scoping exercise to determine considerations to develop an overall water quality program. The review concluded that, of the various approaches discussed, chemical oxygenation using calcium peroxide (CaO_2) "could be an interesting study and lead to potential applicability". It also noted that this "is a novel potential treatment option for anoxic lake sediments. It has only been investigated in model systems and has not been proven in whole lake applications…. Therefore, this method is at a research state and not recommended as a ready-for-use approach for Swan Lake." and "Material costs seem to be high and should be considered."

In May 2022, CWAT submitted a proposal through FOSLP on the 'Development of a Scope of Work for Research into Water Quality on Swan Lake" for the use of "oxygen release

[1] https://www.sciencedirect.com/science/article/abs/pii/S0045653523004393?via%3Dihub
[2] https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/hydro/klamath-river/khsa-implementation/technical-documents/2021-11-15_Biochar-filter-final-rpt.pdf
[3] https://www.statista.com/statistics/972912/-building-costs-ontario-canada-by-type/
[4] https://www.jobbank.gc.ca/marketreport/wages-occupation/20827/ON (assuming payroll burden 2x salary)
[5] https://www.mdpi.com/2073-4441/12/12/3561

compounds". This research, at $37,000, would include laboratory-scale testing of sediment samples from Swan Lake.

In September 2022, the Council directed Staff to review and report on the feasibility and cost of oxygen enhancement using the proposed method.

Staff and the City's consultant (AECOM) reviewed this proposal (see Attachment B) and found that apart from one study on a pond, all the cited research was based on laboratory-scale investigations and on water and sediment from waterbodies receiving domestic sewage, which are very different from Swan Lake.

Due to these differences, in addition to the research quoted above, additional investigations will be required to account for the complex physical, chemical, and biological processes in Swan Lake that could affect or be altered by the treatment, including:

- Impact on pH increase and dissolution of metals, which can have unintended consequences for aquatic toxicity
- Impact on prior and future chemical treatments involving Phoslock or PAC, as the high pH generated by CaO_2 may cause the release of previously immobilized phosphorus in the sediment
- Impact of peroxide at the sediment surface on the microbial community. Peroxide could also degrade organic matter and release phosphate.

Staff met with CWAT on November 16, 2022, to discuss the feasibility and cost of in-lake implementation of this approach (assuming the laboratory-scale testing would be successful). Subsequently, we obtained a quote for the supply of calcium peroxide for a one-time application at a dosage of 100 or 1000 g/ m^2 (the range used in available literature). At $30.04/kg, the material cost for a surface area of about 5 ha (50,000 m^2) would amount to $150k to $1,500M. Additional fees will be involved, including labor and equipment costs for application (spreading from a boat rowing slowly over the whole surface of the Lake), at an estimated cost of $50-100k (based on the 2021 PAC application).

Staff does not support the proposal to use calcium peroxide for oxygen enhancement due to the potential impacts of this proposal on the Swan Lake environment. Material costs will also be prohibitive. In light of recent improvements made by the approved management measures (i.e., reducing internal and external sources of nutrients), resulting in high oxygen levels in 2022, further chemical alteration of the system is not recommended.

c. Survey of Lower Level Aquatic Life

The third proposal brought forward by FOSLP in 2022 was a survey of lower-level aquatic life to "take a measure as a benchmark for future success".

The City is currently monitoring parameters targeted for improvement in Phase 1, including total phosphorus, Secchi transparency, chloride and the frequency of algae blooms. The City is also collecting phytoplankton samples for cell counts and identification, which are used for understanding the algae community.

Interim targets have been developed for these noted monitored parameters, which are correlated with improvements in aquatic health. Information already being collected can be used to assess and improve the management plan's effectiveness and achieve habitat improvements.

Monitoring of other lower level aquatic life, such as zooplankton, will not provide any benefit to the overall health of Swan Lake, nor do monitoring results of such monitoring have a defined target to evaluate against. Therefore, Staff does not recommend expanding the monitoring program to include zooplankton or other lower level aquatic life.

Review of FOSLP 2023 Proposal

On April 14, 2023, FOSLP provided a draft report entitled 'Towards a Comprehensive Restoration Plan for Swan Lake' indicating that the 2021 Long-Term Management Plan 'needs to be updated to incorporate solutions to the chloride issues and to address the need for oxygenation'. It also proposes a water quality workshop to choose between two possible outcomes of 'Water Treatment Only' and 'Treat Water and Sediment'. The report concludes that the Lake water should be drawn down and discharged into the downstream Rouge River to remove chloride from the Lake. Based on the FOSLP's estimate, the Lake will be refilled with rainwater and groundwater in 1-3 seasons. When the lake bed is exposed, about 5,000-8,000 m^3 of sediment would to be removed and stored on the lake shoreline. Leaching of contaminants from sediment pore water would be prevented using geotextile material or a concrete wall.

In response to the recurring challenge by FOSLP that the approved Long-Term Plan only focuses on phosphorus and has no impact on other nutrients (i.e., nitrogen) and does not improve dissolved oxygen, all stakeholders should be reminded that:

- Source control efforts, including external load reduction by geese management and internal load management through chemical treatment, reduce both nitrogen and phosphorus, as evident by the 2022 monitoring results.
- Current management measures successfully improved oxygen levels. Low oxygen level is a symptom best managed by tackling the root cause (high nutrient levels) through source control.

The FOSLP report asks for dramatic measures such as Lake drawdown for chloride removal. Staff's assessment is that this proposition would serve an unnecessary objective while involving several significant issues and would be very costly and disruptive, i.e.,:

- The Long-Term Plan has defined interim targets of 400-500 mg/L of chloride that are consistent with historical values in the Lake (2012-2103) and also considering the location of this waterbody in the watershed (close to values measured in Rouge River)[6]. These targets can support various aquatic life such as water flea and minnows (abundantly observed in the Lake). The long-term guideline of 120 mg/L are for the protection of the most sensitive species and are not applicable to Swan Lake (FOSLP report also uses this guideline as a benchmark for runoff, which is not relevant). Therefore, there is no rationale for the proposed costly, disruptive interventions to reduce current chloride concentrations.
- Ecological impacts on the Lake and the downstream receiving water have not been considered in the FOSLP proposal. Dewatering will significantly disrupt the Lake ecosystem, and discharging the Lake water into Rouge River, which is already deteriorated, will have regulatory implications/potential impacts.
- Lake refilling with precipitation and groundwater over 1-3 seasons is ambitious. The FOSLP report does not account for the impact of evaporation (higher than precipitation), and the groundwater recharge rates cited are not valid. A groundwater model is not

[6] https://sustainabletechnologies.ca/app/uploads/2021/10/2016-2020-SWQ-Report-v11_FINAL_AODA-FA.pdf

available for this area, and it is not possible to quantify the aquifer recharge or discharge rates. Therefore, due to limited data considered in the proposed concept, the estimated timelines for refilling the lake are uncertain/unreliable.

- Several scientific studies and experts have recommended against disturbing sediment in Swan Lake due to the unknown and potentially contaminated portions of the lakebed. The FOSLP plan therefore risks disturbing and releasing of contaminants, contrary to past recommendations.
- Sediment is needed to support plant growth in the Lake, a measure which is being advanced by the City. Therefore, the proposed concept will interfere with other management measures.
- The FOSLP proposal to store sediment on the Lake shore does not consider the available space for storage nor does it have a viable solution for leachate control. Containment within proposed concrete walls is expected to be unsightly, not environmentally friendly, and costly.
- Dewatering and sediment removal will involve multiple years of park closure and significant disturbance to the park area and amenities.

To manage chloride in the lake, the City will continue seeking source control options, including opportunities that may arise through the Flow Diversion study and research into a biochar application for reducing chloride levels in the Lake. Therefore, pursuing the FOSLP's lake drawdown and sediment storage proposition is not recommended.

Staff agrees with a water quality workshop or another form of consultation with the stakeholders after the Flow Diversion Study and the second chemical treatment is completed and once sufficient data are available to inform discussions. This workshop could be held in 2026 to discuss the path forward and update the Long-Term Plan as necessary. A workshop in early 2024 as proposed by FOSLP is therefore considered to be premature and is not recommended.

2023 Scope of Work

a. Phase 1 Core Measures

In 2023, the planned Phase 1 Core measures will continue, including water quality monitoring, geese management, and fish management. The scope of geese management has been expanded to further reduce the number of resident and migratory geese. In addition, planning for the next chemical treatment (in 2024, i.e., three years after the first one) will occur, including pre-consultation with the Ministry of Environment, Conservation, and Parks (MECP).

b. Introducing Submerged Plants

Phase 2 of the Long-Term Plan included provisions for introducing native submerged plants in Swan Lake to help solidify the sediment and provide fish habitat.

After a review of 2022 water quality results by the City's limnologist consultant, it was determined that the introduction of submerged aquatic plants (macrophytes) should be advanced to Phase 1 so that beneficial plant communities can compete with and help mitigate algae (phytoplankton) growth. Macrophytes will increase water clarity, which in turn, enhances their own growing conditions. Aquatic plantings will complement existing management activities.

Staff has started working on this initiative and is aiming to undertake a pilot in 2023.

c. Flow Diversion Scope of Study

In June 2021, FOSLP submitted a report to the City entitled ‘Pathway to Sustainable Water Quality: Ending Swan Lake’s Stormwater Management Role’. The report asked that in order to control chloride concentrations, Swan Lake’s role in the ‘local stormwater management regime’ should be reduced by rerouting the flows from the Oil and Grease Separators (OGSs) and stormwater flows bypassing the ponds, and ‘restoring the Lake water level to its natural depth’.

These proposals were presented to the Markham Subcommittee in November 2021 under a presentation entitled ‘A Holistic Approach to Realizing Community Goals’. Staff responded in a memo to FOSLP in March 2022 as follows (see the General Committee Meeting Agenda of September 6, 2022):

- The current stormwater management system provides flood protection in the Swan Lake catchment area, and any change may increase flood risk upstream or downstream.
- Source control has been determined as the primary means of chloride control in Phase 1.
- Structural change to the stormwater management system (e.g., through diversions) and lake operations may be considered if other Core and Complementary measures do not achieve the set targets.
- When the Markham Village Project 2 Area design advances, the role of the Lake and any change in flow patterns can be modelled and confirmed.

In September 2022, Council directed Staff to undertake “a technical analysis of Swan Lake to assess the feasibility of proposed changes to determine if the infrastructure within Swan Lake can support the proposed changes”. This study, planned for 2023/2024, will include a technical analysis of the potential impacts of implementing various scenarios on flooding upstream or downstream of the Lake. In addition, the technical feasibility and cost of implementing each scenario, including mitigation options for any flooding impacts, will be determined. Scenarios may include:

- Redirecting flows:
  - from AMICA OGS and Swan Lake Blvd OGS to 16th Ave. sewer
  - from AMICA OGS and Swan Lake Blvd OGS to the Lake outlet
  - “first flush” flows from AMICA OGS and Swan Lake Blvd OGS to 16th Ave. sewer (i.e., redirect the most pollutant-laden runoff in a small diversion sewer)
  - from Swan Club OGS to the North Pond
- Adjusting the flow splitter weir for the East Pond and North Pond to reduce flow bypass to the Lake
- Expanding the storage capacity in East Pond and North Pond to reduce flow bypass to the Lake (to consider if the redirecting scenarios increases flood risk and if less costly than any sewer capacity upgrades)
- Redirecting flows from some Foundation Drain Collectors toward Swan Lake (i.e., supply potentially cleaner, cool groundwater)
- Various combinations of the above scenarios

The City will use the results of this analysis to build a chloride budget model and determine potential impact of each scenario on chloride concentration in the Lake.

This analysis will be of a technical nature and depending on the outcome and other considerations (e.g., system ownership), a Municipal Class Environmental Assessment may be required to engage all stakeholders and identify a preferred alternative.

Planning for both the 2024 chemical treatment and the research into chloride treatment technologies will also be completed in 2023.

Summary of Evaluation and 2023 Plan

Plan	Measure	Allocated Budget	Additional Costs	Assessment	Recommendation
Core measure	Water quality monitoring	30K/yr	-	Required for decision making	Implement annually
	Geese management	70K/yr	-	Proven efficiency	Implement annually
	Chemical treatment	150K/ 3yrs	-	Proven efficiency	Plan in 2023 Implement in 2024
Complementary measure	Planting Submerged Aquatic Vegetation	20K	-	Potential for competing with algae and increasing water clarity	Implement in 2023
	Chloride Removal technologies (assessment done for Biochar)	50K	200-300K (material/ equipment) + operation, or lower *	Test as no other feasible technology exist	Research in 2024
	Oxygen Enhancement using Calcium Peroxide	-	37K initial lab testing + $$ for additional testing; 200-1,600K/yr implementation	DO levels high in 2022; Potential impacts on Swan Lake and other treatments; costly	Not recommended
Alternative measure	Flow Diversion Study	150K	TBD for implementation (initial estimate 5M)	Informs source reduction strategy for chloride	Implement in 2023/2024
-	Survey of Lower Level Aquatic Life	-	20-50K (nominal)	No tangible benefit	Not recommended
-	Drawdown and Sediment Removal	-	1.5-3.7M (FOSLP estimate for storage option)	Uncertainties and issues re Lake refilling timeline, ecological impacts on the Lake and downstream during dewatering, Sediment quality and, storage space and contamination leachate, disposal cost, park disturbance	Not recommended

* Depending on the outcome of the research planned for 2024.

FINANCIAL CONSIDERATIONS:

No financial impact.

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:

Not applicable.

RECOMMENDED BY:

Eddy Wu, Director, Environmental Services	Mary Creighton, Acting Commissioner, Community Services

ATTACHMENTS:

Attachment A - 2022 Annual Water Quality Report

Attachment B - Review of Research Initiatives

Attachment A- 2022 Annual Water Quality Report

Swan Lake Water Quality Monitoring 2022 Annual Report

March 2023

Project Number: 22198

MARKHAM

Environmental Services

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Executive Summary

Background

Swan Lake is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road. Swan Lake has an approximate area of 5.5 ha and a maximum water depth of 4.5 m (from the edge of the Lake at 210 MASL). A gravel pit in the 1960s and 1970s, Swan Lake is currently a community feature with multiple trails and urban development surrounding it.

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

In 2019, the City of Markham conducted a study to define a Water Quality Management Strategy for Swan Lake. The Strategy, finalized in July 2020, recommended a chemical treatment in 2021.

In August 2021, 13 tonnes of Poly Aluminum Chloride (PAC) were applied to the Lake in a controlled manner over several days.

The Swan Lake Long-Term Management Plan was received by the Markham Sub Committee in November 2021 and approved by the Council in December 2021. It describes a phased adaptive approach, including provisions for chemical treatment every three years. Activities planned for 2022 included enhanced geese management, fish removal, water quality monitoring, and investigation of additional measures to improve water quality in the Lake.

Water quality monitoring of Swan Lake has been conducted almost annually since the first treatment in 2013 to track water quality and the continued effectiveness of the treatment. The collected data presented in this report is part of the ongoing monitoring program that will allow for continuous assessment of the water quality in Swan Lake and will be used to implement and adapt the Long-Term Management Plan for Swan Lake.

In 2022, sampling for chloride measurement was also conducted at several locations to determine the relative contribution of each source to the Lake.

This report discusses observations at the monitored stations in the Lake and several runoff stations throughout 2022.

Results- Lake Water Quality

Water quality is regularly monitored at two shoreline sites: the Dock and the Bridge, on a bi-weekly basis (from April to November). Samples and measurements are taken at 0.5 m or 1m increments for the depth of the lake. A level logger is used to record the water level in the Lake.

The following paragraphs provide the monitoring results for the 2022 monitoring period, as well as annual summaries of available data from 2011 to 2022. The figures include plots of measured dissolved oxygen (DO), water clarity, phosphorus concentration, chloride concentration, and geese count.

Targets

Phosphorus concentration and clarity were compared to the eutrophication thresholds and/or the interim targets developed for Swan Lake through the 2019 Water Quality Management Strategy. For DO and chloride, Federal and/or Provincial water quality Guidelines or Objectives are shown for perspective. It should be noted 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), Temperature, and pH

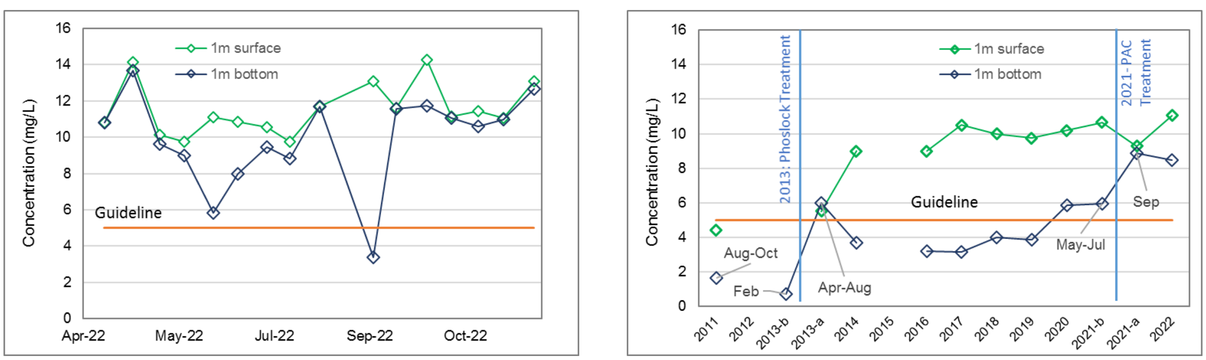
The minimum dissolved oxygen concentration required for the protection of warm water fish is 5 mg/L for water temperatures up to 20 °C, and 4 mg/L for temperatures above 20 °C. DO concentrations for the 1m from the surface and 1m from the bottom layers are shown below.

Measured day-time surface concentrations were above the DO guideline throughout 2022 (above 9.5 mg/L). DO concentration at the bottom layer was also above the guideline, except for two measurements at 2.2 and 3.4 mg/L, which occurred on dates when the water column was thermally stratified.

Lower DO 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.

Although measured DO levels did not indicate anoxia during the sampling events, its decline at the bottom of the water column could suggest that if the stratification persisted, it could have led to anoxic episodes (at night when respiration occurs), contributing to the release of nutrients from the sediments. Such potential occurrence would, however, be less severe than pre-treatment conditions as implied from the annual trend of day-time surface and bottom concentrations.

Figure ES-2: 2022 Monitoring Results and 2011-2022 Annual Results- Dissolved Oxygen



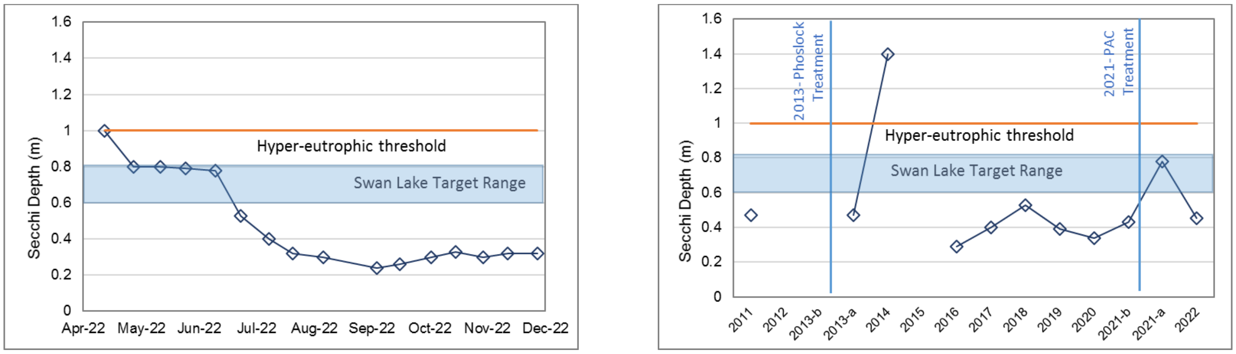
Note 1: DO concentrations are shown at 1 m from the surface (average of 0.5 and 1 m) and 1 m from the bottom (average of two bottom depths).
Note 2: Historical data are shown for the average growing period (June-Sep) unless otherwise indicated.

pH measured at the lab ranged from 7.5 to 9.4 throughout the year. High pH is consistent with high levels of algae. Algae take up carbon dioxide, a weak acid, from the water for photosynthesis, causing the water to become more basic (higher pH).

Water Transparency (Secchi Depth)

Secchi depth represents water transparency, which declines when the algae level increases. In the trophic state classification scheme, growing period average water clarity of under 1 m is the threshold for a hyper-eutrophic condition. The proposed interim target for Swan Lake is 0.6-0.8 m based on correlation with the phosphorus target. In 2022, water clarity was above 0.5 m until the end of June but dropped to below 0.4 m for the remainder of the monitoring period.

Figure ES-3: 2022 Monitoring Results and 2011-2022 Annual Results- Secchi Depth

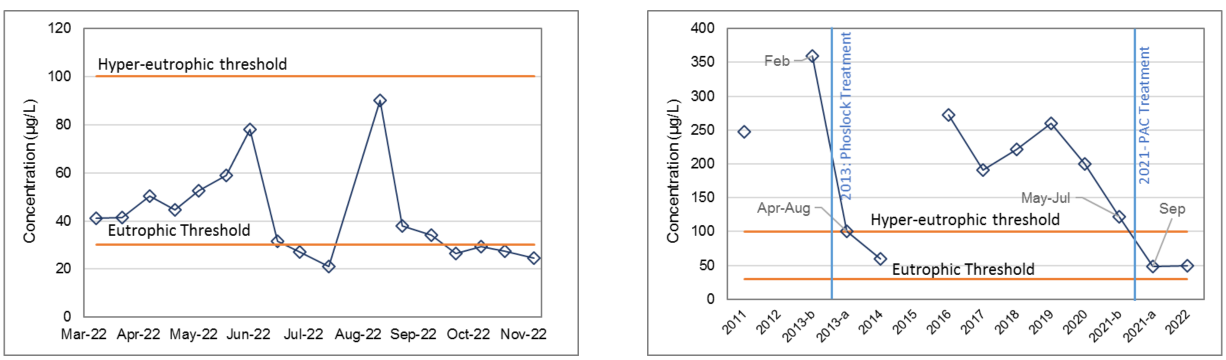


Phosphorus and Nitrogen Concentrations

Phosphorus concentration is the most important indicator of the trophic state in Swan Lake. It is an indication of how prone the Lake is to algae growth.

Phosphorus concentrations above 100 µg/L represent a hyper-eutrophic condition, which lead to high algae concentrations. Total phosphorus concentration in the top 0.5 and 1.5 m depths averaged under 50 µg/L during the growing season (under the 100 µg/L threshold for a hyper-eutrophic condition, and below the interim target of 50-100 µg/L). There was significant improvement in phosphorus concentrations after treatment by Phoslock and PAC.

Figure ES-1: 2022 Monitoring Results and 2011-2022 Annual Results- Total Phosphorus



Note 1: The 2022 values are averages of samples collected at 0.5 and 1.5 m from the surface.
Note 2: Annual concentrations are summaries of the growing period (June-Sep) unless otherwise indicated.

Total nitrogen concentrations over the growing season averaged about 0.60 mg/L (below the 1.2 mg/L threshold for a hyper-eutrophic condition). In 2022, ammonia and nitrate concentrations (the forms available for uptake by biota) were generally very low (except in April), and nitrogen was mainly present as organic matter.

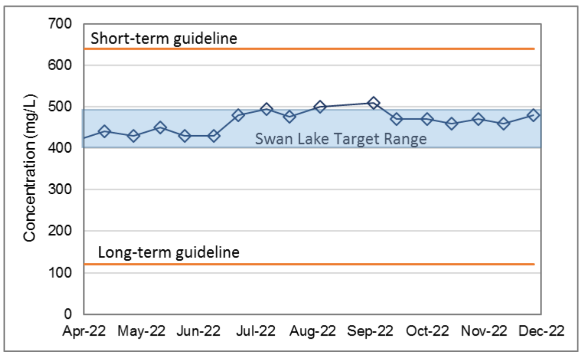
Chloride Concentration

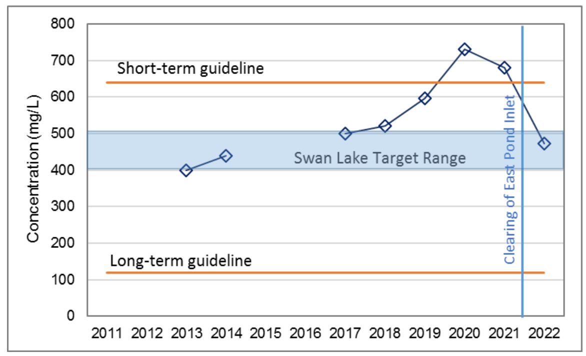
Chloride concentration has been increasing in urban lakes as a result of de-icer application for winter maintenance of roads and walkways. Chloride does not biodegrade, readily precipitate, volatilize, or bioaccumulate. It does not adsorb readily onto mineral surfaces and therefore when introduced, concentrations remain high in surface water.

Chloride guidelines developed for generic environmental data include a long-term guideline (120 mg/L) and a short-term guideline (640 mg/L). The long-term guideline has been developed to protect all organisms (present in Canadian aquatic systems) against negative effects during chronic indefinite exposure. The short-term guideline aims to protect most species against lethality during a sudden hike in chloride concentration for an acute 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. The interim target for chloride is 400-500 mg/L consistent with 2013-2014 values.

In 2022, chloride levels reduced considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake. The lower water level in the summer may have resulted in more concentrated amount of chloride starting from end of June.

Figure ES-4: 2022 Monitoring Results and 2011-2022 Annual Results- Chloride





In 2022, water samples were collected from various inlets to the Lake and analyzed for chloride. The mass balance established using these data is documented in a separate report.

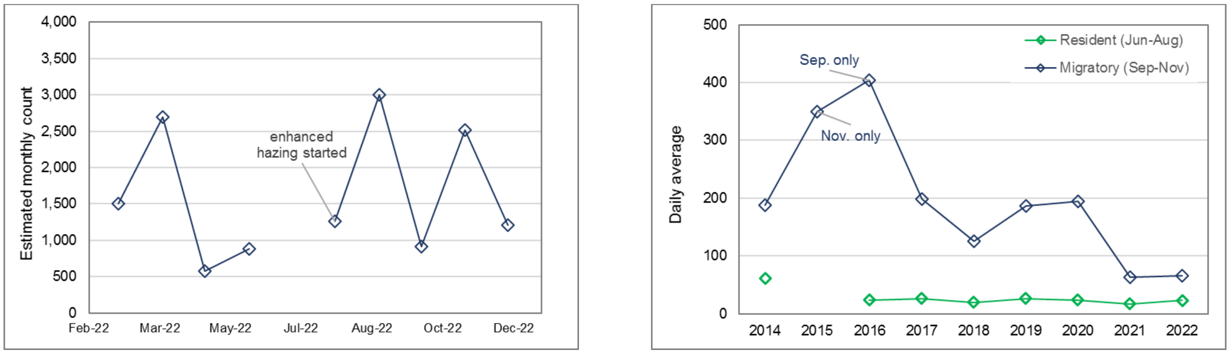
Geese Count

Geese are the primary external source of nutrients in the Lake. Therefore, active geese management is completed annually. The geese control program started in 2014, focusing on resident geese. The program extended to the management of migratory geese in 2016.

The 2022 program included a hazing program in the Spring, with an expanded version starting in mid-August to mid-December, nest management and geese relocation, the installation of nine strobe lights on the Lake and adjacent stormwater ponds, and geese count program.

In 2022, the increased hazing efforts were very effective in reducing the number of migratory geese visiting the Lake, similar to those achieved in 2021 when the extended program started. The strobe lights did not have any noticeable impact on the counts. The geese count data helped provide more certainty in the results, and were used to more effectively schedule hazing efforts.

Figure ES-5: 2022 Monitoring Results and 2011-2022 Annual Results- Geese Count



Note 1: 2022 data are the sum of counts in each month, compensated for days with no count.
Note 2: Annual trends are shown as daily averages of counts over June-August and September to November, representing resident and migratory geese, respectively.

Other management activities completed in 2022 included a fish inventory, the removal of bottom-dwelling fish to reduce sediment disturbance, and Phragmites management through spraying and physical removal.

Algal Growth

In 2022, limited surface scums were observed along the shoreline around the Dock, as well as in the northern bay at the Bridge site. While the Lake was dominated by phytoplankton from late June, surface scums were not widespread.

Samples were collected and sent to the laboratory for phytoplankton and cyanobacteria. Test results showed lower diversity and higher total counts compared to 2021.

Several algal blooms with potentially toxic cyanobacteria were observed in years before 2011; however, testing completed before 2011 and following treatment (2013-2016) did not detect any Microcystin in the water. In 2016, a bloom was tested and resulted in a Microcystin concentration of 73 µg/L. Extended blooms were observed at several sites in 2018; however, cell density was at half of WHO's threshold for significantly increased human health risk. These results suggest that in most years, toxin-producing cyanobacteria are not the dominant form of phytoplankton in Swan Lake. In recent years, Abraxis tests have resulted in Microcystin levels below the recreational limit (20 µg/L, recently updated to 10 µg/L).

Summary and Recommendations

Overall, the management activities in 2021/2022 that focused on the significant nutrient loadings identified in the water quality improvement study (i.e., chemical treatment and fish management to reduce internal loads and geese management to reduce external loads), were effective at improving water quality in the Lake as shown in reduced phosphorus concentrations and improved dissolved oxygen levels. These improvements represent a positive step towards improving the aquatic habitat in the Lake and meeting the long-term water quality goals.

In 2022, chloride levels decreased considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake.

While internal and external source controls successfully reduced nutrient concentrations, the Lake was dominated by phytoplankton, and water clarity did not improve. This could be partly due to the absence of submerged aquatic vegetation (SAV), which has been replaced by phytoplankton (algae) due to low water clarity.

The 2023 monitoring program will follow the recommendation of the Long-Term Management Plan. Additional measures will be investigated for the return of SAVs to the Lake, as well as strategies to reduce chloride concentration in the Lake.

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Appendices

Appendix A : Swan Lake Water Quality Inspection Forms

Appendix B : Certificates of Analysis

Tables

Figures

1. Introduction

Swan 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 has an approximate area of 5.5 ha and a maximum water depth of 4.5 m (from the deepest point to the Lake edges at 210m). Formerly a gravel pit in the 1960s and 1970s, Swan Lake is currently a community feature with multiple trails and urban development.

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

In 2019, the City of Markham conducted a study to define a Water Quality Management Strategy for Swan Lake. The Strategy, which was finalized in July 2020, recommended chemical treatment starting in 2021.

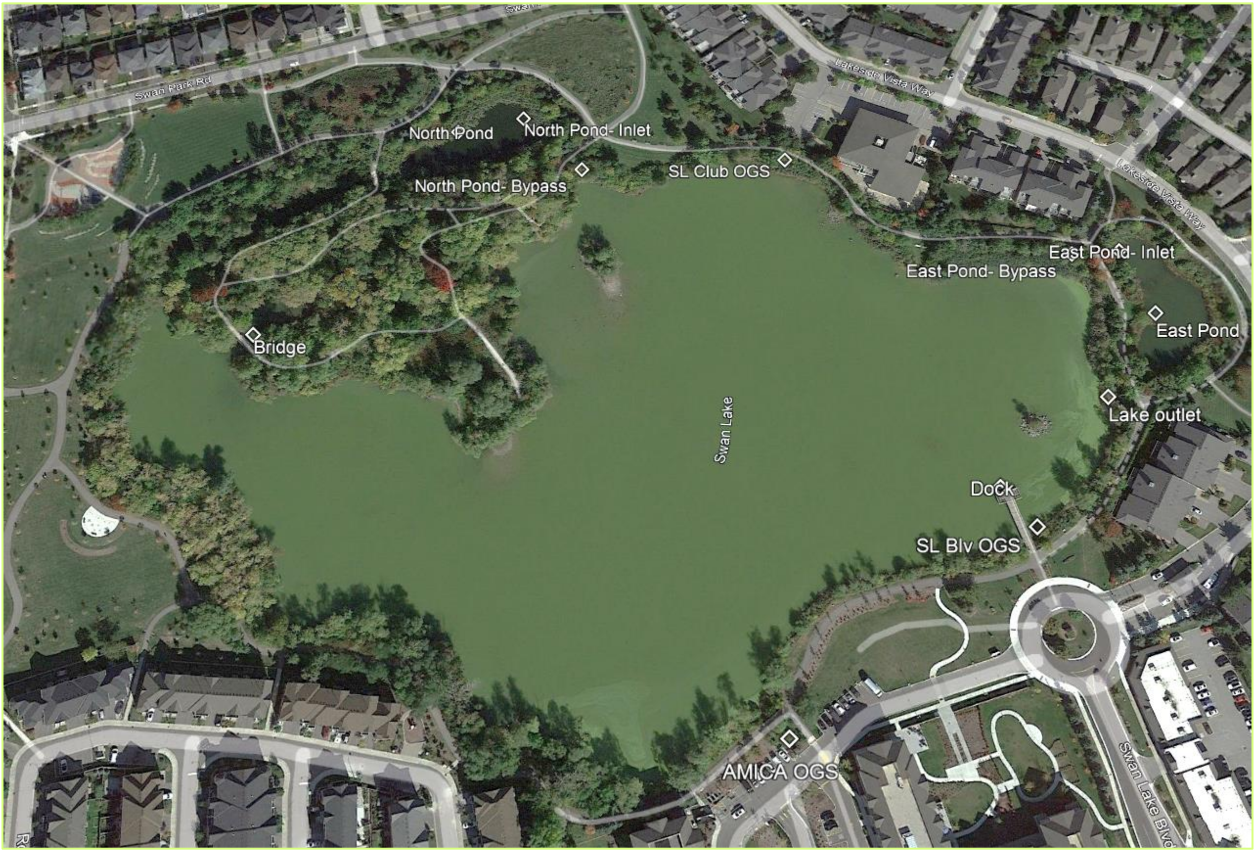
In August 2021, 13 tonnes of Poly Aluminum Chloride (PAC) were applied to the Lake in a controlled manner over several days.

The Swan Lake Long-Term Management Plan was received by Markham Sub Committee in November 2021 and approved by the Council in December 2021. It describes a phased adaptive approach, including provisions for chemical treatment every three years. Activities planned and completed for 2022 included enhanced geese management, fish removal, and water quality monitoring, as well as investigation of additional measures to improve water quality in the Lake.

Water quality monitoring of Swan Lake has been conducted annually since treatment in 2013 in order to track water quality and the effectiveness of management activities. The 2022 monitoring results presented in this report are part of the ongoing monitoring program that will allow for continuous assessment of the water quality in Swan Lake and help establish a long-term plan for the treatment of Swan Lake.

In 2022, sampling for chloride measurement was also conducted at several locations to determine the relative contribution of each source to the Lake.

Figure 1: Swan Lake and Runoff Monitoring Stations



2. Monitoring Program

2.1 Annual Water Quality Monitoring

2.1.1 Locations

Water quality was monitored at two shoreline sites, the Dock, and the Bridge, as shown in Figure 1. On average, the water depth at the Dock is approximately 2.5 meters, which allows it to represent Swan Lake as a whole. The water depth at the bridge is about 0.5 meters, and it is used to represent the conditions of the shallow bays around Swan Lake. Field testing and sampling for laboratory analysis were completed at both sites to ensure the water conditions at Swan Lake were properly represented.

During the bi-weekly monitoring, samples and measurements were taken at 0.5 m or 1 m increments for the depth of the Lake. The dock site was the deeper of the two sites, allowing for sampling and monitoring from 0.5 – 2.5 m, whereas the bridge site was shallow and sampling was typically only achievable under the surface, slightly above the bottom of the Lake to avoid sediment contamination.

When the water level dropped to around 2 m, samples were not collected from the 2.5 m depth at the Dock station.

2.1.2 Duration and Frequency

In 2022, water quality was monitored bi-weekly from April to November.

A total of 17 sampling events were completed.

2.1.3 Parameters and Methodology

Vertical water quality profiling, water transparency readings (Secchi depth), and photographic documentation were performed during each site visit.

Field testing was done utilizing an YSI ProODO meter to determine the temperature and dissolved oxygen (DO) at each sampling interval over the vertical profile of the lake. To ensure accurate readings, the meter and probe were stored in a proper carrying bag and regularly calibrated as instructed in the handheld quick-start guide.

Water transparency was measured as part of the field testing at both the dock and bridge monitoring sites. Transparency was measured using a Secchi disk by lowering it into the water while rotating the handle until the black and white pattern of the Secchi disk was no longer visible. The water depth read from the Secchi disk was then recorded as the transparency (i.e., water clarity).

Water samples for laboratory testing were taken using a horizontal water sampler at different depths. Parameters analyzed at various stations and times included:

- Nutrients including total and ortho phosphorus, ammonia, nitrate, Total Kjeldahl Nitrogen (TKN)
- Chloride, color, Dissolved Organic Carbon (DOC), pH
- Phytoplankton

Observations of Swan Lake were noted, and photographs were taken during each monitoring/inspection site visit. Photographs provide a way to record the condition of vegetation and algae around Swan Lake. Completed inspection forms and photos can be found in Appendix A.

2.1.4 Targets and Thresholds

Generic thresholds for eutrophic and hyper-eutrophic conditions in the lakes are provided in Table 1.

Table 1: Eutrophic State Classification

Parameter	Eutrophic Condition	Hyper-eutrophic Condition
Secchi Depth (m)	1-2.1	<1
Total Phosphorus (µg/L)	31-100	100
Total Nitrogen (mg/L)	0.65-1.20	>1.20

The 2019 Water Quality Management Strategy proposed a set of interim targets for Swan Lake to be used as triggers for management actions if the triggers are tripped in two consecutive years. Numerical values were defined for total phosphorus (100 µg/L) and Secchi depth (0.6-0.8 m, as updated in 2021 based on correlation with the phosphorus target).

For DO and chloride, Federal and/or Provincial water quality Guidelines[1] or Objectives[2] were considered for perspective. It should be noted 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.

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. 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.

Chloride guidelines developed based on generic environmental data include a long-term guideline (120 mg/L) and a short-term guideline (640 mg/L). The long-term guideline has been developed to protect all organisms (present in Canadian aquatic systems) against negative effects during indefinite exposure. The short-term 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. The interim target for chloride is 400-500 mg/L consistent with 2013-2014 values.

For Cyanotoxins, the Health Canada guideline for recreational activities was updated from 20 µg/L to 10 µg/L in 2022[3]. The 2022 guidelines also provide indicator values for the potential production of cyanotoxins including:

- Total cyanobacteria cells: 50 000 cells/mL
- Total cyanobacterial biovolume: 4.5 mm^3/L
- Total chlorophyll a: 33 µg/L

[1] Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life (http://ceqg-rcqe.ccme.ca/en/index.html)
[2] Ontario Provincial Water Quality Objectives (PWQO) (https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives#section-13)
[3] Health Canada, 2022. Guidelines for Canadian Recreational Water Quality, Cyanobacteria and their Toxins, Ottawa, Ontario.

2.2 Runoff Monitoring

In the Swan Lake catchment, salt application for winter maintenance is mainly completed by the City's Road department and the Swan Lake Village Corporation.

Winter maintenance of 1 km 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 on current and future forecast models and temperatures to determine the required action and material usage in compliance with the desired level of service and O.Reg 239/02 requirements.

The remaining roads and parking areas, as well as private walkways and driveways, are serviced privately. As per the Village Amenities Committee (VAC), the Village Corporation employs "a qualified, reputable cleaning and maintenance service employing Smart About Salt principles to plow/shovel and their insurance recommends the de-icing methods of rock salt, applied as necessary to maintain their insurance and mitigate potential claim".

Chloride in salting materials is readily dissolved in water and transported overland by runoff or infiltrated into soils, contaminating groundwater and surface water. A fraction of chloride in applied road salt is retained by soil and is not observed in surface runoff. As a result, salt loading to surface water occurs primarily in winter and spring during melt conditions but continues through the summer and fall via the discharge of impacted groundwater, dry deposition of dust to the lake surface, non-point source runoff washing dry salt from land surfaces. Salt accumulated in the ponds could also be discharged into the Lake through the flushing of stormwater ponds.

In 2022, water samples were collected from various inlets to the Lake to quantify and determine the relative contribution of each source to chloride concentration in Swan Lake. Samples were collected from both ponds' inlets, as well as outfalls from the ponds and OGS's to the Lake. Samples were also collected from the shoreline runoff and Swan Lake Blvd.

The outfalls were not flowing during some sampling events, in which case, samples were collected from the pool of water present. There was no flow/ visible water at the outfall from the Swan Club's OGS, and therefore, no sample was collected at this location.

Conductivity was also measured in a number of samples, as this parameter can be used as a surrogate for chloride. Samples were collected during seven snowmelt events from November 2021 to April 2022.

2.3 Water Level Monitoring

The water level was monitored using HOBOware U20 Water logger mounted at the Dock. The data logger records the pressure and temperature of the water every 15 minutes. The measured pressure is compensated using a baro-logger to calculate water depth. Missing data were calculated using the methodology developed in 2021.

3. Results

3.1 2022 Water Quality

The following sections discuss water quality results in 2022.

3.1.1 Dissolved Oxygen and Temperature

Table 2 provides the measured DO profile over the 2022 monitoring period.

At the Dock station, all measured day-time surface concentrations were above 5 mg/L throughout 2022. At 1.5- 2 m depth, the DO was also above the guideline, except on two occasions, but never under 2 mg/L, which would be indicative of anoxic conditions. All but one measurement at the Bridge indicated a DO concentration of above 4 mg/L. Night-time oxygen was not recorded.

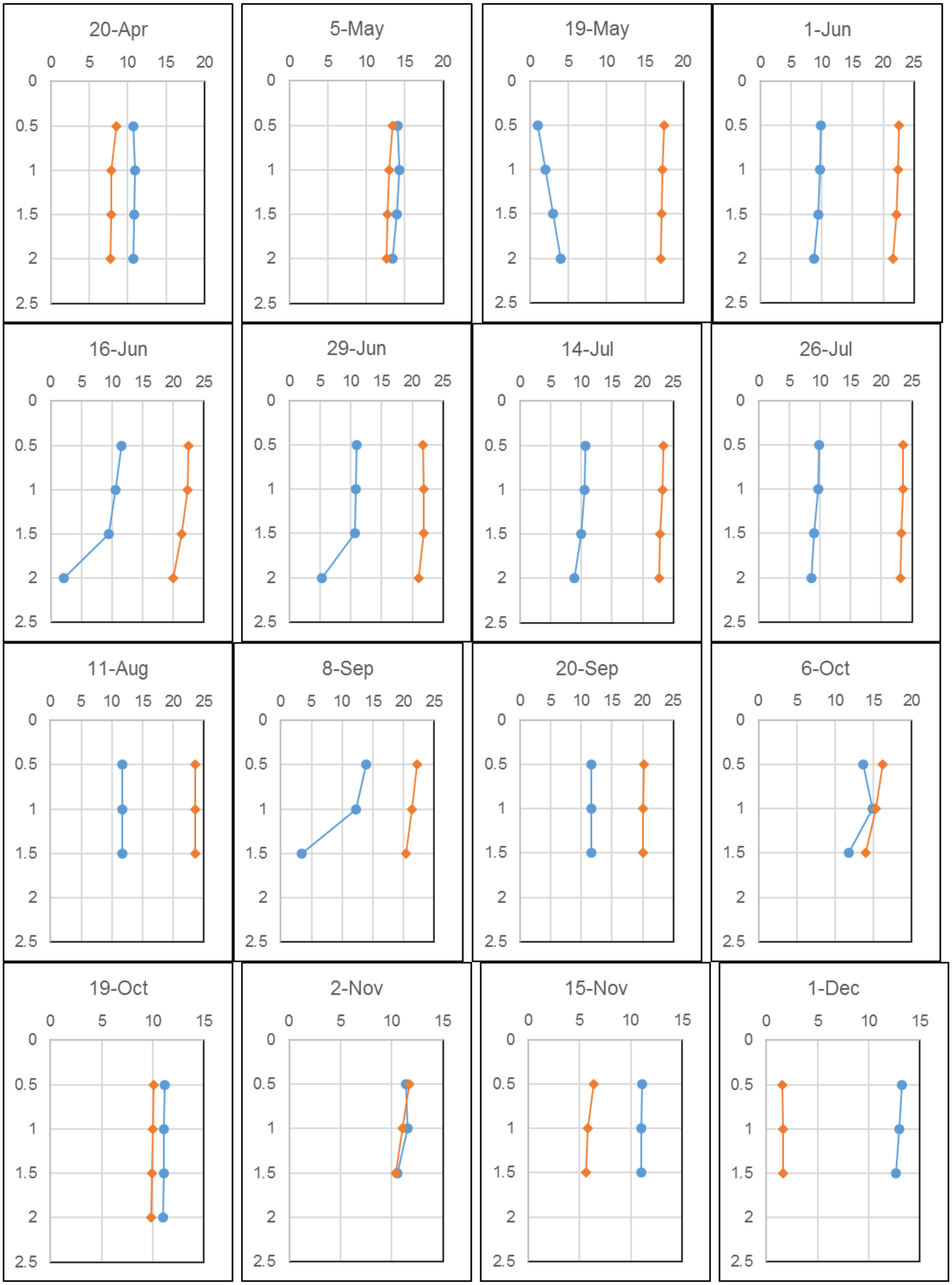
Table 2 also provides measured temperature profiles in 2022, indicating warm water throughout the depth in the summer months.

Profiles of temperature and dissolved oxygen (see Figure 2) indicate that Swan Lake was thermally stratified during June and transiently in the fall (when temperature decline is above 1 °C per m of depth or DO decline of above ~2 mg/ m of depth). Transient stratification can cause reduced mixing/aeration and lead to anoxia with the release of nutrients from the sediments.

Table 2: Measured DO and Temperature

	DO Concentration (mg/L)					**Temperature (°C)**				
	Bridge	**Dock**				**Bridge**	**Dock**			
	Depth (m)	Depth (m)				Depth (m)	Depth (m)			
Date	0.5	0.5	1	1.5	2	0.5	0.5	1	1.5	2
4/20/2022	10.3	10.7	10.9	10.8	10.8	8.7	8.5	7.8	7.8	7.7
5/5/2022	12.2	14.1	14.3	13.9	13.5	12.7	13.4	13.0	12.7	12.6
5/19/2022	7.4	10.2	10.1	10.0	9.3	14.9	17.5	17.3	17.2	17.0
6/1/2022	4.4	9.9	9.6	9.4	8.7	20.1	22.5	22.4	22.2	21.6
6/16/2022	4.2	11.6	10.6	9.5	2.2	21.6	22.5	22.3	21.4	20.0
6/29/2022	4.7	10.9	10.8	10.7	5.3	20.1	21.7	21.8	21.8	21.0
7/14/2022	3.4	10.6	10.5	10.0	8.9	21.0	23.4	23.2	22.8	22.7
7/26/2022	4.5	9.8	9.7	9.1	8.6	21.3	23.5	23.5	23.2	23.1
8/11/2022	4.8	11.7	11.7	11.7	-	22.0	23.6	23.6	23.6	-
9/8/2022	8.6	13.9	12.3	3.4	-	21.2	22.2	21.4	20.4	-
9/20/2022	7.7	11.6	11.6	11.6	-	19.4	20.2	20.1	20.0	-
10/6/2022	10.2	13.7	14.9	11.8	-	16.5	16.2	15.3	14.0	-
10/19/2022	9.8	11.2	11.1	11.1	11.0	9.0	10.1	10.0	9.9	9.8
11/2/2022	7.6	11.4	11.5	10.6	-	8.6	11.7	11.1	10.4	-
11/15/2022	9.1	11.1	11.1	11.0	-	1.1	6.4	5.8	5.6	-
12/1/2022	13.7	13.2	13.0	12.7	-	0.6	1.5	1.6	1.6	-

Figure 2: Temperature (orange) and DO (blue) Profile at the Dock Station



Note: The vertical axis shows depth (m), while the horizontal axis represents both Temperature (°C) and DO (mg/L).

3.1.2 Water Transparency

Table 3 summarizes the results of the water transparency readings. Transparency at the Dock station was above 0.5 m until the end of June but dropped to below 0.4 m for the remainder of the monitoring period. The proposed interim target for Swan Lake is 0.6-0.8 m. Water transparency at the Bridge site was generally equal to the water depth.

Table 3: 2022 Secchi Depth Results (m)

Date	Dock	Bridge
20-Apr	1	0.43
5-May	0.8	0.43
19-May	0.8	0.43
1-Jun	0.79	0.465
16-Jun	0.78	0.5
29-Jun	0.53	0.44
14-Jul	0.4	0.38
26-Jul	0.32	0.2
11-Aug	0.3	0.3
8-Sep	0.24	0.2
20-Sep	0.26	0.15
6-Oct	0.3	0.2
19-Oct	0.33	0.2
2-Nov	0.3	0.2
15-Nov	0.32	0.2
1-Dec	0.32	0.2

3.1.3 Nutrients Concentrations

Samples collected during each visit were tested for Total Phosphorus (TP), Orthophosphate, Total Kjeldahl Nitrogen (TKN), Nitrate, and Ammonia. The results can be found in Figure 3 for the Dock site and Figure 4 for the Bridge site. The Certificate of Analysis from Bureau Veritas Laboratories is in Appendix B. Nutrient concentrations are shown for the depths sampled.

Total phosphorus concentration at 0.5 and 1.5 m depths averaged under 50 µg/L during the growing season and throughout the year (below the 100 µg/L threshold for a hyper-eutrophic condition).

The summer peak in total phosphorus (September 8) occurred during a dry period when the Lake was stratified. Still there was no concurrent increase in orthophosphate or ammonia to suggest that there was a pulse of nutrient release from the sediments due to anoxia. Therefore, it is possible that anoxia or decomposition-related internal nutrient loading occurred in the days preceding the September 8 sampling event resulting in the increased algae abundance and elevated total phosphorus. Other potential mechanisms include wind-driven suspension of nutrient-rich sediments or germination of resting cells in the sediments.

Total nitrogen concentrations over the growing season averaged about 0.60 mg/L (below the 1.2 mg/L threshold for a hyper-eutrophic condition). Total concentrations at the Bridge site averaged 0.62 mg/L. Ammonia and nitrate are the directly-bioavailable forms, with Ammonia being the most usable form for algae. In 2022, Ammonia and Nitrate concentrations were generally close to or below Method Detection Limit (MDL), and nitrogen was mainly present as organic compounds (i.e., TKN less Ammonia) with the exception of spring samples. Bioavailable nutrient pulses (orthophosphate and ammonia) in late summer and fall are consistent with the release of these nutrients due to episodic anoxia and decomposition of organics, including algae.

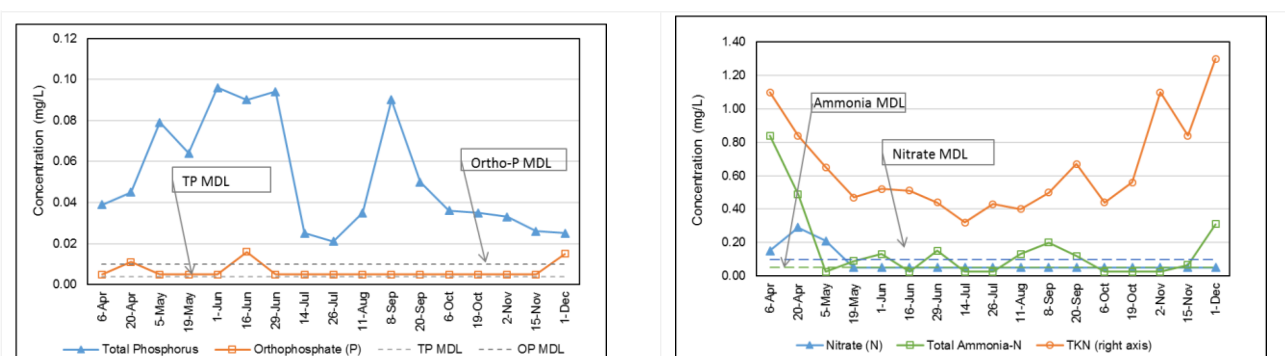
Elevated nitrate and ammonia in early spring are common in eutrophic waterbodies due to colder water temperatures and lack of uptake by plants and algae. Spring increase in TP as nitrate and ammonia/TKN (and transparency) decline suggests increasing spring algal activity, peaking in late June.

TP declined between June 29 and July 14, likely reflecting a collapse of the spring/early summer algal community. TP remained relatively low until September 8, when a bloom could have developed (although there is no supporting evidence from other indicators suggesting a bloom event). Pulses of elevated Ortho-P and ammonia in late summer and fall are consistent with transient stratification and anoxia followed by mixing that introduces nutrients into the water column and/or decomposition of algae.

Figure 3: Measured Nutrients Concentrations - Dock Site

Note: Values below MDL are shown as MDL/2

Figure 4: Measured Nutrients Concentrations - Bridge Site



Note: Values below MDL are shown as MDL/2.

3.1.4 pH

pH measured at the lab ranged from 7.5 to 9.4 throughout the year, with higher values measured between July and September, reflecting high algae production.

3.1.5 Chloride in Lake and Runoff

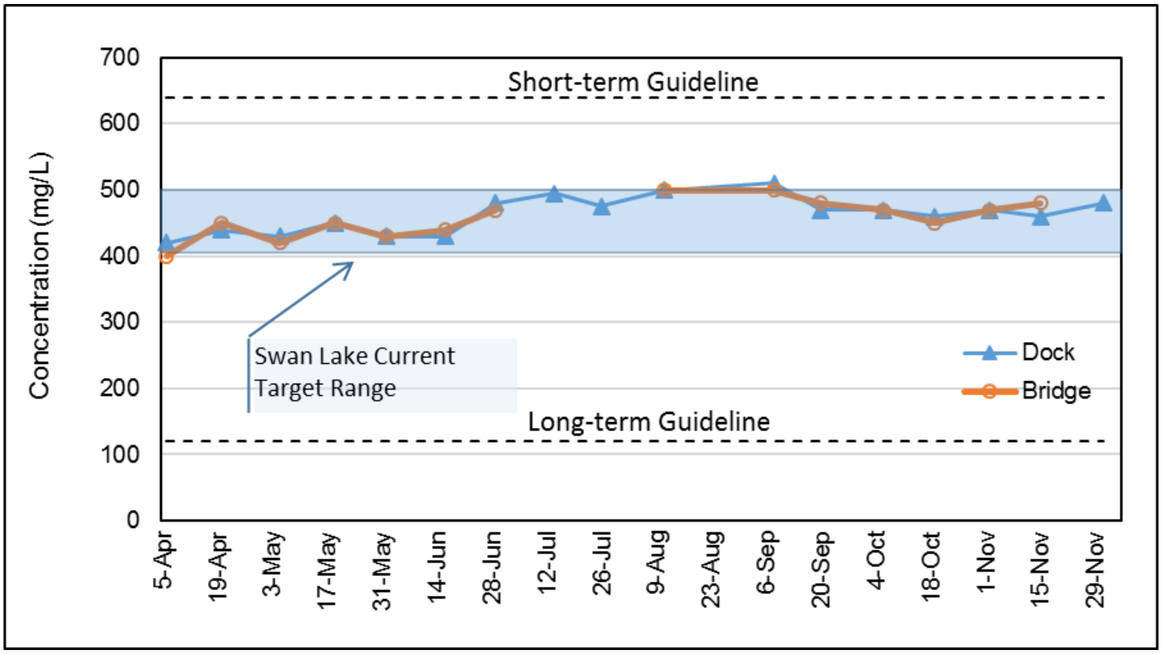
Surface samples collected during each visit were also analyzed for Chloride, as summarized in Figure 5.

Water quality testing results indicated that the samples contained between 400 and 510 mg/L of Chloride.

In 2022, chloride levels decreased considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake. The lower water level in the summer may have resulted in a more concentrated amount of chloride starting from the end of June.

Chloride guidelines developed based on generic environmental data include a long-term guideline (120 mg/L) and a short-term guideline (640 mg/L). The interim target for chloride is 400-500 mg/L consistent with 2013-2014 values.

Figure 5: Chloride Concentrations in Swan Lake in 2022



In 2022, water samples were collected from various inlets to the Lake and analyzed for chloride.

These data, along with scattered data from previous years, are shown in Table 4. Based on this limited dataset, chloride concentration in the spring runoff from the pond catchments is about 1000 mg/L (median of pond inlet measurements, except for January 13). This concentration would not usually end up in the Lake, except through the East Pond bypass when the pond inlet was blocked. At other times, the bypass would carry 'cleaner' water (after the first flush), with concentrations around 200 mg/L. Flows from the ponds to the Lake have an average concentration of 350 mg/L (average of pond and outlet concentrations).

The runoff collected from SLB OGS contained about 2000 mg/L of chloride, while AMICA OGS had a concentration of about 500 mg/L. Samples were also collected from the shoreline runoff, which resulted in very low chloride concentrations (about 25 mg/L). The OGS at Swan Club did not have any flow through the outfall due to blockage, and it is possible that this OGS requires maintenance and may convey the untreated runoff towards the Lake through an overland path.

The mass balance established using these data is documented in a separate report.

Table 4: Chloride Concentrations in Runoff

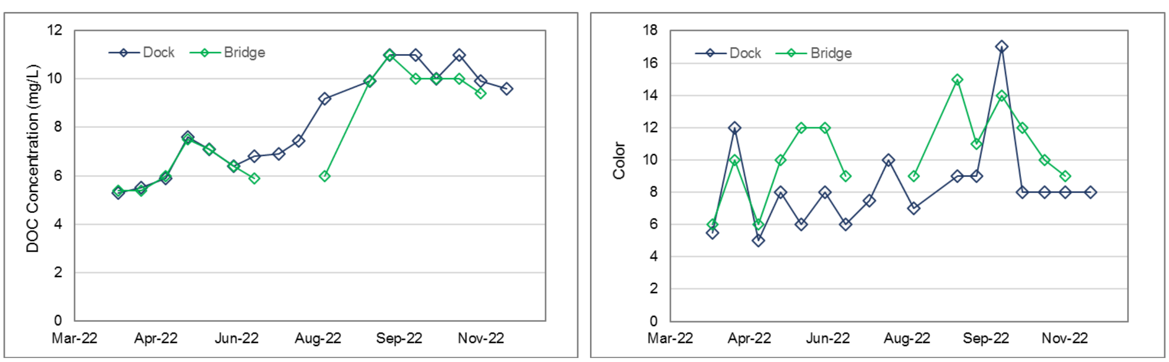
	Inflow to Ponds		Bypass from Pond to Lake	Inflow to Lake from Ponds				Inflows to Lake from OGS	
Date	**East Pond**	**North Pond**	**East Pond**	**East Pond- in pond**	**From south**	**North Pond- in pond**	**Road**	**Swan Lake Blvd.**	**AMICA**
3/20/2012 *	577	673		572		56			
3/26/2021	957	98.5		343		199			
4/11/2021		79	131		673				
1/13/2022	13200**							3160	
2/15/2022	2340	2120					326	836	360
3/6/2022	380	410		410		180		1200	610
3/16/2022	3700	3100						4800	470
3/24/2022	1200	1100	150					1900	240
4/6/2022	2800		350						1100
Median/average	1029		210	345				1900	470

* Data were used cautiously since the exact location of samples and sampling conditions are not known.
** Standing water, not used in calculations.

3.1.6 DOC Concentrations and Color

Surface samples collected during each visit were also analyzed for Dissolved Organic Carbon (DOC), and Color. The results are summarized in Figure 6. Increased DOC and colour may be associated with high decomposition rates releasing DOC.

Figure 6: Measured DOC and Color in 2022



3.1.7 Algae Growth

In 2021, samples were collected before and after chemical treatment and sent to the laboratory for phytoplankton and cyanobacteria identification. Test results are summarized in Figure 7 below, and show a significant reduction in concentrations following the treatment, potentially due to the particle scavenging characteristics of the treatment chemicals. Phytoplankton density increased almost five weeks post-treatment to values comparable to pre-treatment levels.

In 2022, limited algae scum was observed in early June, and while the Lake was dominated by phytoplankton for the remainder of the monitoring period, surface scums were not widespread.

Abraxis tests were performed on June 29, July 14, and August 11 and resulted in Microcystin levels below the recreational limit (recently updated to 10 µg/L).

Four sets of samples were collected from the Lake between August and December for phytoplankton identification, as shown in Figure 8. These results should be considered with caution due to lab errors in the identification of Microcystis. In general, the results showed lower diversity and higher total counts compared to 2021. While total microcystins concentrations were below 10 µg/L during the monitoring events in 2022, the presence of known toxin producers at high cell densities suggests that cyanotoxins can potentially occur at elevated concentrations that exceed recreational guidelines. Toxin concentrations can vary tremendously over small spatial and temporal scales, and it is, therefore, possible that higher concentrations occurred elsewhere in the Lake or at different times.

Figure 7: Planktonic Cyanobacteria Population in Swan Lake in 2021

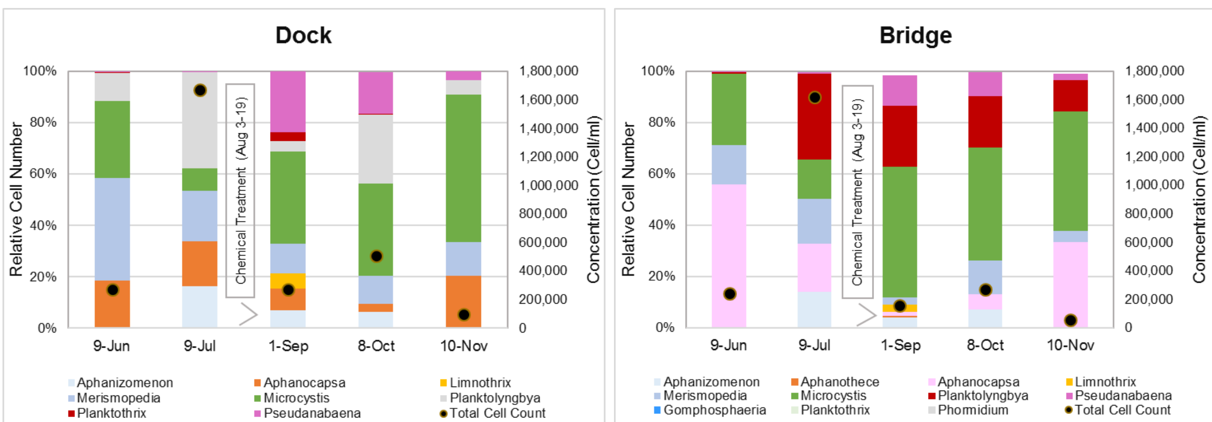
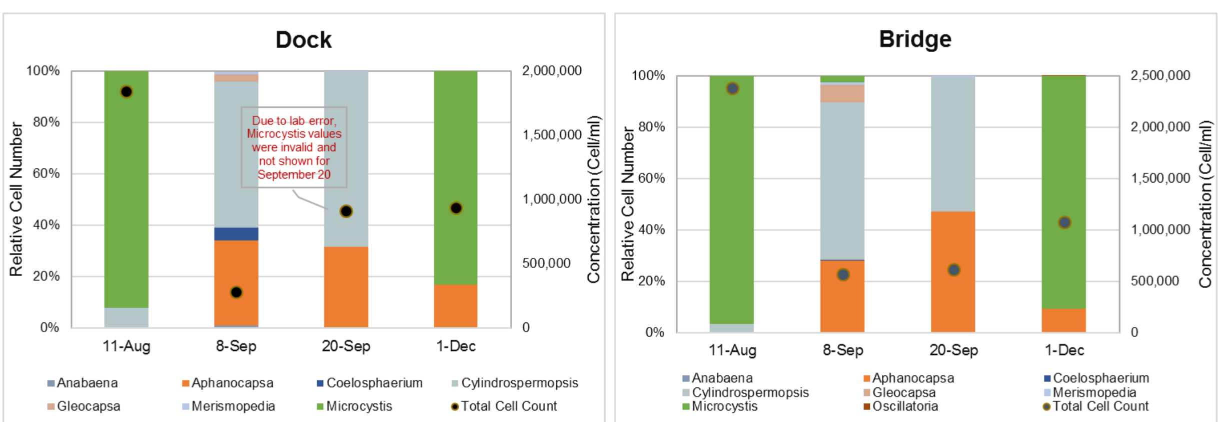


Figure 8: Planktonic Cyanobacteria Population in Swan Lake in 2022



3.2 2022 Water Level

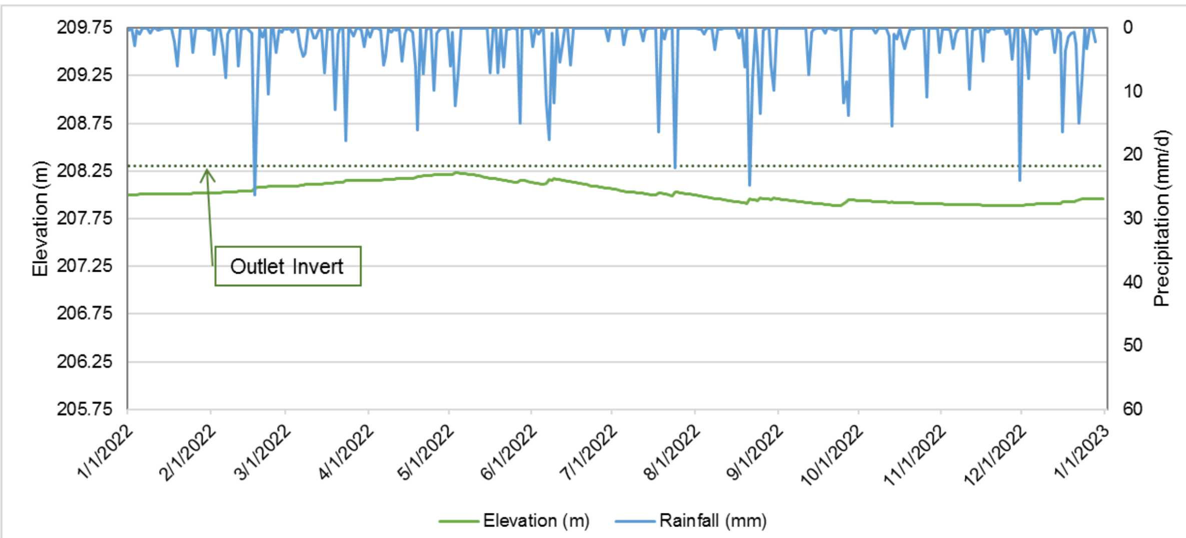
In 2022, the calculated water level changed from a max of 208.23 m in May to a low of 207.9 in November. Total precipitation in 2022 was 670 mm, as recorded at the Markham Museum station.

The maximum water level recorded or estimated between 2017 and 2021 ranged from 208.25 m to 208.48, when total precipitation ranged from 745 to 934 mm.

In addition to 2022 being a relatively dry year, the clearing of the blockage at the East Pond inlet resulted in lower flows from the inlet bypass to the Lake, further lowering the water level in Swan Lake. Extended dry periods in 2022 coincide with the approximate time of stratification.

Calculated water level and daily precipitation data from the nearby rain gauge are shown in Figure 9.

Figure 9: Lake Elevation Records and Precipitation in 2022



3.3 Water Quality Trends

Water quality monitoring of Swan Lake has been conducted annually since treatment in 2013 to track water quality and the effectiveness of implemented mitigation measures.

The following paragraphs and Figure 10 provide a summary of water quality trends for the period of monitoring.

Dissolved Oxygen (DO)

Historical records of DO and temperature profile show that Swan Lake thermally stratifies during the summer despite its shallow depth. Anoxic conditions were observed at depths below 2 m, to as high as 1 to 1.5 m (in 2016). The majority of surface concentrations have been above 5 mg/L since 2014. In 2022, day-time surface concentrations at the Dock station were above 9.5 mg/L. DO concentration at the bottom layer was also above the guideline, except for two measurements at 2.2 and 3.4 mg/L, which occurred on dates when the water column was thermally stratified.

Water Clarity (Secchi Depth)

In Swan Lake, Secchi depth has typically been quite low throughout the summer, but it increases in November, reflecting the end of the growing period for phytoplankton. The average annual values shown in Figure 10 are all below 1 m, except in 2014 and 2021, following chemical treatment. In 2022, water clarity was above 0.5 m until the end of June but dropped to below 0.4 m for the remainder of the monitoring period.

Total Phosphorus (TP)

Average growing period (May - September) TP concentrations indicated hyper-eutrophic conditions in all monitored years except for the post-treatment years, 2013 and 2014, as well as 2021 and 2022. There was no monitoring in 2015.

Nitrogen Compounds

Total nitrogen concentration over the growing period has been above the 1.2 mg/L threshold for a hyper-eutrophic condition, except in the post-treatment year, 2014, and in 2021 and 2022. Nitrogen is, however, not believed to be the limiting nutrient for eutrophication in Swan Lake (i.e., the nutrient that elicits the largest response in algae growth).

Inorganic nitrogen compounds (NO_2, NO_3, and NH_3) have often been below detection limits, indicating relatively low levels of bioavailable nitrogen concentrations. In 2022, ammonia and nitrate concentrations were generally very low (except in April), and nitrogen was mainly present as organic matter.

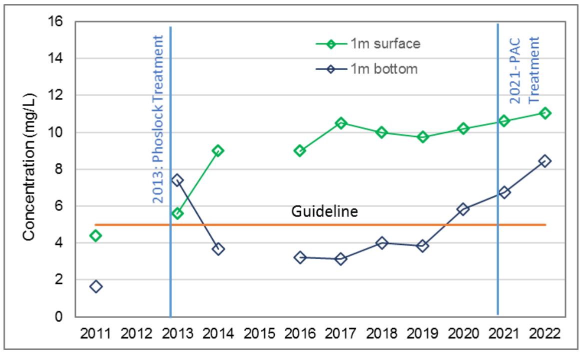
Chloride

Chloride concentrations were increasing in Swan Lake over the past few years with a slight drop in 2021. Removing the blockage at the East Pond inlet resulted in lower flows from the inlet bypass to the Lake, lowering chloride concentration in Swan Lake in 2022.

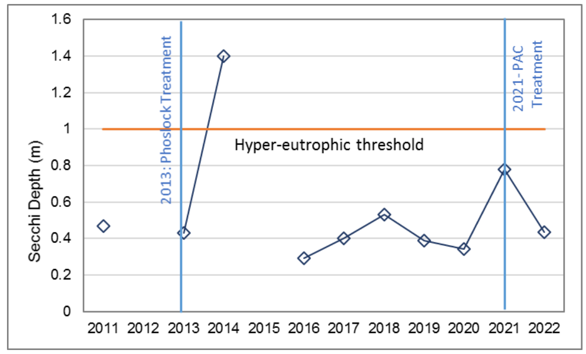
The Long-Term Management Plan for the Lake suggests that the main mechanism for lowering chloride levels would be source control. Emerging technologies and flow redirection may be considered in the future.

Figure 10: Historical Water Quality Results (Growing-Season Averages)

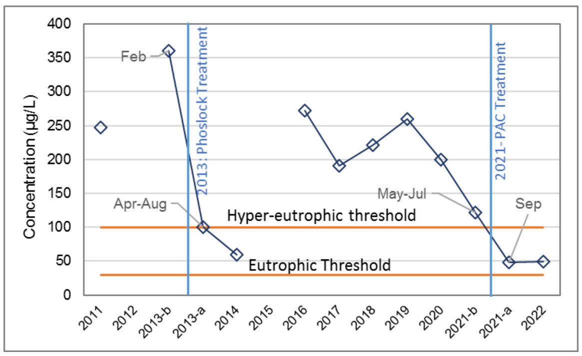
DO



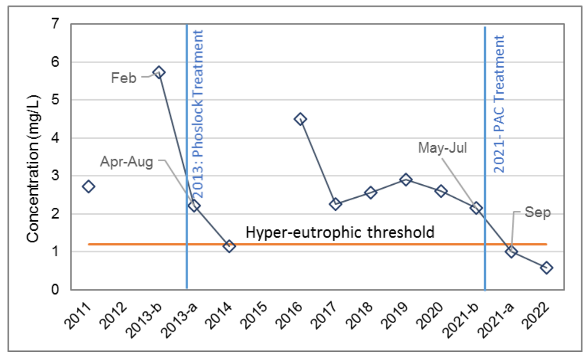
Secchi Depth



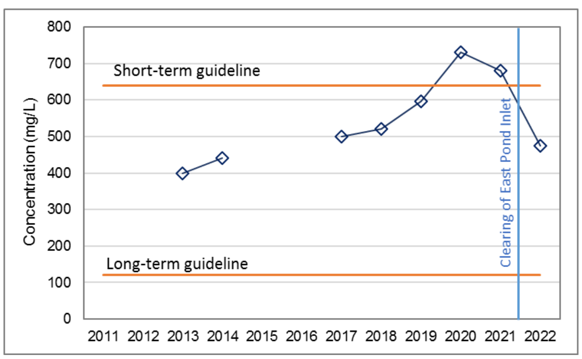
Total Phosphorus



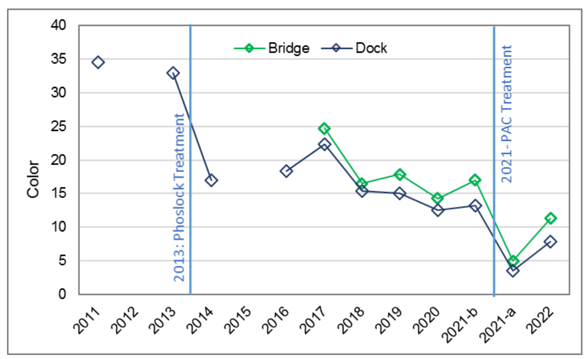
Total Nitrogen



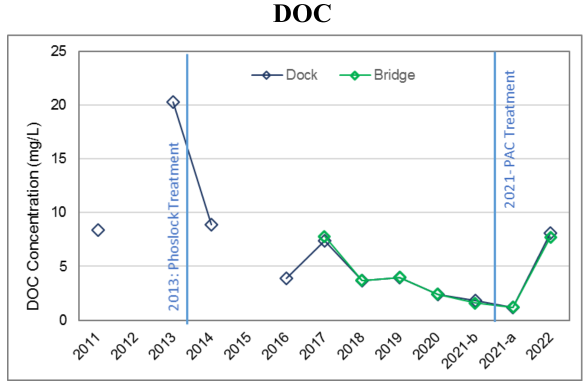
Chloride



Color



DOC



Algae Blooms and Cyanobacteria

Table 5 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.

Table 5: 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
2019	Extended blooms were observed at several sites	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L
2020	Blooms were observed at several sites	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L
2021	Blooms were observed at several sites before treatment; the high biomass was inhibited by the August PAC treatment; however, by October, cyanobacteria were as high as in previous summers and falls.	Not tested for toxicity
2022	Surface scum were not widespread; Lab results showed lower diversity and higher total counts compared to 2021.	Microcystin toxicity was measured with test strips; all samples were below 10 µg/L

While internal and external source controls in 2021/2022 successfully reduced nutrient concentrations to below the specified targets, in 2022, the Lake was dominated by phytoplankton, and water clarity did not improve. This could be partly due to the absence of submerged aquatic vegetation (SAV), which has been replaced by phytoplankton (algae) due to low water clarity. SAV compete with algae for nutrients and light, and the establishment of SAV growth may help to reduce phytoplankton blooms later in the season.

SAV would prevent sediment resuspension, take up nutrients from the water, and act as habitat for zooplankton, which in sufficient densities would help control algal blooms. The return of SAV could be key to shifting the lake to a clear state; however, this shift seems unlikely without active bio-manipulation to break the cycle of high turbidity- phytoplankton dominance – high turbidity[4].

[4] Scheffer, M. Alternative Attractors of Shallow Lakes. The Scientific World (2001) 1, 254-263.

4. Geese Management

4.1 Geese Management Approach

Geese reduction at Swan Lake is necessary due to the nutrient load they contribute to the Lake.

In 2022, the geese management program was completed by two external contractors.

Border Control Bird Dogs, an external consultant, was hired to chase (i.e., 'haze') terrestrial geese by border collies (including the Toogood Pond, where they also performed egg oiling). Program activity frequency was modified in 2021 to focus on the migration seasons. The frequent geese chasing would encourage the geese to relocate to a quieter place and reduce the number of resident geese at Swan Lake.

The Toronto Region Conservation Authority (TRCA) was hired to relocate resident geese from Swan Lake (and Mount Joy Park) and to remove the nests and eggs from the area.

The strobe lights purchased in 2020 at the request of Friends of Swan Lake Park were also 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.

4.2 Geese Count

In 2022, the geese count was completed by the consultant, City staff, and volunteers from the community.

Border Control Bird Dogs recorded the number of geese observed during each visit. Staff counted the number of geese every two weeks, coinciding with the water quality sampling site visits.

Staff also developed a geese count App using ArcGIS Survey123, which a number of residents used to record geese count and note other wildlife observations.

4.3 Results

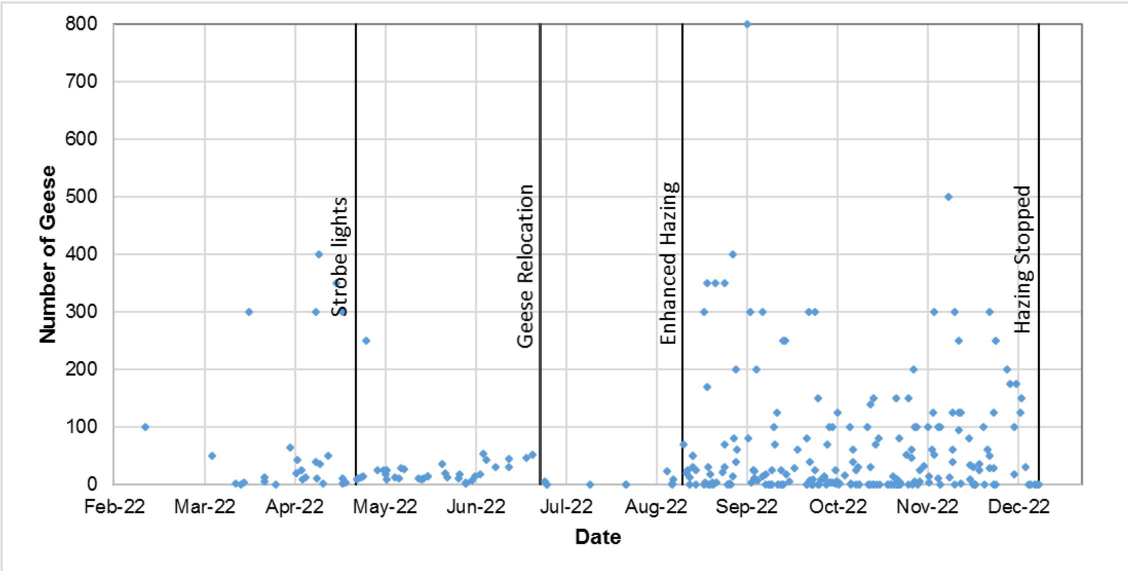
Figure 11 illustrates the number of geese counted at Swan Lake throughout the 2022 monitoring period.

In this figure, a significant increase in geese during the fall months is evident, which occurs when they migrate south; however, the increased hazing frequency (starting on August 15) effectively reduced the number of geese present at different times of the day. Following the enhanced hazing, daily numbers dropped to below 400 and remained much lower than in previous years and similar to 2021. Any impact that strobe lights might have had on the geese count is not readily evident from the data. Limited data are available for June and July when hazing was not occurring.

In addition, six nests and 28 eggs were managed at Swan Lake from late April to early May.

In total, 46 Canada Geese were rounded up from Swan Lake and 25 from Mount Joy Park on June 28, 2022. Fifteen of the birds were goslings. All birds were captured except for adults who could fly away.

Figure 11: 2022 Geese Count Results

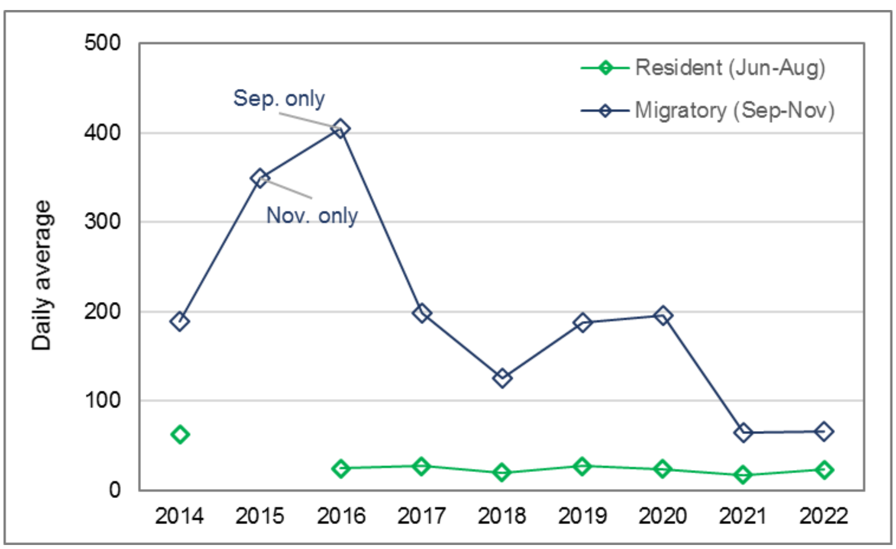


4.4 Historical Trends

Active geese management has been completed annually since 2014. The geese management program focused on resident geese at the beginning and extended to the management of migratory geese in 2016.

Daily Averages of counts are shown for each year in Figure 12. Data are summarized for June to August and September to November, representing resident and migratory geese, respectively. Despite a general increase in geese population in Southern Ontario, the numbers at Swan Lake have been controlled over the past years.

Figure 12: Historical Geese Counts



5. Other Management Activities

5.1 Fish Inventory and Removal

The Long-Term Management Plan for Swan Lake (2021) has a provision for managing bottom-dwelling fish to reduce sediment disturbance.

Similar to 2021, the City hired the TRCA in 2022 to complete a fish inventory and removal operation.

In 2021, three fish species were captured across five different sampling events. The three species were Brown Bullhead (*Ameiurus nebulosus*), which were relocated to Milne Dam, Common Carp (*Cyprinus carpio*), which were euthanatized, and Fathead Minnow (*Pimephales promelas*), which were returned to the Lake.

TRCA completed the 2022 work under License to Collect Fish for Scientific Purposes #1101177 (AU2022-00242). TRCA applied for a Fish Stocking License similar to 2021, but was informed by the Ontario Ministry of Natural Resources and Forestry (OMNRF) that the license would not be granted in 2022 due to the possibility of disease transfer. Instead, OMNRF requested that both Common Carp and Brown Bullhead be euthanized.

The same three fish species as in 2021 were captured during one electrofishing sampling event and one netting sampling event on August 23 and 24, 2022. A summary of the results for both years is shown in Table 6. The timing of the sampling (April vs. August) likely influenced the catch because water temperatures are warmer in August, and fish are less active in cold water.

Table 6: Fish Species Collected from Swan Lake

Date	Fish Species	Number of Fish
April 2021 (3 days electrofishing + 2 days nets)	Brown Bullhead	210
	Common Carp	7
	Fathead Minnow	>10,000
August 2022 (1 day electrofishing, 1 day nets)	Brown Bullhead	80
	Common Carp	20
	Fathead Minnow	875

5.2 Shoreline Restoration

As part of the Parks Refresh program for Swan Lake, herbicides were used on the Phragmites/common reeds in Swan Lake and the two stormwater management ponds, followed by physical removal by an amphibious vehicle. The herbicide application was carried out by licensed contractors working on behalf of the TRCA, following and taking all necessary safety precautions to protect the public. A second application is planned for the spring of 2023.

6. Summary and Conclusions

6.1 Summary of Monitoring Results

Through the Swan Lake monitoring program, data were collected in 2022. The collected data provide insight into long-term trends in water quality and will also help determine the need for and impact of management activities on Swan Lake.

Dissolved oxygen, temperature, and water transparency were measured at two stations through bi-weekly site visits. Profiles of temperature and dissolved oxygen indicated that Swan Lake was thermally stratified in June and in the fall. The minimum dissolved oxygen concentration required for the protection of warm water fish is 5 mg/L, which was met in the surface water and the bottom layer, except on two occasions.

pH measured at the lab ranged from 7.4 to 9.7, with higher values measured between July and September, indicative of high algae concentration.

Transparency at the Dock station was above 0.5 m until the end of June but dropped to below 0.4 m for the remainder of the monitoring period. The proposed interim target for Swan Lake is 0.6-0.8 m based on correlation with the phosphorus target.

Water samples were analyzed for nutrients (phosphorus and nitrogen compounds). Total phosphorus concentration in the 0.5 and 1.5m depth averaged under 50 µg/L during the growing season (June-July) and throughout the year (below the 100 µg/L threshold for a hyper-eutrophic condition).

Total nitrogen concentrations over the growing season averaged about 0.6 mg/ (below the 1.2 mg/L threshold for a hyper-eutrophic condition).

Chloride concentrations in the Lake were within the target range specified for the Lake (between 400 and 500 mg/L), and considerably lower than 2021 values.

Chloride concentrations were also measured in stormwater runoff to the ponds and the Lake (from ponds, OGS's, and overland flow) during snow melt and spring freshet. The data were used to establish a chloride balance and determine the relative contribution of each source to chloride concentration in Swan Lake.

In 2022, limited surface scum was found at both the Dock and Bridge sampling sites; however, the Lake was dominated by phytoplankton. Samples analyzed for cyanobacteria indicated lower diversity and higher total counts than 2021.

The water level at the logger location changed from a maximum of 208.25 m in May to 207.9 in November.

6.2 Management Activities

In 2022, geese management was completed by chasing terrestrial geese by border collies and egg oiling, as well as nest management and geese relocation in the spring. Program frequency was modified in 2021 to focus on the migration seasons. Nine strobe lights were also maintained on the Lake and the two stormwater management ponds. The increased hazing frequency (starting on August 15) effectively reduced the number of geese present at different times of the day to about 50% of numbers in 2020, and comparable to those in 2021. Any impact that strobe lights might have had on the geese count is not readily evident.

Fish management and the removal of bottom-dwelling fish was completed by the TRCA, and 80 Brown Bullhead and 20 Common Carp were captured and euthanized. About 900 Fathead Minnow captured were released to the Lake.

As part of the shoreline restoration program, herbicides were used on the Phragmites/common reeds in Swan Lake and the two stormwater management ponds, followed by physical removal by an amphibious vehicle.

6.3 Conclusions

Based on the measured nutrient concentrations in 2022, Swan Lake is classified as a low-eutrophic condition. Figure 13 provides a summary of phosphorus concentrations for all the years with available data.

Overall, the management activities in 2021/2022 that focused on the significant nutrient loadings identified in the water quality management plan (i.e., chemical treatment and fish management to reduce internal loads and geese management to reduce external loads), were effective at improving water quality in the Lake as shown by reduced phosphorus concentrations and improved dissolved oxygen levels. These improvements represent a positive step towards improving the aquatic habitat in the lake and meeting the long-term water quality goals.

In 2022, chloride levels decreased considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake.

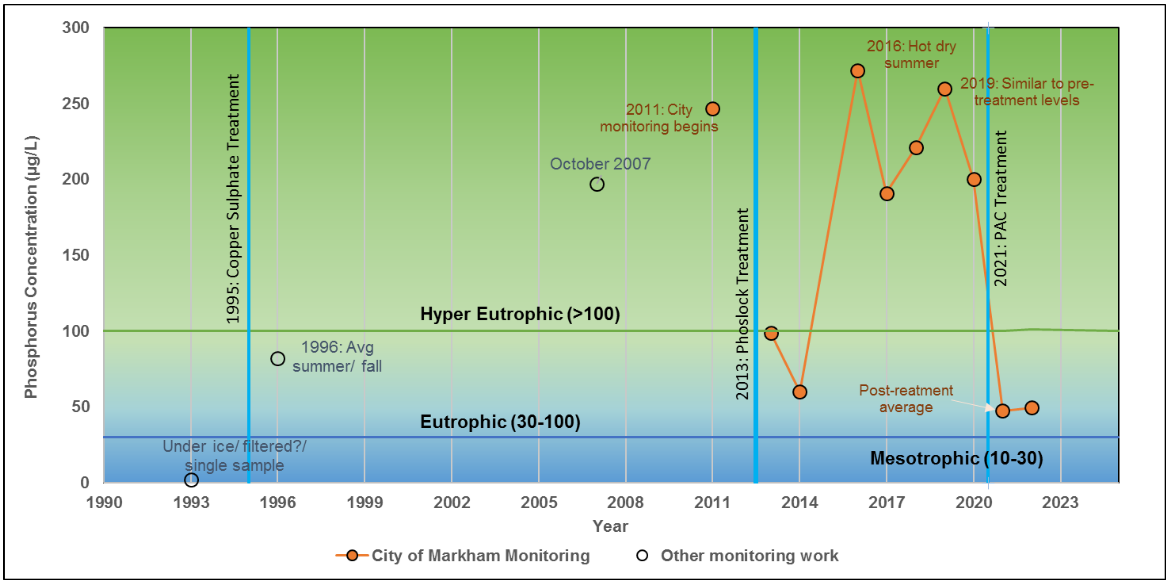
While internal and external source controls successfully reduced nutrient concentrations, the Lake was dominated by phytoplankton, and water clarity did not improve.

This could be partly due to the absence of submerged aquatic vegetation (SAV), which has been replaced by phytoplankton (algae) due to low water clarity.

The 2023 monitoring program will follow the recommendation of the Long-Term Management Report. In addition, continuous dissolved oxygen loggers will be considered at the monitoring sites to evaluate potential anoxic episodes at night and better determine periods of transient stratification and bottom anoxia as they relate to internal nutrient loads. This information can inform the nutrient budget for the lake and future chemical dosing requirements. Phytoplankton taxonomy will also be expanded to include all taxa to provide additional information on phytoplankton dynamics and support future management decisions.

Additional measures will be investigated for the return of SAV to the Lake, as well as the evaluation of cost and feasibility of treatment options to reduce chloride concentration and improve oxygen levels in the Lake.

Figure 13: Trophic State Classification for Swan Lake based on Phosphorus Concentration



Appendix A : Swan Lake Water Quality Inspection Forms

Appendix B : Certificates of Analysis

Attachment B- Review of Research Initiatives

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Date:
April 18 2023

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Senior Environmental Engineer, Stormwater
City of Markham

CC:
Robert J. Muir, M.A.Sc., P.Eng.
Manager, Stormwater
City of Markham

Memo

Subject: Calcium Peroxide and Biochar Proposals - Review

I have completed a technical review of proposals prepared for the Friends of Swan Lake Park (FSLP) to study the potential for using calcium peroxide and biochar to help address water quality issues in Swan Lake, including:

1. Calcium Peroxide: *Development of a Scope of Work for Research into Water Quality on Swan Lake*, prepared by Barbara Siembida-Lösch (Fleming College Centre for Advancement of Water and Wastewater Technologies)

This project proposes to perform laboratory-scale testing of chemical oxidation to increase dissolved oxygen (DO) concentrations in Swan Lake using calcium peroxide (CaO_2). The experimental design involves the comparison of water and sediment quality in a control tote and a treatment tote over a 4 to 6-week incubation period. The totes would be filled with surficial sediments (top 40 cm) and water collected from Swan Lake, with granular-grade CaO_2 added to the surface of the sediments in the treatment tote. Water and sediments would by analyzed for a comprehensive suite of water quality parameters to evaluate the effectiveness of the treatment to increase DO over time and changes in other key variables of interest including nutrients (phosphorus and nitrogen), metals, and pH.

2. Biochar: *Research Into Removal of Nutrients and Chlorides from Swan Lake,* prepared by Rama Pulicharla and Satinder K. Brar (York University), May 2, 2022.

This project proposes to develop and test biochar as an adsorption technology to remove nutrients (nitrogen, phosphorus, and chloride) from Swan Lake water. The experimental design includes monitoring and characterization of Swan Lake water over one month and a series of laboratory experiments to identify critical parameters to achieve optimal nutrient adsorption efficiency and determine potential of using biochar at scale for Swan Lake.

To support the review of the proposals, other related documents were reviewed including:

- *Literature Review of Potential Engineering Solutions for the Restoration of Swan Lake*, Report prepared by Barbara Siembida-Lösch, Fleming College, for Friends of Swan Lake Park, February 2021
- Memo from Gertrud Nürnberg, Freshwater Research (FWR) to Rob Grech, City of Markham dated 2021-04-08 (revised) regarding the *Evaluation of the recommendations by the Friends of Swan Lake Park, as summarized in an e-mail by Markham staff on March 25, 2021*

Review Comments – Calcium Peroxide Proposal

Rationale for Study

The proposal provides a review of background research on the use of CaO_2 as an oxygen release compound citing multiple research papers that document improved DO concentrations in surface water and sediments, as well as evidence for additional benefits including reduced organic matter in surface sediments, reduced phosphorus release from sediments, and precipitation of phosphate from water. The review also cited research on the need to modify the CaO_2 to cause the product to sink, release oxygen more gradually, and reduce high pH caused by the dissolution of CaO_2 in water.

Apart from one study on a pond in Finland, all the cited research was based on laboratory scale investigations and on water and sediment from "black water" waterbodies in Asia. These black water waterbodies are urban streams that receive domestic sewage and have exceptionally high concentrations of nutrients and bacteria which give the water its black colouring. The water and sediment quality of black water waterbodies differs substantially from that of Swan Lake, and therefore the cited research does not assess the feasibility of using CaO_2 at Swan Lake to increase dissolved oxygen (DO). The proposed research, therefore, would be needed to advance the understanding of the potential treatment capabilities of CaO_2 in Swan Lake, if warranted following ongoing measures that have increased DO concentrations.

Experimental Design, Chemistry and Potential Impacts

Overall, the proposed scope of work is well designed and is a common approach used to evaluate chemical treatments in a laboratory experiment. I offer the following comments on potential limitations of the proposed research and recommendations for consideration to improve the experimental design.

1. The study proposes to collect 1000 L of surface sediment (top 40 cm) from Swan Lake that will be transferred to two totes for the experiment. Mixing of the sediments during collection and transfer to the totes would homogenize spatial differences in sediment quality but would also alter the vertical sediment structure which could influence the results of the experiment with implications for the expected response of the treatment if it were to be applied to the lake. The geochemistry of Swan Lake sediments varies with depth from 0-10 cm as illustrated in the sediment quality/phosphorus fractionation analysis by Freshwater Research (2021). The sediment collection method would likely cause the loss of the highly flocculant and organic sediments at the sediment water interface in the lake. Furthermore, geochemical differences in the sediments at various depths due to previous chemical treatments [Phoslock® and polyaluminum chloride (PACL)] would be destroyed. As the CaO_2 will be applied to the sediment surface, the altered sediment characteristics due to mixing during sample collection may influence the results of the study.

   An alternative study design could be to collect the samples with sediment core tubes and to perform the experiment on the undisturbed sediments in the tubes. This approach, however, may limit the volume of sediment and water needed to perform the full suite of chemical analyses that is proposed. Core tube incubation studies could also be done alongside the totes with the analysis of a reduced set of parameters to document potential differences between the intact and mixed sediments.

2. Granular grade CaO_2 will be applied to the surface of the sediments in the totes. Calcium peroxide increases pH when added to water, which may have unintended consequences for aquatic toxicity and increased internal phosphorus loading.

   – Swan Lake has elevated pH that has exceeded the Provincial Water Quality Objective of 8.5, in part due to high photosynthetic activity of algae. A further increase in pH can therefore be detrimental to aquatic life.

   – Aluminum (Al) and lanthanum (La, in Phoslock) form a stable bond with phosphorus in sediment and water that is not sensitive to anoxia, but dissolution of these compounds occurs at high pH. Aluminum can be mobilized at a pH ~>8.5 (Reitzel et al., 2013) and the phosphorus adsorption capacity of lanthanum decreases at a pH >9 (Ross et al., 2008). Increasing pH at the sediment-water interface with the addition of CaO_2 could promote this dissolution causing the release of phosphorus from the sediments and potential toxicity due to dissolved aluminum (and other pH sensitive metals). Furthermore, the potential for mobilization of these metals at high pH is increased in shallow lakes that are prone to sediment resuspension like Swan Lake. The mixing of the sediments and the resultant dilution of La and Al in the proposed experimental design may mask the potential negative effect of the treatment on the phosphorus binding capacity from previous chemical treatments in the lake.

– Using a modified CaO_2 product that buffers pH may be appropriate for the experiment to avoid potential issues with high pH.

3. Calcium peroxide is a strong oxidant. When added to water, it dissociates to produce oxygen gas (O_2) that could help to prevent anoxia. While the dissociation of CaO_2 directly produces O_2, it may also produce H_2O_2 (peroxide):

$$CaO_2 + H_2O \rightarrow Ca(OH)_2 + \tfrac{1}{2}O_2 \qquad \text{(Equation 1)}$$

$$CaO_2 + 2H_2O \rightarrow Ca(OH)_2 + H_2O_2 \rightarrow Ca(OH)_2 + H_2O + \tfrac{1}{2}O_2 \qquad \text{(Equation 2)}$$

– Peroxide at the sediment surface could negatively impact the microbial community. Bacteria are highly susceptible to oxidation by peroxide, which is why peroxide has been used as an algaecide to treat cyanobacteria blooms. Heterotrophic bacteria play an important role in aquatic ecosystems, thus changes in the abundance or composition of microbial communities could potentially affect biogeochemical cycles, nutrient availability, and water quality. At high concentrations, peroxide can also potentially affect benthic invertebrates and zooplankton.

– Peroxide would degrade organic matter in the sediments, which would release phosphate. It is not clear from the research presented in the background review whether or not the calcium hydroxide ($Ca(OH_2)$) released by the CaO_2 dissolution would be sufficient to bind the phosphorus that is released.

– It is noted that peroxide production by the dissolution of CaO_2 declines as pH (and temperature) increases, therefore if a buffered CaO_2 is used to prevent potential toxicity and nutrient release at elevated pH, higher concentrations of peroxide could be generated with negative impacts on aquatic biota.

4. The dosage that will be used in the experiment has not been well defined with a proposed dosage of 100 g CaO_2/m^2 or 1000 g CaO_2/m^2. These doses appear to be based on the background research projects on sediments and water from black water waterbodies, which may not be appropriate for use in this experiment. Calculations using oxygen demand of the sediments and water in Swan Lake, or jar tests may be helpful to determine dosages specific to Swan Lake.

5. High phytoplankton concentrations in Swan Lake can cause large diurnal changes in pH and dissolved oxygen of the water and contribute to the deposition of organic matter to the sediments as cells die and sink to the bottom. These effects could affect the dosage and efficacy of the CaO_2. Swan Lake also undergoes mixing that can cause sediment resuspension, potentially causing the CaO_2 granules to become suspended or redistributed, which would also affect dosage and efficacy. The study design cannot account for the effects of phytoplankton, mixing and sediment resuspension, and other lake processes that vary over time, supporting the need for future study if the results of this project are positive.

The proposal includes optional bench-scale testing to determine the different phosphorus forms that are present in the sediments, through a bioavailable phosphorus assay (or phosphorus fractionation). In 2020, multiple lake cores were collected from Swan Lake, and this analysis was performed at a laboratory in Germany (Freshwater Research, 2021). The results of this study were then used to determine the necessary dosages for the chemical treatment of the lake in 2021. It would be preferred if the researchers at Fleming College could conduct this analysis in the future, rather than sending core samples to Germany. The next chemical treatment is scheduled for 2024, and there is likely to be minimal sediment accumulation since the previous analysis. Therefore, repeating the analysis before the 2024 chemical treatment would not yield much benefit. The 2020 cores showed that La from the Phoslock treatment in 2013 was mostly present in the upper 5 cm of the sediment cores, indicating an accumulation of only ~5 cm of sediment over seven years. The mobile sediment fraction in the recently deposited sediments (~2.5 cm) for dosing requirements in 2024 could be approximated using the 2020 results.

General Comments and Recommendations

The proposed scope of work has technical merit, and the study would help to advance the understanding of the capability of CaO_2 to increase DO in water from Swan Lake. While the research would answer many questions about the treatment potential of CaO_2, it is anticipated that additional study will be required to fully understand the advantages of the treatment and potential negative effects on aquatic biota and nutrient cycling before this product could be considered for full scale use at Swan Lake. The additional research may include more laboratory-scale testing and lake mesocosm studies. The latter would likely be needed to account for the complex physical, chemical, and biological processes in Swan Lake that could affect, or be altered by, the treatment, and the lack of such studies in other similar waterbodies. This means that it could be some time (several years) before all the necessary research is completed and enough data could be gathered to support the use of CaO_2 in Swan Lake.

A key consideration for the feasibility of using CaO_2 in Swan Lake is its impact on prior and future chemical treatments involving Phoslock and/or PACL. The previous chemical treatments were highly successful in decreasing total phosphorus levels in Swan Lake, and the binding of phosphorus by La and Al in the sediment remained stable under anoxic conditions, which reduced internal phosphorus loading from the sediment. However, as previously mentioned, the high pH generated by CaO_2 may cause the release of previously immobilized phosphorus in the sediment. While the proposed experiment will provide some data on the pH effects at the tested CaO_2 dosage, core incubation studies and/or lake mesocosm studies would be necessary to confidently assess the potential mobilization of La and Al-bound phosphorus from the previous chemical treatments in the lake.

The proposal correctly notes that anoxia is a primary driver of internal phosphorus loads from sediments such that preventing anoxia through chemical oxidation could help to reduce phosphorus concentrations in the lake. Following the PACL application in 2021, however, anoxia was not detected during the City's water quality monitoring in 2022, and water column DO concentrations were improved over pre-treatment conditions to above water quality minimum guidelines for the protection of aquatic life on all but two sampling events. It is possible that anoxia develops at night due to respiration of algae or during extended periods of calm weather that were not captured by the monitoring. The City plans to install continuous data loggers to document the occurrence of anoxia more fully. If oxygen levels/anoxia is not problematic, or only occasionally problematic, then chemical oxidation using CaO_2 may not provide substantial benefit. As the City continues to implement nutrient reduction strategies, it is anticipated that DO issues will continue to decline as algae levels are reduced over time. It should also be recognized that anoxia is not the only driver of internal phosphorus loading. Decomposition of newly deposited organic matter to the sediments by bacteria (or degradation by peroxide) can also cause the recycling of phosphorus.

If the ongoing efforts to improve DO concentrations fail to meet the approved targets, and if the City decides to move forward with the proposed scope of work, it is recommended that the study consider a core tube incubation approach instead of, or in addition to, the tote reactors. Also, initial jar testing or other bench-scale test could be completed before moving forward with the experiment to first determine the potential impacts of the CaO_2 on pH at the dosages needed to produce enough oxygen to prevent anoxia in the Swan Lake water. If elevated pH is found to be problematic, then the researchers could consider a buffered CaO_2 product for testing.

Review Comments – Biochar Proposal

Rationale for Study

The research proposal's introduction presents a summary of nutrient pollution, its sources, and its impact on water quality, emphasizing the need for the development of innovative technologies to reduce nutrient pollution. However, biochar is not described and only one refence is provided on the use of biochar, and it was a lab-scale study that examined nitrogen and phosphorus removal by magnesium-amended biochars. A rationale for the potential use of biochar to remove chloride was not provided.

Biochar is a type of charcoal that is produced by heating organic material, such as wood, municipal sludge, or agricultural waste, in the absence of oxygen at high temperatures. It is known to have a range of beneficial effects on soil health, including improving nutrient retention and reducing soil erosion, and for removing a variety of contaminants such as volatile organic compounds, heavy metal ions, pesticides, pharmaceuticals, dyes, and polycyclic aromatic hydrocarbons from soils and wastewater (Qiu et al., 2022).

There is a growing interest in the potential use of biochar as a management tool to address nutrient enrichment in surface waterbodies based on laboratory research documenting its ability to adsorb nitrogen and phosphorus (Jiang et al., 2019; Zhu et al., 2020; Wang et al., 2021; Qin et al., 2022; Xu et al., 2022). This research has determined that pristine biochar typically has a low capacity to adsorb phosphate, however, the adsorption capacity can be increased significantly by modifying the biochar with metal oxides of aluminum, iron, magnesium, and others. Similarly, recent laboratory testing and modeling suggest that biochar can adsorb chloride ions and the adsorption capability depends on the type and density of functional groups on the biochar surface (Phalavan et al., 2023).

Research, such as the proposed study, is needed to evaluate the effectiveness of biochar in reducing phosphorus, nitrogen, and chloride levels in surface water that considers several factors including the specific characteristics of the water source, the type and amount of biochar used, and the application method. Additionally, research will be needed to investigate potential environmental concerns such as toxicity of aging biochar and the desorption of adsorbed pollutants (Qiu et al., 2022). Biochars can contain high levels of heavy metals and free radicals that can pose a threat to the environment, which also needs to be tested before its usage (Srivatsav et al., 2020).

Experimental Design, Chemistry and Potential Impacts

Overall, the researchers have presented a well-designed experiment that will answer key questions on the use of biochar to remove nutrients. I have some remarks on the proposed study and suggestions for the experimental design for your consideration, as follows:

1. The project includes monitoring at Swan Lake (twice a week for one month) to characterize water quality. The City has been monitoring water quality at Swan Lake for several years, and the monitoring has included most of the parameters that are proposed for the study. The City's data set would provide a better representation of the variability in water quality characteristics of Swan Lake over the growing season than intensive monitoring over one month and may be more relevant to evaluate biochar treatment needs. To reduce costs, the proposed monitoring could be scaled back to capture parameters not regularly monitored by the City or to include fewer sampling events. Alternatively, the City's program could also be expanded in the proposed study year to fill in data gaps, if necessary.
2. The study proposes to analyze nitrogen, phosphorus, and chloride, in the Swan Lake water and in the influent/effluent of the lab-scale filter experiment. The analytical methods for these parameters, the nitrogen and phosphorus species to be analyzed, and the laboratory detection limits were not provided. It is recommended that the analysis include total phosphorus, soluble reactive phosphorus, ammonia-N, nitrate-N, nitrite-N and total Kjeldahl nitrogen which are relevant to eutrophication, with methods and detection limits suitable for lake water.
3. The proposed biochar testing methods (characterization, dosing, and column tests) have been used previously by Dr. Brar for similar research projects that have been published in peer-reviewed scientific journals, providing confidence that the project will provide the data needed to answer the proposed research questions. However, for the lab-scale filter test, Swan Lake water samples will be spiked with nutrients (N, P, Cl^-), which is reasonable to test the biochar performance at higher nutrient concentrations that could occur in the Lake. The proposed concentrations (1 – 10 mg/g), however, are exceptionally high and not representative of the concentrations in Swan Lake. It is recommended that the test be run on Swan Lake water without nutrient spiking and spiked with a much lower concentration of nutrients. While it is understood that the goal of this test is to determine the normalized concentration (i.e., % removal efficiency)

which can be done with high spiked concentrations, the removal efficiency of the biochar may be different at the lower concentrations observed in lake water. It is also noted that the test may not determine the removal efficiency of different nitrogen and phosphorus compounds, depending on the spike compounds, which could have implications for assessing its effectiveness for application in a lake setting.

4. The aim of the research project is to examine the effectiveness of biochar on Swan Lake water. However, for potential future applications, it may be pertinent to also conduct the test on stormwater runoff to the lake, particularly if the biochar is shown to effectively remove chloride. Removing chloride before it enters the lake during high chloride loading events, such as the spring thaw, would be highly beneficial in preventing elevated chloride concentrations in the lake.
5. Biochar can contain heavy metals that if released in water, could pose a concern for environmental toxicity. The biochar characterization and adsorption capacity tests could include analysis of heavy metals to evaluate the potential for metals release to water.

General Comments and Recommendations

The proposed scope of work is well designed, and the results of this research would be valuable to determine the effectiveness of the biochar product to remove nutrients under real water conditions at Swan Lake. The researchers have rightfully pointed out that this type of study is necessary before conducting pilot or field-scale experiments or contemplating the product's full-scale application in a lake. If the results indicate good nutrient removal capability of the biochar, additional research could lead to the development of a valuable lake management tool. This is especially the case for chloride removal as there are presently no cost-effective and feasible technologies to remove chloride from freshwater bodies.

If the City decides to move forward with the proposed scope of work, it is recommended that the project be revised to study both the lake water (to remove existing chloride) and runoff (to control runoff input). Furthermore, it would be of interest to include a desorption test to evaluate the potential for the release of nutrients, metals, or other contaminants of concern from the biochar with aging in Swan Lake water and stormwater.

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Friends of Swan Lake Park

Three steps to restoration

From this

Back to This

Markham Subcommittee
May 11, 2023
2:00 – 4:00 pm

Thank You to Staff

- Focused, dedicated effort obvious and appreciated
- Consistently provide prompt, courteous guidance on regulatory issues and on information needed to clarify questions
- Following up on research proposal from York U and Fleming College

Differences Remain

A) Differences in Goals – "Restoration" vs "Containment"

- FOSLP supports current plan as a "building block" but view it as insufficient in breadth and scope
- Ultimately Council needs to arbitrate issue – core decision for Council
  - following independent/objective guidance from Workshop

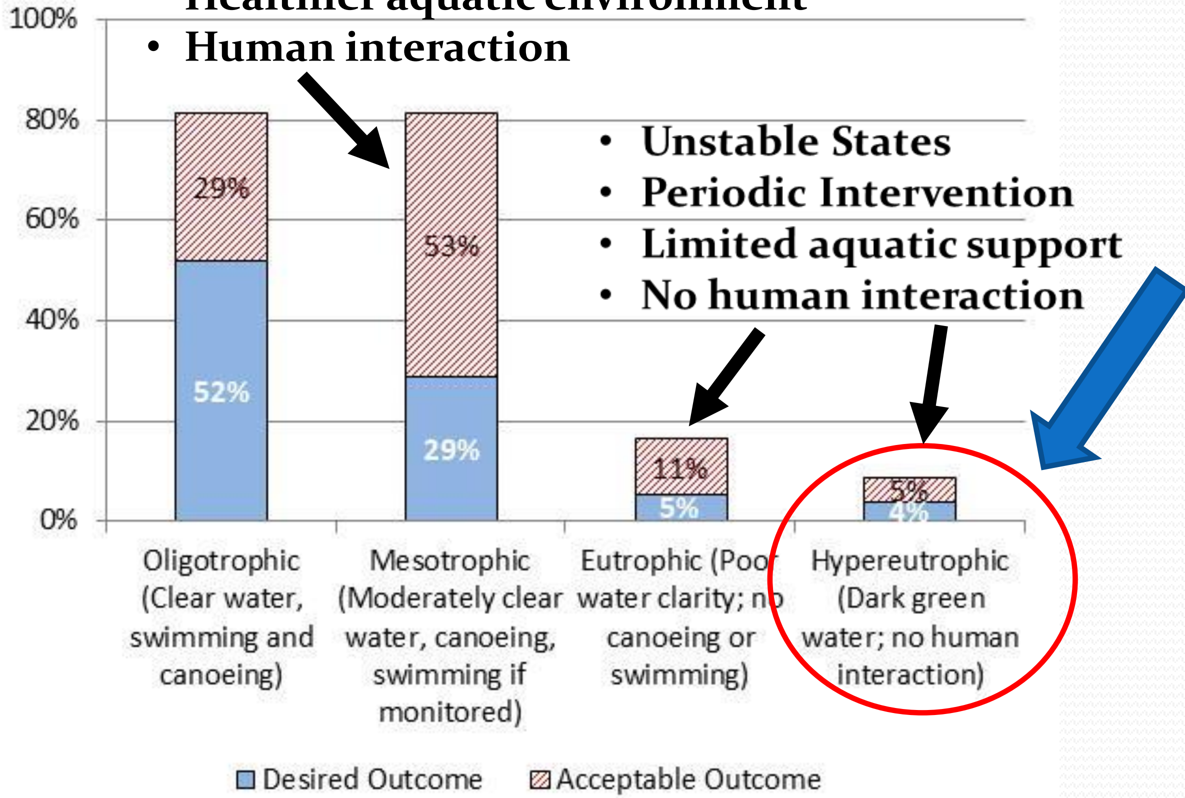
B) Differences in style

- Some proposals rejected due to obstacles/ issues (which are valid) however analysis of "benefits" missing so can't assess whether cost/benefits warrant addressing the challenges
  - eg: drawdown and sediments
- Investigate and understand the benefits – that may justify the challenges
  - Hutchinson Environmental proposal

FOSLP Survey March 2021 (367 Respondents)

Community Support For Restoration

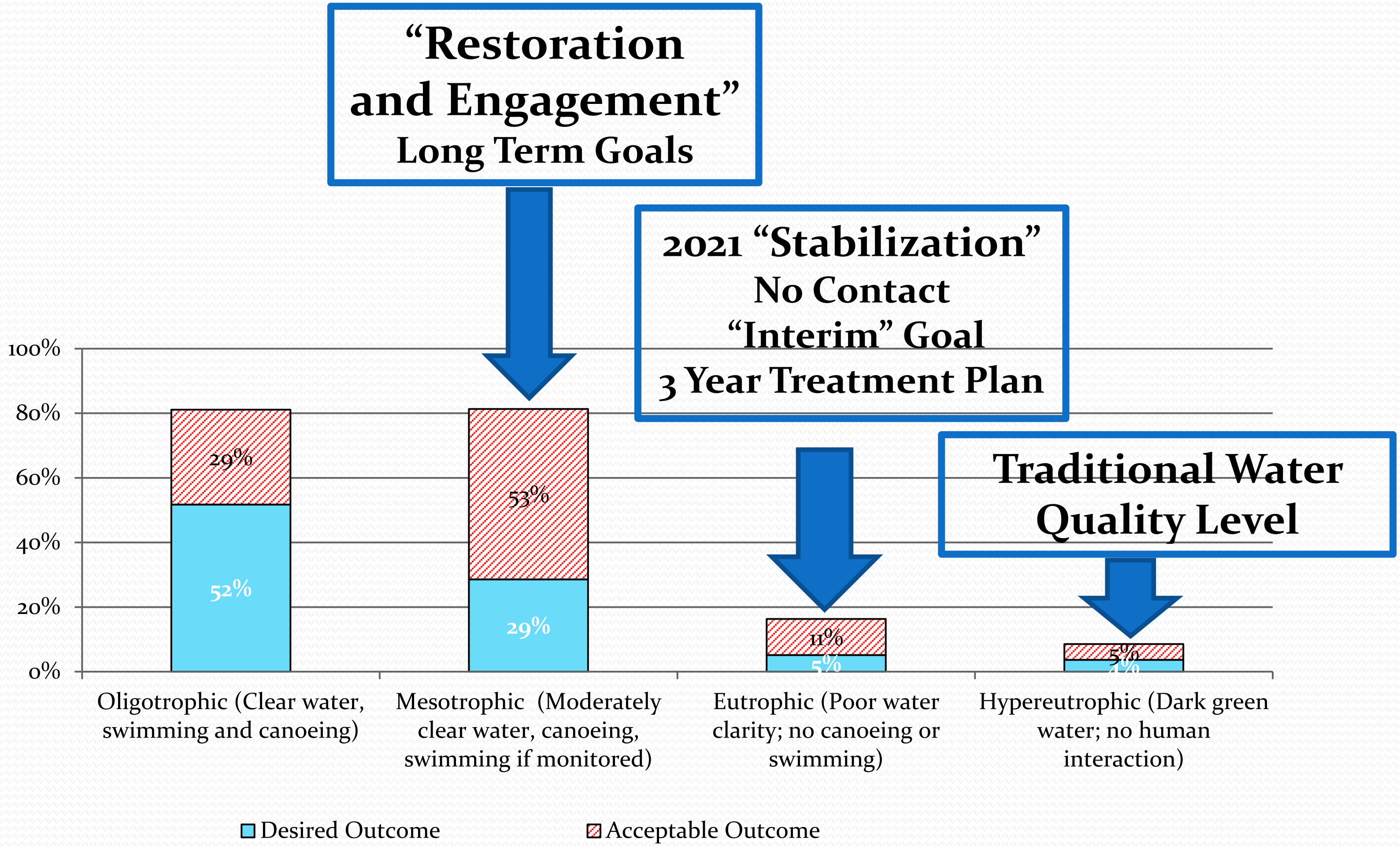
- More stable
- Natural balance
- Less Intervention
- Healthier aquatic environment
- Human interaction



Swan Lake has poorest water quality rating

Workshop: Independent, Objective Guidance

What Level of Water Quality Achievable?/ At What Cost?



FOSLP Initiatives 2022 - 2023

1) 2023 Report: Primary Conclusions:

   "Towards a Comprehensive Restoration Plan for Swan Lake"

   a) Need a "comprehensive" plan that addresses all issues
   b) Rerouting stormwater an essential step (**Support Flow Diversion Study)**
   c) Winter drawdown of lake an effective tool for removal of chloride
      - Other alternatives available
   d) Cost/benefits of removing at least some of sediments needs to be investigated

2) Markham should host a multi-disciplinary ***"Solution Workshop"*** in Jan/Feb 2024 to narrow down options

   a) Following a "Peer Review" by Workshop participants, Staff should submit a Comprehensive Plan in 2025/2026

3) **Research Proposals**

   a) University of Toronto 2) Hutchinson Environmental

Three Steps to Sustainable Restoration

STEP # 1
Keep Bad Stuff Out
Add Oxygen Source

- √ Geese Management
- √ Shoreline Restoration
- ? Reroute Stormwater
- X Add Oxygen Source

STEP # 2
Remove Bad Stuff
From the Lake

- √ Chemical treatment (phosphorus removal)
- X Removal of chloride
- X Removal of Sediments

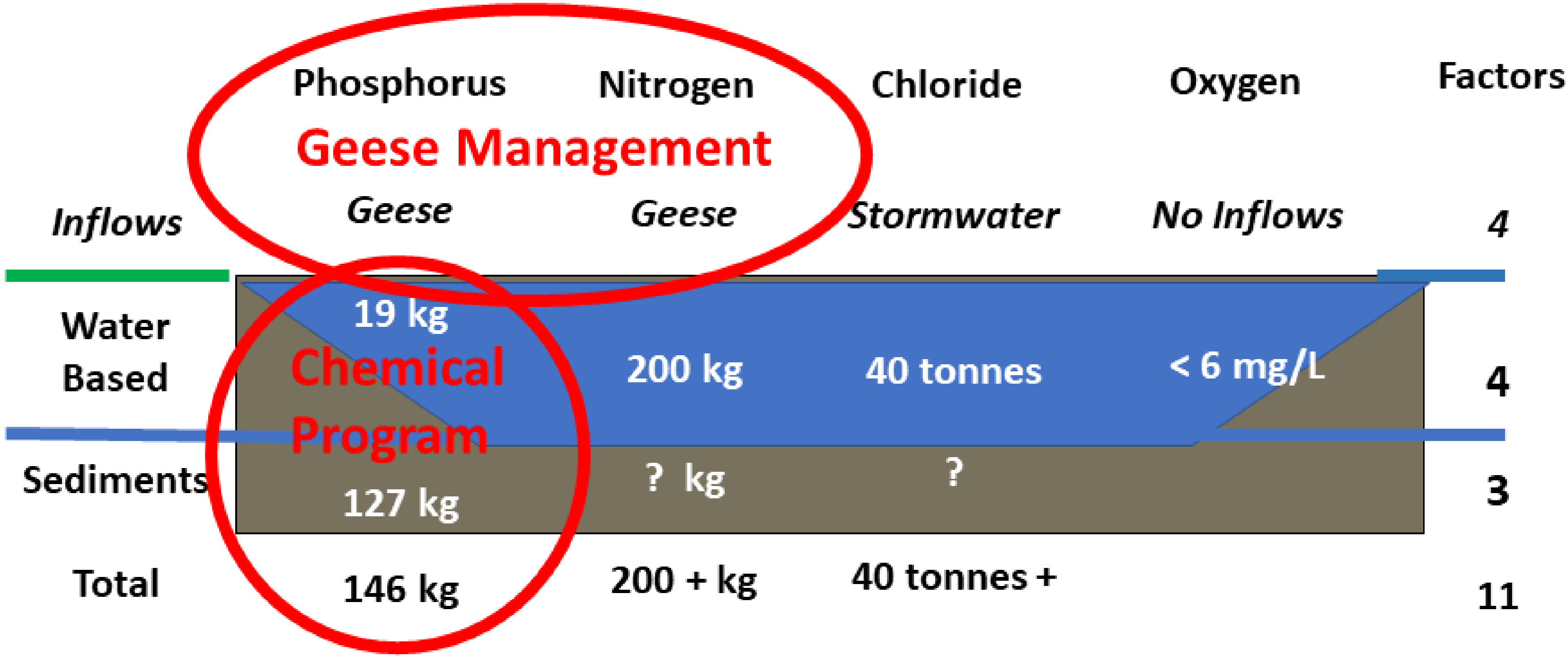
STEP # 3
Keep It That Way

- X Oxygenation
- ? Restore aquatic life
- X Periodic removal of contaminants

√ Current program ? Program Under Consideration X No Current Program

2023 Report Focus: Step #2 – removing the bad stuff
Step #3 – dependent of decisions made in Step #2

11 Factors Influencing Restoration



- **Not all factors of equal importance**
- Phosphorus centric program deals with only 4.5/11 factors

Independent researchers note the importance of addressing chloride and oxygenation

Why Revisit Processes Previously Dismissed?

Following FOSLP 2020 report, Freshwater Research/staff rejected three of the concepts we revisit:

1) **Aeration, Oxygenation** – mixing of layers may "fertilize upper layers and increase algae bloom"
   - Recent research questions significance of oxygen levels on phosphorus release
   - Observers - lake naturally mixes so already a factor. U of T research may clarify impact
   - Analysis did not address "post-restoration role"
2) **Withdrawal of water** – "inefficient process"
   - True if only dealing with phosphorus since it doesn't impact sediments
   - May be only means of reducing predominantly water-based chloride
   - Plan offers no direct-action plan
3) **Sediment removal** – Dredging expensive and potential "toxic" sediments in Block 9
   - Illustrated that low-cost options available once water withdrawn
   - Not stirring water, sediments removed from dry lakebed/ work around Block 9

Processes rejected in a "phosphorus centric program" may have a role in a comprehensive solution

Primary FOSLP Recommendation:

Independent Guidance: Solution Workshop

Goal: Multi-disciplinary guidance for Comprehensive Plan

Expected Outcome: Guidance to Council

- What level of water quality is achievable & sustainable?
- At what cost?

Participants:

Independent Facilitator, Limnologists (2), Biologists (fish & aquatic plant), Water Resource Engineer(s), Sediment Specialist, Markham, FOSLP

When: January/ February 2024

- **Combined with engineering and research findings, guidance for development of a comprehensive plan**
- **Peer Review in 2025**
- **Submission to the Committee review in 2026**

Workshop Guidance:

Four Critical Decisions For Council/ Community

1) What level of water quality is attainable and at what cost?
2) Is it worth investing to reroute stormwater?
3) Is drawdown of lake beneficial & can it be managed safely?
4) Is it worth investing to remove sediments?

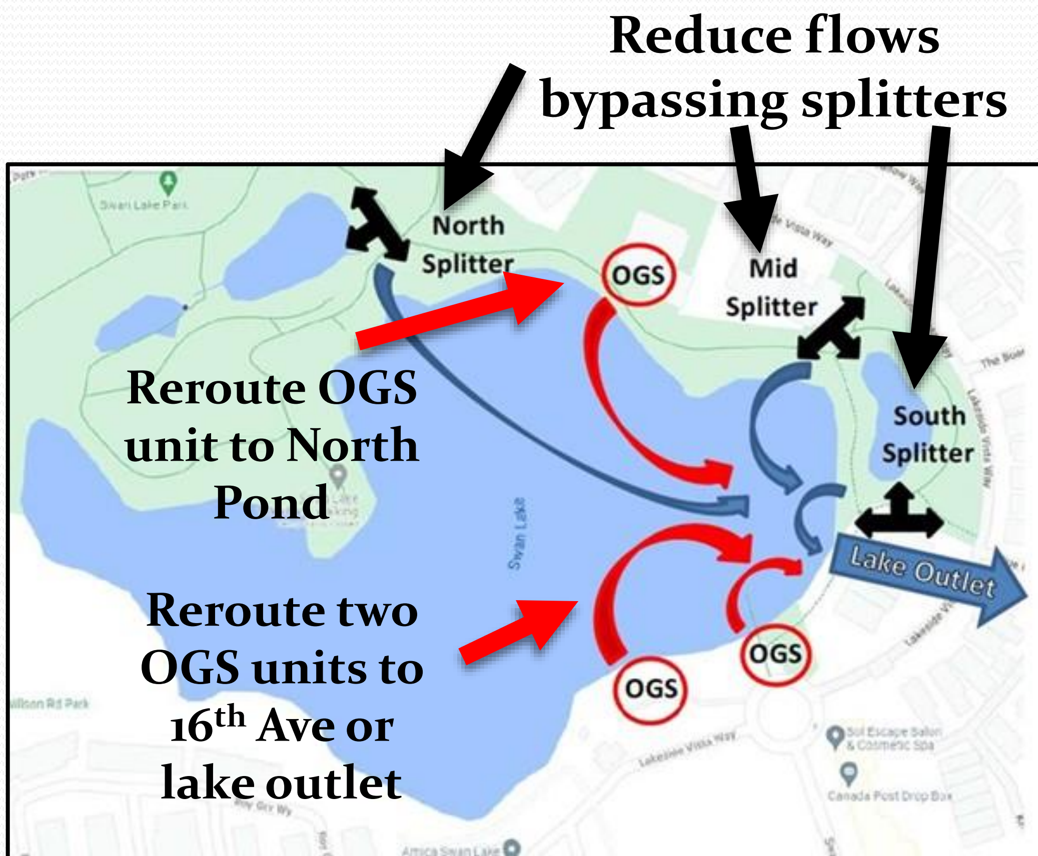
Required: Cost/ Benefit Analysis for each decision

a) Cost of solution
b) Ecological Benefits:
   - Better outcomes (timing, quality, sustainability)
c) Cost avoidance opportunities
   - Minimize chemical treatment, monitoring costs

Critical Decision:

Is It Worth Investing to Reroute Stormwater?

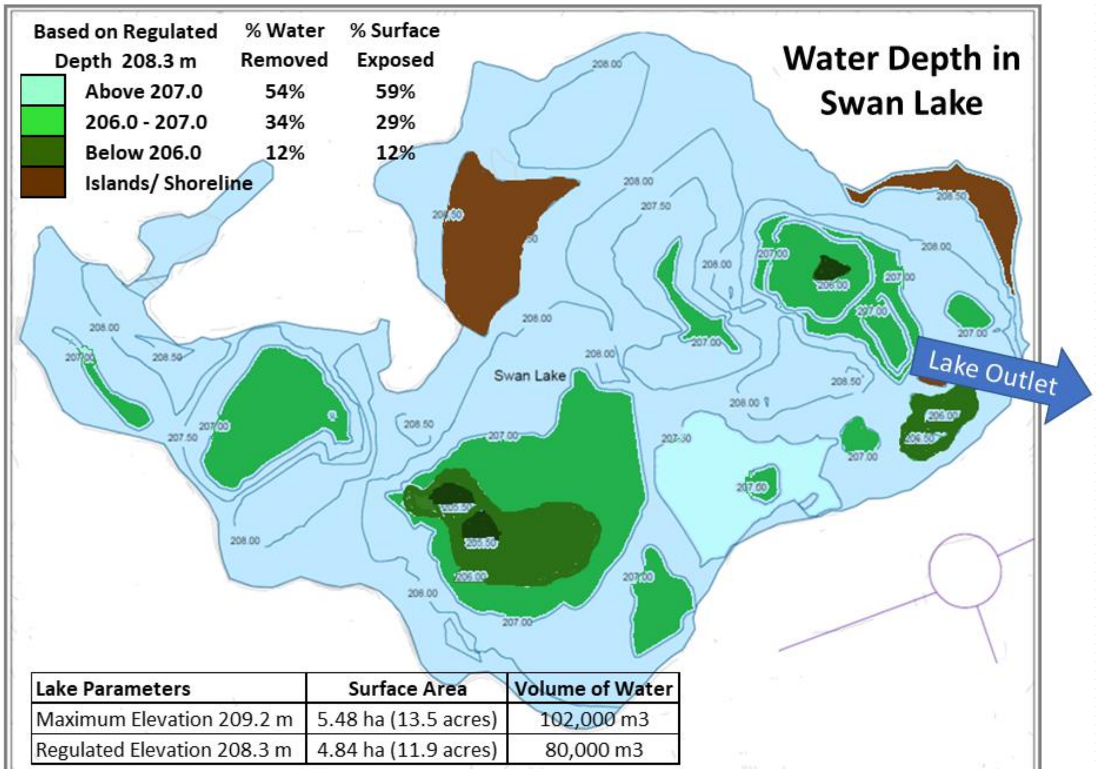
- Flow Diversion Feasibility Study (2024)
- Expected annual flow reduction (currently 3 - 5 tonnes)?
- Expected costs?
- When?
- Ecological benefits?



Critical Decision:

Is Winter Drawdown Beneficial/ Can It Be Done Safely?

- Low-cost solution for chloride in water
- Other benefits?



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

Issues:

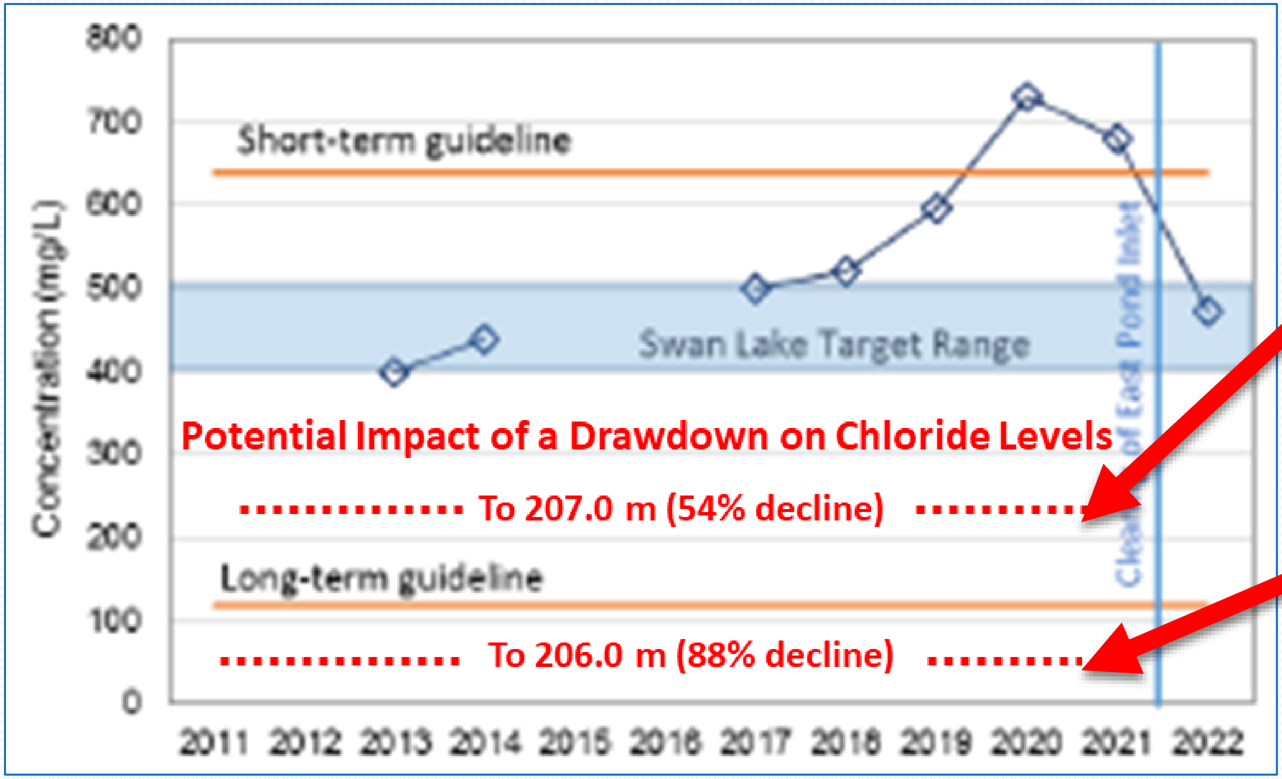
(1) Minimize impact on aquatic life
(2) Downstream concerns
(3) Time/process to refill
(4) Regulatory clearance
(5) When?

Long-term Option?

Partial drawdown every 10 years (?) as a possible management option for removing chloride

Drawdown Immediate Impact on Chloride

A low-cost gravity drawdown removes over 54% of chloride, phosphorus and nitrogen active in the water

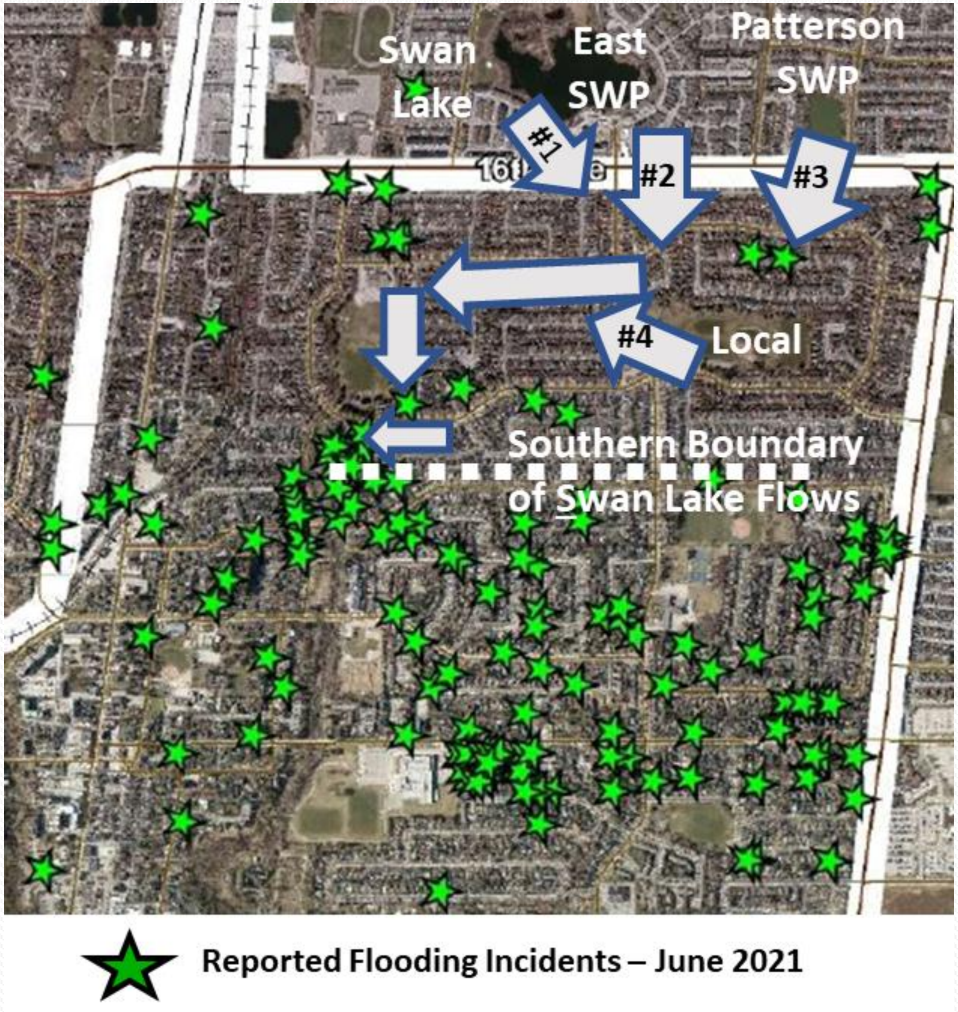


54% drawdown chloride level immediately below Target Range

88% drawdown chloride levels below Federal guidelines

Managing Flooding Concerns

- Swan Lake only 1 of 4 systems contributing to flows south of 16th Ave.
- Few reports of flooding in area that manages Swan Lake flows
- Lake outflows can be controlled to periods with no rainfall in the system from other areas



Regulatory Challenges of Drawdown

Two notable exceptions:

1) Markham Sewer Use By-law 2014-71 (no chloride constraints) - many in excess of PWQO
   - Swan Lake would qualify
2) Removal of water from stormwater ponds permitted for cleaning

Ontario water management: policies, guidelines, provincial water quality objectives (PWQO):

- Policy 1: In areas which have water quality better than the PWQO, water quality shall be maintained at or above the Objectives.
- Policy 2: Water quality which presently does not meet the PWQO shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the Objectives.

Swan Lake Goal: Align with PWQO

- Our mesotrophic phosphorus goal
- Align chloride with Federal Guidelines

Parameter	PWQO/ CCME	Mt. Joy Creek*	Swan Lake
Total phosphorus	30 µg/L	70 µg/L (policy 2)	>100 µg/L (pre treatment) 50 µg/L (post treatment)
Dissolved chloride	120 mg/L	350 mg/L (policy 2)	~ 500 mg/L in 2022

* Rouge River in Box Grove; average of values for 2014-2018 (latest 5-year of available data)

Case: Short-term Pain for Long-term Gain

Currently: Swan Lake a perpetual source of contaminated water to aquifer and Rouge system

Goal: Improved water quality in Swan Lake a long-term benefit for the Rouge system and local wildlife

Hutchinson analysis on benefits of drawdown

Alternatives if Drawdown not Feasible

- Drawdown most impactful and lowest cost but there are other options to consider

Comprehensive Water Based	Nutrients P	N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
a) Recycling & Filtration via North Channel	1	1	1	1	4/11	10+ years	$$
b) Industrial Filtration (Partitioning)	1	1	1	1	4/11	1 year	$$$$
c) Industrial Filtration (Recycling)	1	1	1	1	4/11	1 year	$$$
d) Drawdown	1	1	1	1	4/11	1 - 3 years	$

Focused Solutions	Nutrients P	N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
a) Geese, Fish Management & Monitoring	1	1			2/11	10 + years	$3.2 m
b) Rerouting stormwater, maintenance			1		1/11	3 - 5 years	$0.7 m +
c) Algae Removal	1	1			2/11	1 year	$$$
d) Chemical (Phoslock/PAC)	2			0.5	2.5/11	10+ years	$1.4 m
e) Desalination			1	1	2/11	1 - 5+ years	$ - $$$
f) Oxygenation Equipment				1	1/11	3 - 5 years	$$
g) Recycle via North Channel (No filtration)				1	1/11	5+ years	$

Critical Decision:

Is It Worth Investing to Address Sediments?

Challenges:

1) Volume estimated at 6,000 – 17,000 m³
2) Basic drawdown - exposes 59% of sediment
3) Western and southern areas are former dump sites and considered contaminated

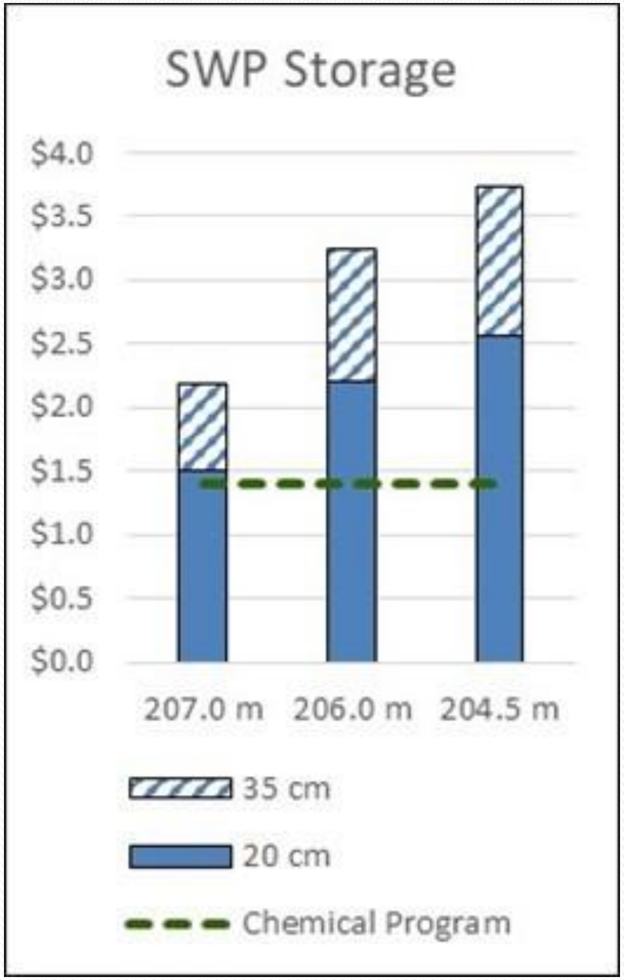
Option #1: Remove ($2.3 - $6.0 m)

1) Identifying acceptable receiving site
2) Trucking costs/ site fees (600 – 1,700 truckloads)
3) Community disruption

Option #2: Retain within Swan Lake ($1.5 - $4.2 m)

1) Construct concrete retaining walls for storage, or
2) Line shoreline with impermeable membranes (SWM techniques) – staff estimate storage for 2,000 m³

Storing Sediments Around the Lake



Benefit #1: Low Cost

Shoreline could store 5,000 – 8,000 m3 or 50% - 90% of the sediments for basic drawdown. Any excess would need to be trucked away.

Comparable or only slightly more expensive than chemical program.

Benefit #2: Secure Shoreline

Shoreline storage should minimize the chance of seepage of contaminants from the former sites and remove another possible complication.

Why Spend More to Remove the Sediments?

Upfront costs of $0.8 - $3.5 million same or greater than chemical program of $1.4 m over 25 years

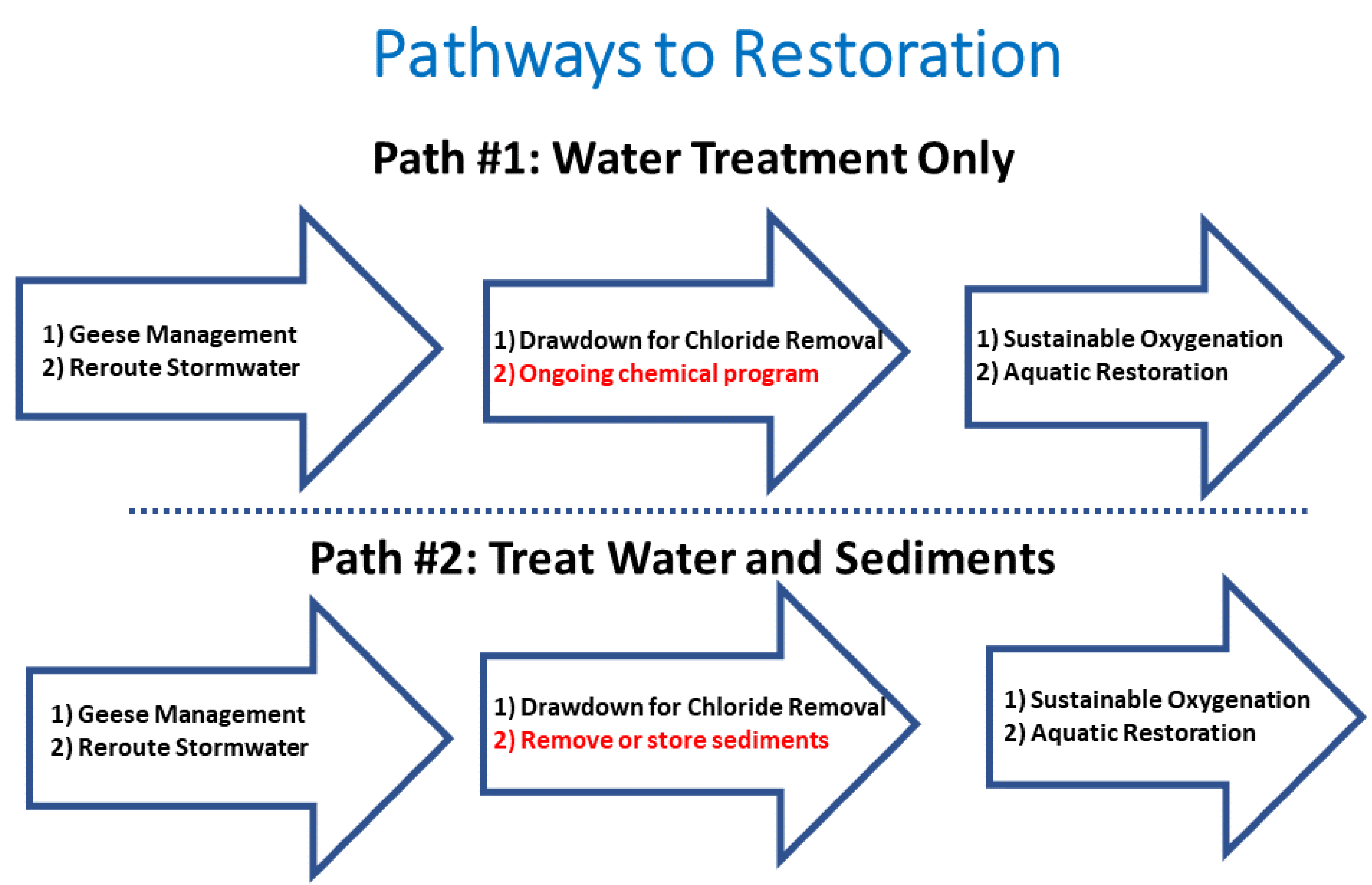
Potential Ecological Benefits:

- Is there a greater assurance of success?
- Will water quality improve and stabilize faster?
- Is there a greater chance to improve water quality (to mesotrophic levels)?

Potential Cost Avoidance Benefits

- Will it reduce costs of chemical program
- Will it lower ongoing monitoring costs?

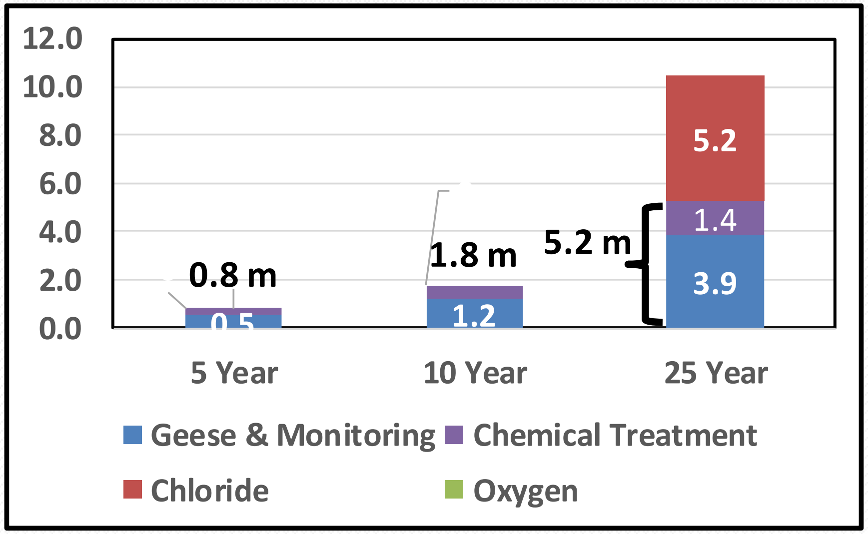
Workshop Guidance:
Level of Attainable and Sustainable Water Quality?



FOSLP Quest 2023:

A Comprehensive Plan for Comparable Money?

- **$5.2 m approved base plan** over 25 years deals for geese management (27%), chemical treatment (26%), stormwater management (10%), monitoring costs (19%) and fish management, research, other (18%)
- **Not included - $5.2 m estimate** for stormwater structural changes to end stormwater role ***[Updated estimates after Flow Diversion Study]***



Does not include costs for:

a) Removal of chloride
b) Improvement in oxygen levels
c) Shoreline restoration (Parks Operation)

Additional provision for dump site issues $2 - $10m

Conclusion: It <u>may</u> be feasible – or at least close!

Potential Workshop Guidance

Illustrative Path #1: Water Treatment Only

- Build upon current chemical program
- Drawdown to bring chloride quickly under control
- Add low-cost oxygenation (ex: recycling via North Channel)
- No substantial increase in costs

Path #1: Water Treatment Only	Nutrients P	Nutrients N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
Geese, Fish Management & Monitoring	1	1			2/11	10 + years	$3.2 m
Rerouting stormwater, maintenance			1		1/11	3 - 5 years	$0.7 m +
Drawdown	1	1	1	1	4/11	1 - 3 years	$
Recycling Via North Channel	?	?	?	1	1 - 4/11	10 + years	$ - $$
Chemical (Phoslock/PAC)	2			0.5	2.5/11	10 + years	$1.4 m
Comprehensive Water Treatment Plan	3	2	2	2	9/11	10 + years	$5.3 m +

* Costs exclude Shoreline Restoration & Rerouting Stormwater

Potential Workshop Guidance

Illustrative Path #2: Remove the Sediments

- Discontinue or reduce chemical program
- Drawdown brings chloride quickly under control
- Add low-cost oxygenation (ex: recycling via the North Channel)
- Partial removal of sediments may be offset by chemical savings.
- Additional sediment costs may be justified if greater assurance of success or better water quality outcomes attainable.

Path #2: Water & Sediment	Nutrients P	Nutrients N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
Geese, Fish Management & Monitoring	1	1			2/11	10 + years	$3.2 m
Rerouting stormwater			1		1/11	3 - 5 years	$0.7 m +
Drawdown	1	1	1	1	4/11	1 - 3 years	$
Recycling Via North Channel				1	1 /11	10 + years	$
Sediment Removal & Storage (SW)	**2**	**2**	**2**	**1**	**7/11**	**1 year**	**$1.5 - $3.7 m**
Comprehensive Water & Sediment Plan	**3**	**3**	**3**	**2**	**11/11**	**10 + years**	**$5.4 - 7.6 m +**

* Costs exclude Shoreline Restoration & Rerouting Stormwater

Material for Solution Workshop

Current Initiatives:

1) 2023 Water Quality (2 full years post PAC treatment)
2) Flow Diversion Feasibility Study on reducing road salt inflows
3) Shoreline Restoration Project (Fall 2023?)
4) Staff review of York U and Fleming College research reports
5) FOSLP report on comprehensive options

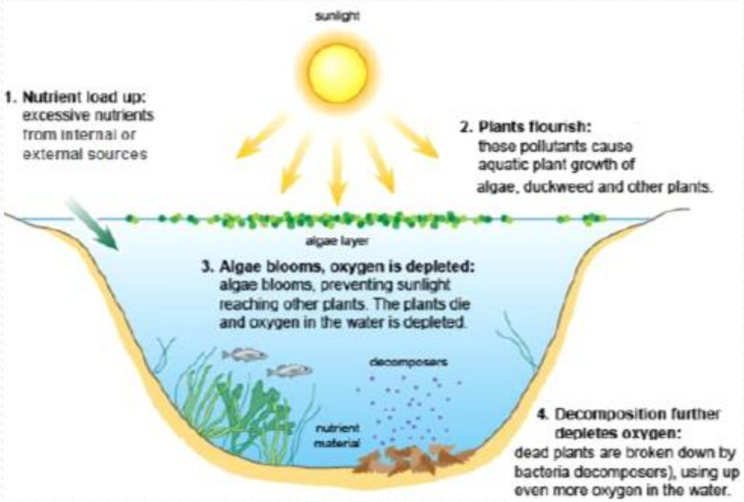
New Initiatives 2023

a) Engineering assessment on system ability to support drawdown
b) Biological review of benefits of drawdown
c) Assessment of issues and costs of removing/storing sediments
d) U of Toronto (oxygenation)

Phosphorus Release from Sediments
Complex Chemical Interactions Involved

Traditional View

- Release of phosphorus from sediments directly related to oxygen levels at the lakebed surface
- Basis for long-term plan



Evolving Alternate Views

- Oxygen levels may not be as significant as first thought
- Chloride levels may be an important factor:
  1) Chemical interaction in sediments
  2) Heavier chloride laden water creates layers within the lake and impacts release from sediments

U. of Toronto Research [Proposal Pending]

Dr. Amy Bilton & Calvin Reider

Dr. Bilton

- Director of Centre for Global Engineering
- Director of Water and Energy Research Lab

- Aeration unit for fish farms in Far East
- Guelph test - increased oxygen (15%)
- Re-do test at Swan Lake but check on impact of drawing phosphorus from the sediments.
- Provide insight into chemical interaction of oxygen and sediments

Potential insight for Workshop discussions on pro's/cons of aeration

Hutchinson Environmental Sciences Ltd.

Phase 1 Proposal: $10k + tax

- **Phase 1: “Background Review”** to determine utility of
  a) Water level drawdown
  b) Sediment removal
- Two primary components:
  - A review of Swan Lake Studies and reports
  - A literature review of utility of drawdown and sediment management in the lake management literature
- Provision of technical report on findings:
  - “Summarize the current science on water level drawdown and sediment removal from a lake management perspective”
- Will not provide detailed commentary on management issues related to management of drawdown, sediment storage and removal and related regulatory issues.
- Seek guidance from staff on scope?

Phase 1: Addresses potential benefits
Phase 2: Costs & implementation issues

Our Recommendations:

I. **Endorse new initiatives proposed by staff**

II. **Markham Host Workshop (Jan/Feb 2024)**

a) What level of water quality is attainable and sustainable?

b) Address Three Critical Investment Decisions

1) Is it worth Investing to reroute stormwater
2) Is drawdown beneficial/ Can it be managed safely?
3) Is it worth investing to remove sediments?

III. **Submit draft Comprehensive Plan for "Peer Review" by Workshop participants before submission to Council**

IV. **Engage Hutchinson Environmental - staff guidance on scope:**

Phase 1: Assessment of benefits drawdown/ sediment options ($10k)

Phase 2: If processes show merit, investigate costs and ways to mitigate environmental and regulatory concerns

Best efforts by FOSLP to provide financial support for Hutchinson Phase I investigation

Proposed Amendments to Resolutions

Staff Recommendations (Slide 39)

Recommendations

Approve — 1. THAT the report entitled "Swan Lake- 2022 Water Quality Status and Updates" be received;

Amend — 2. AND THAT Staff continue to implement the Long-term Management Plan for Swan Lake approved by Council in December 2021, including advancement of submerged aquatic vegetation, research into chloride treatment, and flow diversion evaluation (previously in Phases 2 and 3 of the Plan);

Approve — 3. 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 Plan through the Markham Sub-Committee with the participation of the Friends of Swan Lake Park;

Add New →

Replace — 4. AND THAT the next review of the Plan will be in 2026 (after the completion of Phase 1 and other measures as listed under item 2);

Approve — 5. AND THAT Staff be authorized and directed to do all things necessary to give effect to this resolution.

Staff Slide #39

Proposed Amendments to Staff Recommendations

I. **Approve Recommendations #1, #3 and #5**

II. **Amend Recommendation #2 by adding**

“and flow diversion evaluation ***including an evaluation of the feasibility of the system to safely support a drawdown of the lake”…***

III. **Add a New Recommendation to read:**

“THAT in conjunction with Friends of Swan Lake Park staff engage Hutchinson Environmental Services to advise on the benefits of a drawdown and removal of the sediments.

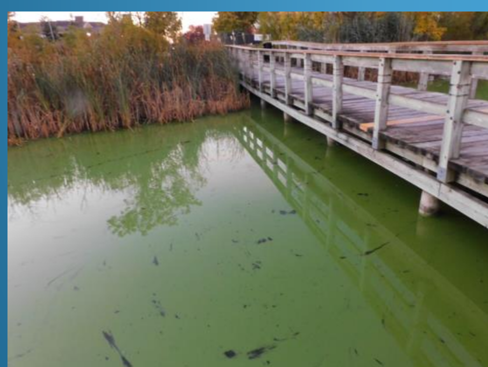
IV. **Replace Recommendation #4 with:**

“AND THAT staff host a Solution Design Workshop with independent environmental advisers in 2024 and submit a draft long-term plan for a “peer review” by the participants prior to a review by the committee in 2025/2026”

Friends of Swan Lake Park

Focused on Restoring Swan Lake and Swan Lake Park

From this



Back to This

Hutchinson
Environmental Sciences Ltd.

www.environmentalsciences.ca

May 8, 2023

Mr. Fred Peters
Friends of Swan Lake Park
fred.peters@rogers.com

Re: Swan Lake Remediation – Review of Water Level Drawdown and Sediment Removal

The Friends of Swan Lake Park (FOSLP) contacted Hutchinson Environmental Sciences Ltd. (HESL) about the remediation of Swan Lake. The lake has been well studied and management actions have been undertaken such as the management of Canadian Geese, and the utilization of Phoslock and Polyaluminum Chloride to reduce internal nutrient loading from sediments, while additional investigations into the feasibility of altered stormwater management are ongoing. The City of Markham recently completed, "*Swan Lake Long-Term Management Plan*" (City of Markham 2021), while FOSLP completed "*Towards a Comprehensive Restoration Plan for Swan Lake*" (FOSLP 2023). It is our understanding based on preliminary discussions and a review of background material, that the City and FOSLP have differing management objectives, with the City focused on containing cyanobacteria blooms and FOSLP focused on a more fulsome restoration of the lake to improve recreational opportunities and ecological features and functions. FOSLP have developed a variety of lake management approaches as detailed in FOSLP (2023) geared towards a more fulsome remediation plan, including water level drawdown and sediment removal.

This proposal was developed to review the appropriateness of water level drawdown and sediment removal in Swan Lake. The review will consist of two primary components, a background review of Swan Lake studies and a literature review of relevant literature. A technical report will be completed that highlights opportunities and constraints associated with water level drawdown and sediment removal in Swan Lake based on Swan Lake characteristics and the utility of such practices in lake restoration as detailed in peer-reviewed literature.

Background Review

Swan Lake is well-studied, and several reports have been completed that could inform the review. It is anticipated that the background review will include focused reviews of the following studies:

- Swan Lake Review (Michalski Nielsen Associates Limited 2008)
- Swan Lake Community Environmental Management Study (Town of Markham 1993)
- Towards a Comprehensive Restoration Plan for Swan Lake (FOSLP 2023)
- Swan Lake Long-Term Management Plan (Town of Markham 2021)
- Swan Lake Sediment Quality and Suggested Doses of Phoslocak Based on Sediment Fractionation Data (Nürnberg 2021)
- Swan Lake, Markham, Ontario – Sediment Analysis (Institut Dr. Novak 2020)

Literature Review

We will review and summarize the current science on water level drawdown and sediment removal from a lake management perspective. To ensure our review covers the most up-to-date and relevant science, we will leverage two important resources:

- First, HESL scientists are active members of the North American Lake Management Society (NALMS), an international society bringing diverse stakeholders together in the interest of lake management. Our affiliation gives us access to NALMS resources, experience and expertise in lake management.
- Second, HESL maintains an extensive, in-house digital library and our scientists have direct unlimited access to online academic libraries and databases, making hundreds of peer-reviewed scientific journals available for our review.

We will develop a list of focused search terms which we will use to search major online databases (e.g., Web of Science, Google Scholar). Studies generated from the search will be screened for relevance by scanning abstracts. The information from the literature review will then be synthesized into a report summarizing the current state of scientific knowledge on water level drawdown and sediment removal for lake restoration, which will be combined with the results of the background review to determine the utility of such practices in the restoration of Swan Lake.

Budget

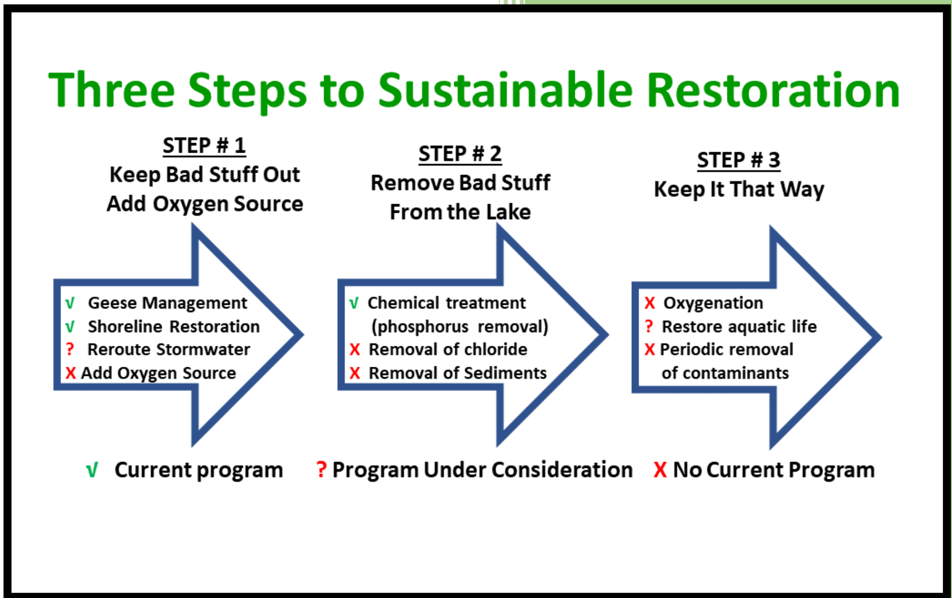
The cost to complete the tasks described here-in is $10,000 + HST. If you agree with the proposal, please provide written authorization to proceed. Feel free to contact the undersigned with any questions.

Sincerely,
per: Hutchinson Environmental Sciences Ltd.

Brent Parsons, M.Sc.
brent.parsons@environmentalsciences.ca

Friends of Swan Lake Park

Towards a Comprehensive Restoration Plan For Swan Lake



May 2023

Contents

EXECUTIVE SUMMARY

Swan Lake Park in Markham is home to a rich diversity of wildlife. But this wildlife is threatened by the deteriorating water conditions in Swan Lake. The Friends of Swan Lake Park are residents of Markham committed to saving Swan Lake and Swan Lake Park through environmental best practices that will restore safe lake water for sustainable human and wildlife activity.

A) Current Long-Term Plan Water Quality Plan

In December 2021, Markham Council approved a Long-term Water Management Plan (the "Plan") for Swan Lake. Details of the Plan are summarized in Appendix H.

The Plan is based on an evolving "adaptive" management approach and focuses on the reduction of algae through actions such as geese management and periodic chemical treatments to reduce phosphorus which is viewed as the critical nutrient spurring the algal growth. The program is expected to show marginal improvement in water quality but is not expected to attain the more stable and better-quality mesotrophic level the community is encouraging.

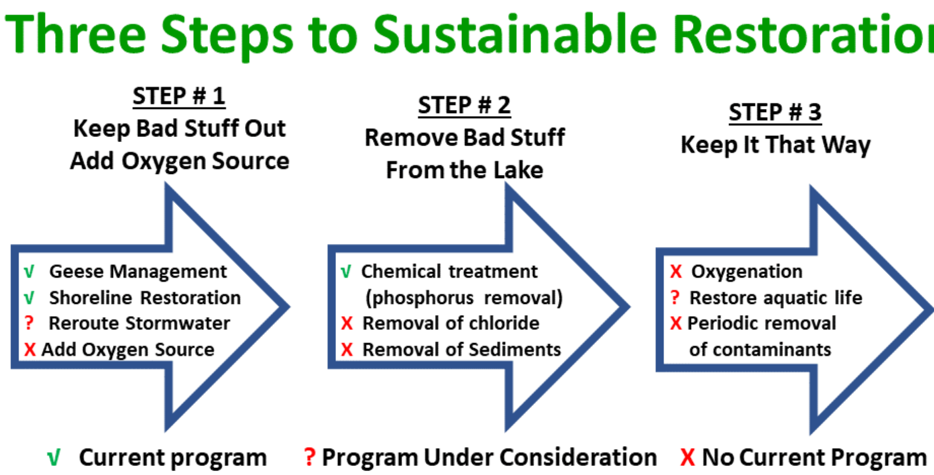
Since the passage of the Plan, additional efforts have been initiated to quantify and identify the sources of the stormwater inflows that are bringing chloride in the form of road salt into Swan Lake. Markham Council has approved a Flow Diversion Study into the feasibility of rerouting stormwater inflows away from the lake. As Markham staff have noted in their 2022 Water Quality report, additional efforts are required to identify approaches for the removal of chloride from Swan Lake.

As a minimum, the Plan needs to be updated to incorporate solutions to the chloride issues and to address the need for oxygenation. Ultimately what is required is a comprehensive plan that addresses all essential factors that influence water quality during the restoration phase leading to an ongoing sustainable cost-effective stewardship plan for water quality management.

B) Three Steps to Sustainable Restoration

There are three fundamental steps to a sustainable restoration plan. The initial challenge is to reduce the nutrients and chloride entering the lake followed by a focus on how to reduce the amounts already built up in the lake which spur the excessive algal growth and undermine the aquatic health of the lake. Once restoration is achieved, the challenge remains to identify a practical way to maintain the improved aquatic environment.

The geese management program is showing initial success in reducing the migratory geese population and thereby reducing the phosphorus and nitrogen entering the lake while the shoreline restoration project is expected to reduce the attractiveness of the shoreline as a nesting area for resident geese.



Investigation is underway to reduce the amount of road salt entering the lake which is the primary source of chloride. At present there is an estimated 40 tonnes of chloride active in the water. An unknown amount may be stored in the sediments.

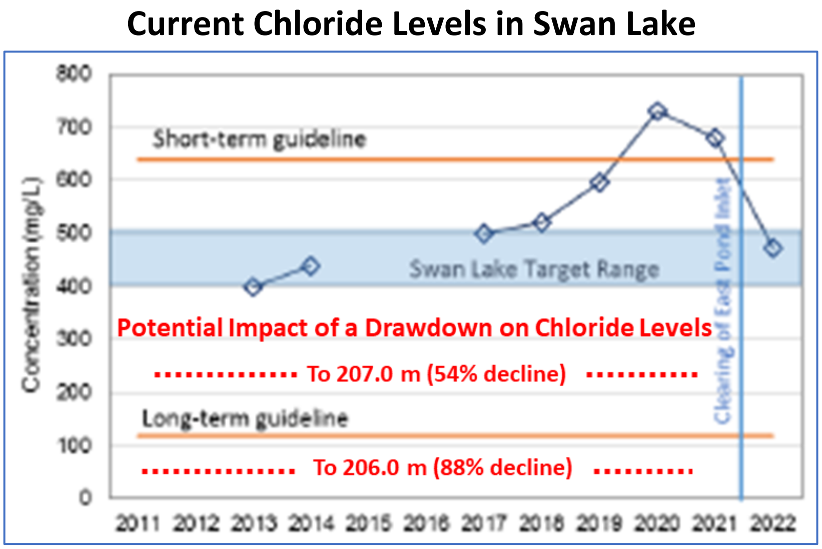
The following report focuses primarily on identifying approaches for removing the build-up of chloride in the lake and explores the feasibility of removing the sediments which are a known storehouse of phosphorus and nitrogen and likely chloride.

C) Low-cost, Winter Drawdown

Various techniques including use of desalination equipment and industrial filtration processes can provide very effective means for the removal of phosphorus, nitrogen and chloride but they are quite expensive. The lowest cost option would appear to be to drain water from the lake and let the lake naturally refresh through precipitation and from the aquifer. The lake naturally filled up in the 1970's after quarry operations ceased. Analysis is required to assess how long the refill process would take and whether it would be acceptable to pump water from the aquifer to accelerate the refill process.

A gravity-driven, controlled drawdown process could remove up to 54% of the lake water within 10 days. Additional volumes could be removed with the use of pumps. Undertaken during periods of low or no rain, the stormwater system can easily accommodate the controlled release flows. The maximum flow from the lake is well within the design capacity of the local stormwater system and the downstream system south of 16th Avenue. We recommend that the Flow Diversion Study be expanded to include a review to confirm that a drawdown of the lake is within the system design capabilities.

To minimize the impact on aquatic life, the drawdown should be scheduled in the early winter months.



A drawdown to 207.0 m would remove 54% of the chloride laden water bringing the chloride level well below the interim target set out in the long-term management plan. Drawing down the lake to 206.0 m would bring the chloride levels below the Federal government long-term guidelines for aquatic life.

A winter drawdown is a low-cost and impactful means for reducing the chloride content in Swan Lake and warrants serious consideration.

D) Sediment Removal

The analysis by Freshwater Research[5] suggests that the sediments are a storage area for phosphorus and nitrogen. It is likely that some of the chloride in the lake is also absorbed in the sediments. Water treatment processes such as a drawdown remove elements active in the water, but the phosphorus and other elements are subsequently released from the sediments back into the water column. The current chemical program using Phoslock and Poly Aluminum Chloride attempts to neutralize the phosphorus in the sediments but has no impact on nitrogen and chloride.

Removing the sediments may provide a more permanent solution and has the potential to accelerate the restoration process and possibly reduce the cost of future chemical treatments. Removal of the sediments is a costly undertaking; however, it may be practical to remove at least a portion of the sediments and to use low-cost techniques to store some of the sediments onsite along the Swan Lake shoreline.

Further analysis is required to determine the technical feasibility and costs of removing the sediments. The next step is a cost/benefit analysis to see if the additional costs of removing the sediments provide a reduction in other costs such as the chemical program and to assess the likelihood of better outcomes in terms of the water quality and long-term sustainability.

E) Solution Design Workshop

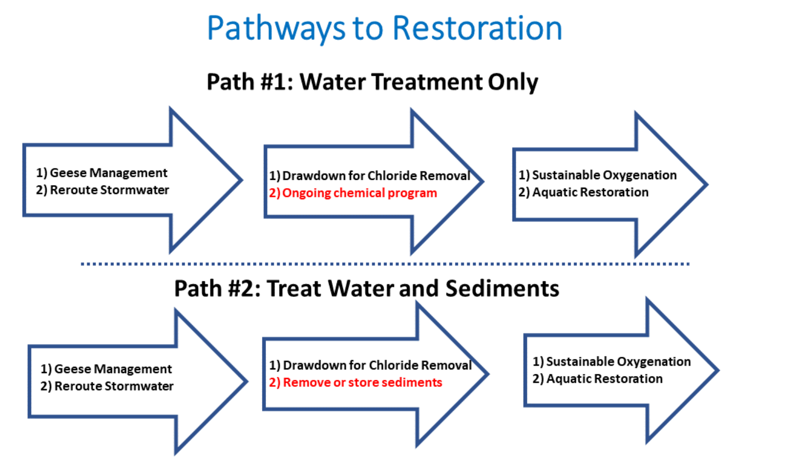
In complex restoration situations such as Swan Lake, a common industry practice is to host a workshop with experts with diverse technical perspectives with the goal of narrowing the path to restoration.

We recommend that Markham host a workshop in early 2024 to outline a path forward for a comprehensive path to restoration. The recommendations of the workshop would provide the framework for the development of an updated comprehensive plan and provide Council and the community with guidance on four critical topics:

1) What level of water quality is achievable and sustainable and at what cost?
2) Is it worth investing to reroute the stormwater?
3) Is a drawdown of the lake beneficial and can it be managed safely?
4) Is it worth investing to remove the sediments?

Two Paths Forward

The recommendations of the workshop should provide the framework for the development of an updated comprehensive plan. Two possible outcomes are expected:



Path #1:
A water-only restoration plan that incorporates the ongoing chemical management program.

Path #2
An alternate plan that addresses the sediments and potentially permits savings by reducing or eliminating the chemical treatment program.

F) Recommendations:

1) **That Markham host a Solution Design Workshop in early 2024 with the goal of providing guidance on the appropriate path forward for an updated long-term water quality plan.**

   In preparation for the workshop, we recommend that the following activities be approved:

   a) Completion of current undertakings in 2023:
      i. Completion of the design phase of the shoreline restoration project.
      ii. Completion of the Flow Diversion Study into the feasibility, costs and timing of rerouting stormwater flows from the lake.
      iii. Expand the scope of the Flow Diversion Study to include a report on the technical feasibility of a drawdown of water from Swan Lake during periods of low or no precipitation.
      iv. AECOM report on the research efforts by Fleming College on use of calcium peroxide to support oxygenation efforts.
      v. An update on the York University research into means of removing nutrients and chloride using biochar.

   b) We recommend support for research in 2023 into the following:
      i. University of Toronto research into whether oxygenation will increase phosphorus release from the sediments during restoration.
      ii. Research into the biological benefits of using a drawdown of the lake as a management tool during the restoration phase and as a future management tool for sustainability.
      iii. Research into the cost/benefits of the removal of sediments as a management tool.
      iv. Research into whether oxygenation processes are helpful or a hindrance during the restoration phase and whether they should be a component of a long-term sustainable plan.

2) **That following the Solution Design Workshop that staff submit a draft Comprehensive Water Quality Plan for a "Peer Review" by the Workshop participants before submission to Council for consideration and approval.**

TOWARDS A COMPREHENSIVE RESTORATION PLAN

I) THE NEED FOR A COMPREHENSIVE PLAN

In December 2021, Mark ham Council approved a Long-term Water Management Plan (the "Plan") for Swan Lake. Details of the Plan are summarized in Appendix H.

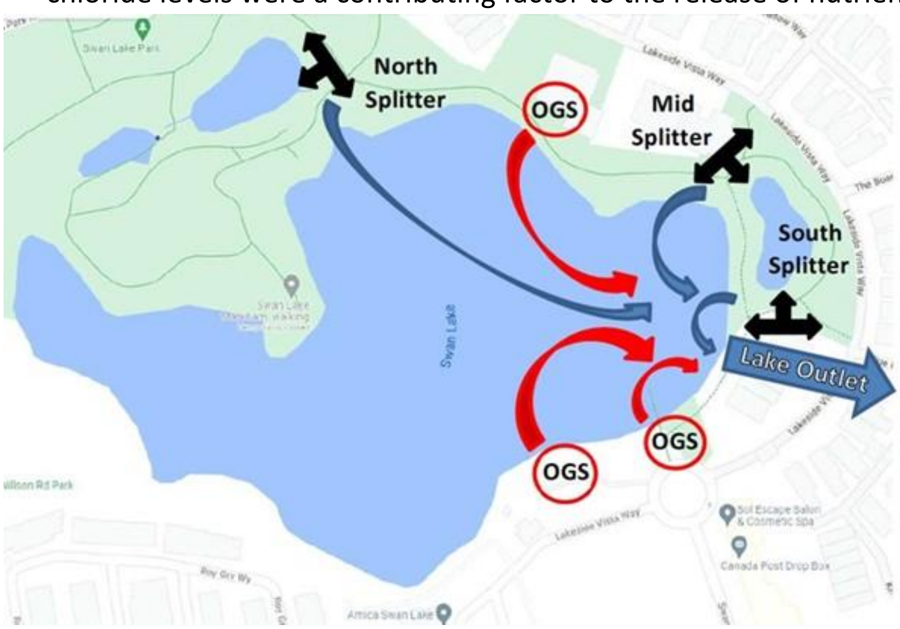
The Plan is based on an evolving "adaptive" management approach and focuses on the reduction of algae through actions to reduce phosphorus as the critical nutrient spurring the algal growth.

As a minimum, the Plan needs to be updated to incorporate solutions to the chloride issues and to address the need for oxygenation. The outcome should be a comprehensive plan that addresses all essential factors that influence water quality during the restoration phase leading to an ongoing sustainable stewardship plan for water quality management.

A) Chloride Issues

Chloride from road salt impacts the restoration in two basic ways:

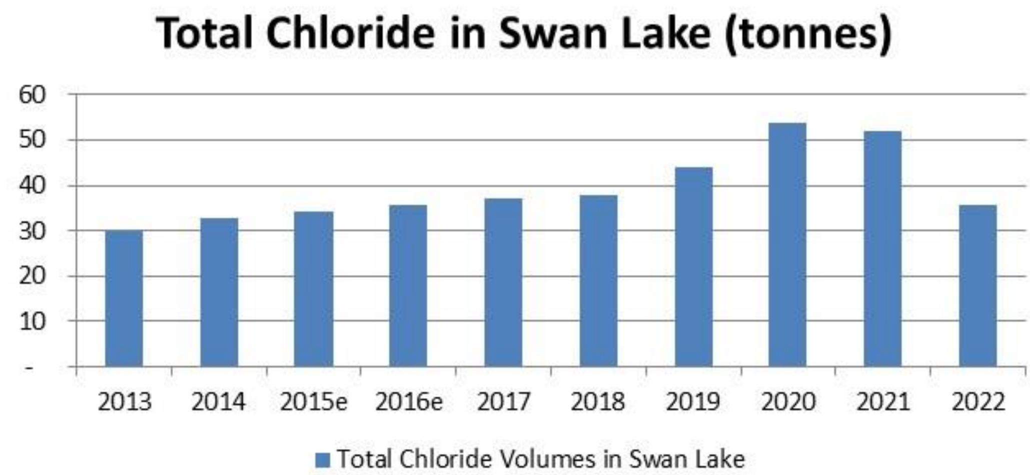
1) Chloride levels in Swan Lake are 4x – 6x the safe level for aquatic life under the federal guidelines, which threatens lower-level aquatic life such as zooplankton and many small fish species that consume algae and are an essential component of a balanced, sustainable solution.
2) Recent research[A3] indicates that high chloride levels can contribute to the release of phosphorus from the sediments. A recent report[A4] on Lake Wilcox in Richmond Hill concluded that while inflows of phosphorus from farmers' fields were reducing, algae continued to grow, suggesting the increasing chloride levels were a contributing factor to the release of nutrients from the sediments.



The Friends of Swan Lake Park's 2022 report, "Action Plan to End Swan Lake's Stormwater Management Role" outlined options for reducing the inflow of stormwater into Swan Lake.

In 2023, Markham staff will undertake a Flow Diversion Study to investigate the feasibility of rerouting stormwater flows away from the lake in an effort to reduce the annual inflow of road salt.

As Markham staff note in their 2022 Water Quality Report, efforts are required to identify approaches for the removal of the 30 – 40 tonnes of chloride already in Swan Lake.



The sharp rise in chloride levels in 2019 - 2021 are attributed to a blocked pipe into the East Pond. The blockage was removed in 2021 reducing the inflow of additional road salt.

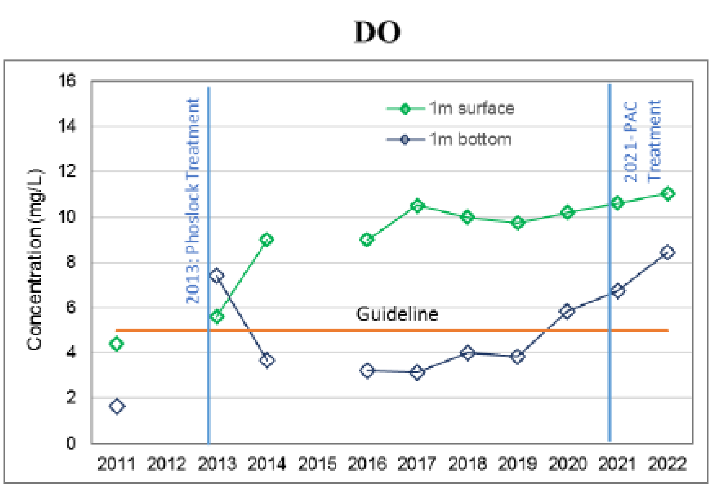
The decline in chloride levels in 2022 is attribute to outflows. The lake level was lower than normal during the summer so little water flowed from the lake into the stormwater system. The decline in chloride may reflect the loss of water through the aquifer and possibly some absorption in the sediments combined with dilution from precipitation.

B) Low Levels of Dissolved Oxygen

Dissolved oxygen (DO) is a measure of how much oxygen is dissolved in the water - the amount of oxygen available to living aquatic organisms. Dissolved oxygen in surface water is used by all forms of aquatic life; therefore, it is measured to assess the "health" of lakes and streams.

Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, whereas stagnant water bodies such as Swan Lake contain less.

Bacteria in water consumes oxygen when organic matter, such as algae, decays. Thus, the decay of excess organic material in lakes can cause an oxygen-deficient situation that can cause a water body to "die." Aquatic life can have a hard time in stagnant water that has a lot of rotting, organic material in it, especially in summer when dissolved-oxygen levels are at a seasonal low. Water near the surface of the lake is too warm for aquatic life, while water near the bottom has too little oxygen.



Recent data shows some improvement in oxygen levels following the 2021 PAC treatment.

It is expected that the chemical treatments will reduce the algae and therefore less oxygen will be lost each year to the decaying algae. The question becomes whether this is sustainable or only a short-term benefit as observed in 2016-2017 following the Phoslock treatment.

Improving oxygen levels in Swan Lake should reduce phosphorus release from the sediments (internal loading) and reduce the amount and possibly the frequency of chemical treatments required in the future. Concern has been expressed that adding oxygenation processes during the restoration phase may in fact increase the release of phosphorus from the sediments. However, some researchers[A6] question the interaction of oxygen and phosphorus at the surface of the sediments.

A group of researchers from the University of Toronto have proposed testing a new wind-powered oxygenation unit on Swan Lake. The unit was designed to support fish farming in underdeveloped areas in the world. They have recently completed some tests on the effectiveness of the units in adding oxygen to the water and are interested in determining if the units would be a factor in releasing nutrients from the sediments.

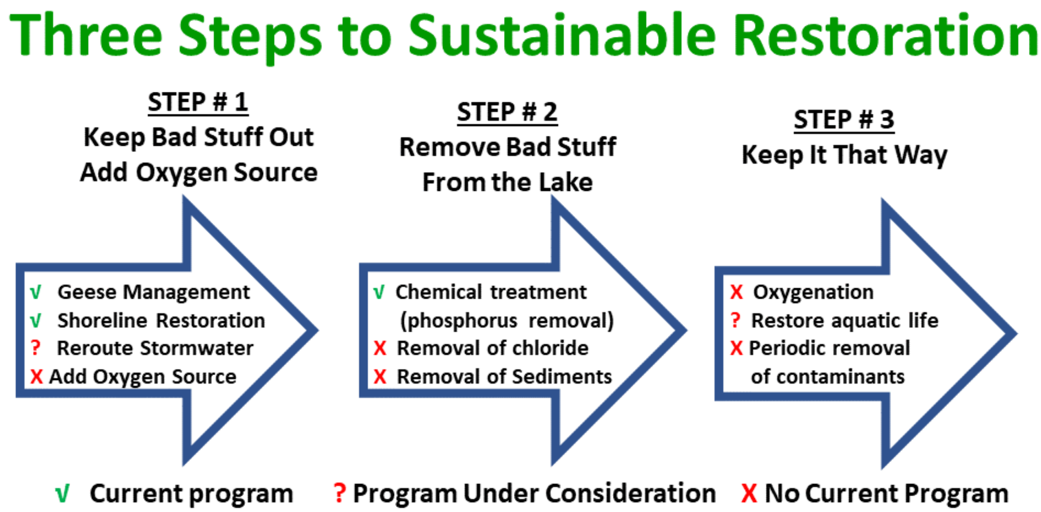
This experiment may shed some light into the complex interaction of the low oxygen levels in Swan Lake and the nutrients in the sediments.

While the chemical treatment may provide some benefit, the chronic issue is that Swan Lake is a stagnant body of water without many natural sources for oxygen. More sustainable options need to be considered. The challenge becomes finding a means to improve oxygenation levels in Swan Lake ideally in a manner that supports the phosphorus management challenges.

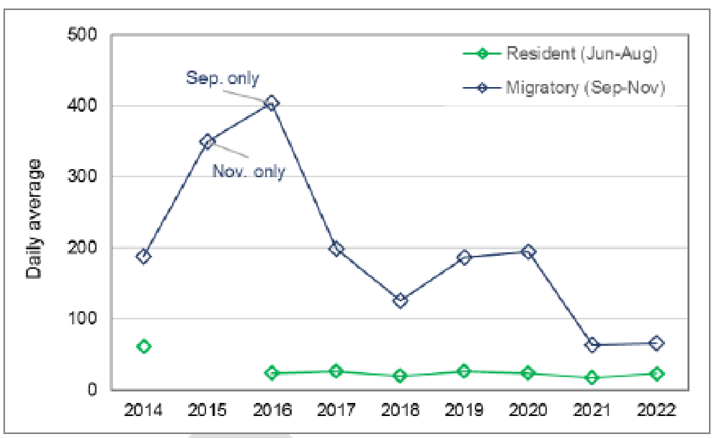
Markham staff reported that the Fleming College research proposal into the potential to use calcium peroxide as a means for enhancing oxygen levels has merit, but the concept is still at an early research stage and does not warrant involvement at this time.

II) THREE STEPS TO RESTORATION

There are three critical steps to a sustainable restoration plan for Swan Lake.



Step #1 – Controlling Inflows, Enhancing Oxygen Sources



Significant progress has been made on the first step of reducing algae by minimizing the nutrients (phosphorus and nitrogen) entering the lake.

The geese management program has been expanded to provide for increased hazing during the fall migration and in 2021 a program was introduced to relocate the geese that are resident during the summer months.

In concert with the geese management program, Markham parks staff are also engaged in redesigning the shoreline. The initial phase involved removing invasive phragmites reeds and redesigning the shoreline to reduce the attractiveness to resident geese.

At this point, there is no specific program targeted to add oxygen to the lake, so more research is required into whether adding oxygen during the restoration phase is helpful or a hindrance to restoration.

One of the primary challenges is to reduce the inflows of road salt from the stormwater system. Markham Council have approved funding for the Flow Diversion Study to determine if the inflows can be reduced. Even though average readings of chloride in Swan Lake have declined to 480 mg/L, the levels are still 4 times the federal guidelines for aquatic life of 120 mg/L. High chloride levels kill the lower-level aquatic life that consume algae, elements that could be contributing to controlling the algae levels. As shown in the following table, the annual inflows from the stormwater system are 20x – 30x the safe level for aquatic life.

Table 4: Chloride Concentrations in Runoff

Date	Inflow to Ponds		Bypass from Pond to Lake	Inflow to Lake from Ponds				Inflows to Lake from OGS	
	East Pond	North Pond	East Pond	East Pond- in pond	From south	North Pond- in pond	Road	Swan Lake Blvd.	AMICA
3/20/2012 *	577	673		572		56			
3/26/2021	957	98.5		343		199			
4/11/2021		79	131		673				
1/13/2022	13200**							3160	
2/15/2022	2340	2120					326	836	360
3/6/2022	380	410		410		180		1200	610
3/16/2022	3700	3100						4800	470
3/24/2022	1200	1100	150					1900	240
4/6/2022	2800		350						1100
Median/average	1029		210	345				1900	470

* Data were used cautiously since the exact location of samples and sampling conditions are not known.
** Standing water, not used in calculations.

Step #2: Removing Nutrients and Chloride from Swan Lake

In addition to the items outlined in Step #1, the current long-term plan consists primarily of a periodic chemical treatment program involving either Phoslock or Poly Aluminum Chloride ("PAC") focused on removing phosphorus from both the water and the sediments. The Plan called for initial treatments in 2021 and 2024 followed by treatments every 3 – 5 years thereafter.

Other than through the geese management program, the Plan does not address nitrogen as a material factor. Recent research studies[A2] recommend that a comprehensive water quality program should incorporate plans for both phosphorus and nitrogen.

The Plan does include initiatives to improve aquatic plant and fish as a component of the long-term restoration efforts. Staff reported that the research by York University professors into removal of nutrients and chloride via a carbon-based filtration process warrants further consideration and are planning to support the initial research phase in 2024.

While the chemical program has an impact on the reduction of phosphorus active in the water and stored in the sediments, there are no planned actions for removal of nitrogen or chloride from the water or the sediments. The primary focus of this report was to investigate options for removal of chloride in particular but also comprehensive processes that could address all three: phosphorus, nitrogen and chloride.

Step #3: Sustaining Restoration Efforts

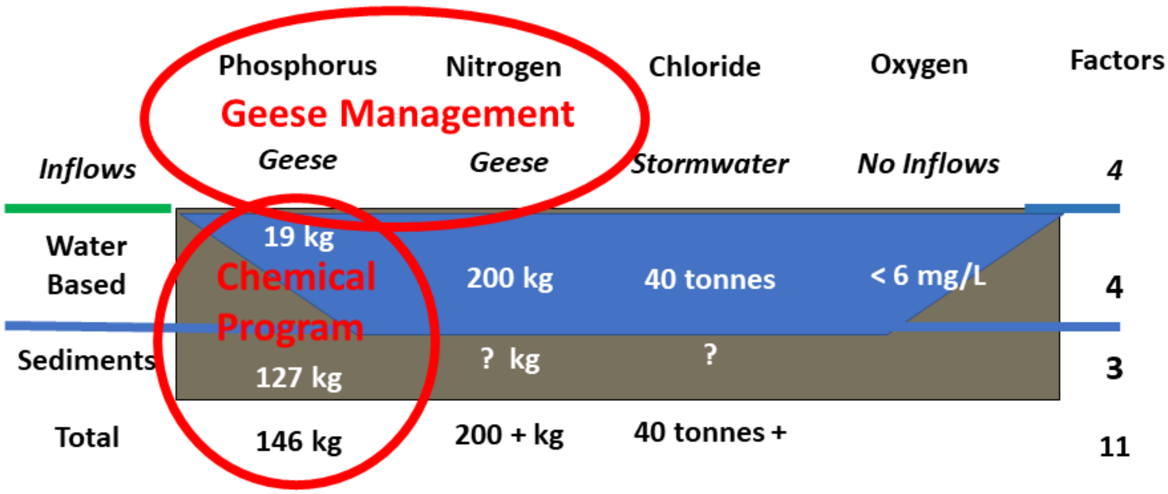
The current long-term plan does not address how improved water quality will be sustained. It is suggested improvements in restoring aquatic animal and plant life and continuing periodic chemical treatments will be required but it is unlikely that these approaches can be successful unless the chloride levels within Swan Lake are significantly reduced.

The approach for sustaining water quality over the long-term will be greatly influenced by the decisions taken during the restoration process. Some restoration processes such as industrial filtration do not lend themselves to ongoing use whereas others such as a drawdown may serve as a practical long-term management tool.

III) FACTORS INFLUENCING RESTORATION

Research on water quality in Swan Lake suggests there are eleven (11) factors to be considered in a comprehensive program for restoring water quality.

11 Factors Influencing Restoration



Inflows (4): Four factors relate to Step #1. Three relate to reducing the inflows of phosphorus, nitrogen, and chloride. Swan Lake is a stagnant body of water, lacking any surface level inflows that naturally would add oxygen to the lake, so the fourth factor is to find ways to add oxygen to the lake on a continuing basis.

Water Based (4): Three factors relate to removal or reduction of phosphorus, nitrogen or chloride once they are in the lake while the fourth is improving oxygen levels in the water either directly or indirectly by reducing the loss of oxygen to decaying algae.

Sediment Based (3): The final three factors relate to the removal or reduction of phosphorus, nitrogen and chloride stored in the sediments.

The current long-term plan addresses four of the factors directly and indirectly is expected to reduce oxygen levels in the lake by reducing the algae levels which in turn means less oxygen is consumed as the algae dies in the fall.

	Nutrients		Cl	O	Factors Addressed	Restoration Timeframe	Costs	Concerns
Current Long-term Plan	P	N						
Geese, Fish Management & Monitoring	1	1			2/11	25 year	$3.3 m	Perpetual program
Chemical (Phoslock/PAC)	2			0.5	2.5/11	25 year	$1.4 m	Addresses only Phosphorus
2021 Long-term Plan	3	1	0	0.5	4.5/11	25 year	$4.7 m +	Uncertainty of success, timeline
* Costs exclude Shoreline Restoration								

IV) EXPECTED AND POTENTIAL COSTS UNDER THE 2021 PLAN

The Plan provides for $4.7 million for water quality restoration over the next 25 years.

Restoration Costs

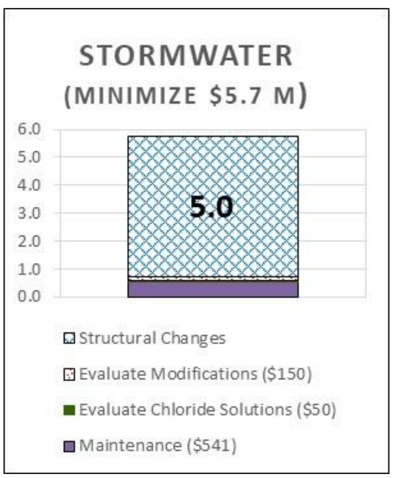
The budget provision in Markham's Life-Cycle Reserve Fund includes $2.3 million (49%) for Ecological Elements including geese management and restoration of fish and aquatic plants.

Another $1.0 million (22%) is provided for water quality monitoring and site testing and $1.4 million (29%) for ongoing chemical treatment program for phosphorus.

The current plan does not include estimates of the costs for restoring the shoreline but provides an outline of potential additional costs related to rerouting stormwater flows and addressing potential issues related to former dump sites.

Stormwater Management Costs

In addition to the water quality program, the long-term budget includes $541,000 for future stormwater pond management and $50,000 for investigation into options for removal of chloride.



Finding a cost-effective approach for reducing stormwater inflows is an essential component of a restoration program.

Markham Council recently approved $150,000 for the Flow Diversion Study to investigate the feasibility of rerouting the stormwater away from the lake. Results are expected in 2024.

The long-term plan indicates a potential cost of $5 million for rerouting stormwater flows. It is expected that the Flow Diversion Study will provide a refinement to this estimate in 2024.

Potential Dump Site Related Costs

If it is determined that seepage from the old dump sites is undermining restoration success, the plan has indicated that costs for addressing groundwater issues could be in the range of $2.0 - $10.0 million.

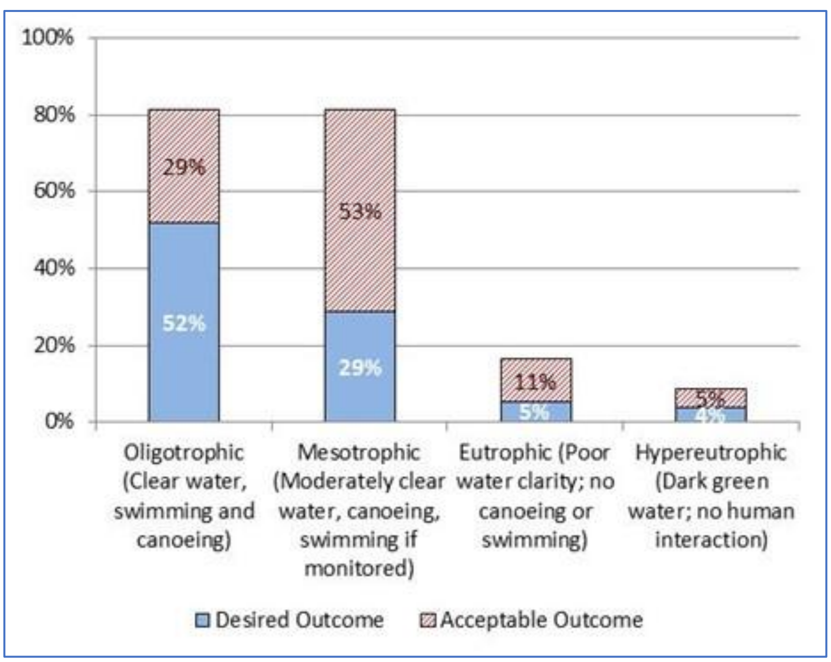
Development of a comprehensive plan for restoration should endeavour to minimize or avoid issues that may trigger costs related to the dump sites. Storage of sediments along the shoreline near the dump sites could possibly reduce the risk of seepage from the dump sites.

V) WATER QUALITY GOALS AND EXPERIENCE

Scientists categorize water quality environments into "Trophic States". Swan Lake is categorized as a hypereutrophic lake, the lowest quality and highest risk category. The lower quality levels of eutrophic and hypereutrophic are not environmentally stable and continual damage to the aquatic and plant life can be expected, as well as potential ongoing health risk to humans and animals due to cyanobacteria.

TROPHIC STATE	AQUATIC ENVIRONMENT	COMMUNITY OPTIONS
Oligotrophic	Lack of plant nutrients keep productivity low, lake contains oxygen at all depths, clear water.	Swimming, paddle sports, wide range of fish options.
Mesotrophic	Moderate plant productivity, lower levels may lack oxygen in summer, moderately clear water and warm water fisheries only.	Paddle sports, swimming possible if monitored, good range of fish options.
Eutrophic	**Contains excess nutrients, blue-green algae dominate during summer, algae scums are probable at times, lower levels lack oxygen in summer, poor transparency, rooted aquatic plant problems may be evident.**	**No swimming, paddle sports possible, limited range of fish options.**
Hypereutrophic	**Algal scums dominate in summer, cyanobacteria, few aquatic plants, no oxygen in lower levels, fish kills possible in summer and under winter ice.**	**No human interaction, potential health risk for humans and small animals.**

The mesotrophic category represents a more stable environmental goal with better community options. It is, however, a challenging objective that, if feasible, will require a comprehensive program that addresses all of the underlying factors contributing to the deterioration in water quality.



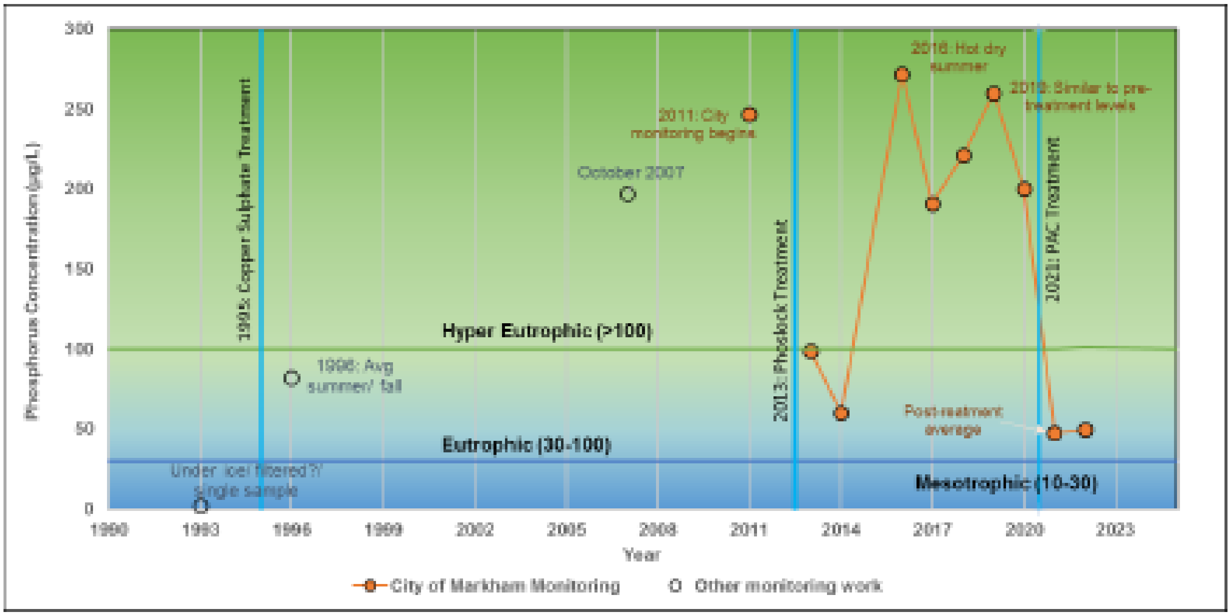
Park Improvement Survey

In a March 2021 survey, over 80% of the 367 responding area residents expressed the desire for restoration of Swan Lake to a mesotrophic or oligotrophic level of quality.

The challenge is to determine if a more comprehensive program can attain and maintain a mesotrophic level of quality.

Except for a 2-year period following the Phoslock treatment in 2013 and the PAC treatment in 2021, Swan Lake has been classified as hypereutrophic as shown in the chart below from the 2022 Water Monitoring Report.

Figure 13: Trophic State Classification for Swan Lake based on Phosphorus Concentration



The current chemical treatment program has the potential to increase the water quality to a eutrophic level, but it is not clear that the current program is adequate to sustain the eutrophic level.

Details of the current water quality measures for Swan Lake is provided in Appendix G: Executive Summary of 2022 Water Quality Report.

The following chart summarizes the 5-year interim goals set out in the December 2021 Long-Term Plan approved by Markham Council and the aspirational "mesotrophic" goals proposed by Friends of Swan Lake Park.

	Interim Goal Long-term Plan	**Community Aspirational Goals**	**2020**	**2021 (1)**	**2022 (1)**
Trophic State	Eutrophic	Mesotrophic	Hypereutrophic	Eutrophic	Eutrophic
Seechi depth (m)	0.6 – 0.8	➢ 2.0	< 0.5	0.8	0.4
Chlorophyll (µg/L) **(2)**	No goals	< 9.0	n/a	n/a	n/a
Phosphorus (µg/L)	50 – 100	< 30	183	50	50
Nitrogen (mg/L)	No goals	< 0.65	2.56	1.0	0.5
Chloride (mg/L)	400 – 500	< 120	720	700	480
Dissolved Oxygen (mg/L)	No goals	➢ 6.5	6.0	6.3	8.0
Note 1: Results for 2021 and 2022 reflect impact of Poly Aluminum Chloride (PAC) treatment in 2021					
Note 2: Chlorophyll last recorded in 2018 at 41.3 µg/L					

VI) TREATMENT OPTIONS REVIEWED

Treatment approaches were assessed for their effectiveness in addressing the three critical issues of nutrient reduction (phosphorus and nitrogen), chloride removal and oxygenation and their individual impact on the 11 major factors that influence restoration.

One objective is to develop a sense of the costs of a comprehensive restoration plan relative to the current budgeted amounts. In most cases specific costs are not known so an attempt was made to indicate relative cost structures.

The options were categorized into three different streams:

1) Single Purposed Options
2) Comprehensive Water Treatment Options
3) Comprehensive Sediment Treatment Options

In its July 17,2020 report[5], Freshwater Research commented on a variety of management options in the context of treating excessive phosphorus as the primary issue. Their analysis led to the development of the current chemical treatment program.

Our focus has been to build upon the current phosphorus focused program to address perpetual issues of excessive chloride and low oxygen levels and consequently this report revisits some of the management approaches previously rejected in the context of a phosphorus focused management program.

Freshwater's report outlined concerns on the following specific items revisited in this report including:

a) Withdrawal of water –" inefficient process "
b) Sediment removal – "High dredging and removal costs and potentially "toxic" sediment in Block 9"
c) Aeration, Oxygenation –" May fertilize upper layers and increase bloom."

The merit of these concerns needs to be considered in the context of the development of a broader more comprehensive restoration plan.

1) Single Purposed Options

a. Algae removal techniques
b. Nutrient focused programs
c. Chloride focused options
d. Oxygenation focused options

While the single-purposed options address only one or two specific factors, they may have merit when combined with other approaches. The primary limitation of water-only treatment options is that in most cases they have little or no effect on the contaminants stored and potentially releasable from the sediments.

Appendix A provides a review of the focused solutions while Appendix B outlines the details about oxygenation by recycling lake water through the North Channel.

Focused Solutions	Nutrients P	Nutrients N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
a) Geese, Fish Management & Monitoring	1	1			2/11	10 + years	$3.2 m
b) Rerouting stormwater, maintenance			1		1/11	3 - 5 years	$0.7 m +
c) Algae Removal	1	1			2/11	1 year	$$$
d) Chemical (Phoslock/PAC)	2			0.5	2.5/11	10+ years	$1.4 m
e) Desalination			1	1	2/11	1 - 5+ years	$ - $$$
f) Oxygenation Equipment				1	1/11	3 - 5 years	$$
g) Recycle via North Channel (No filtration)				1	1/11	5+ years	$

2) Comprehensive Water Treatment Options

a. Recycling and Filtration via the North Channel
b. Industrial Filtration via Partitioning
c. Industrial Filtration via Recycling
d. Drawdown

The comprehensive water treatment options address multiple elements at the same time. Details of the options are outlined in Appendix D.

Comprehensive Water Based	Nutrients P	Nutrients N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
a) Recycling & Filtration via North Channel	1	1	1	1	4/11	10+ years	$$
b) Industrial Filtration (Partitioning)	1	1	1	1	4/11	1 year	$$$$
c) Industrial Filtration (Recycling)	1	1	1	1	4/11	1 year	$$$
d) Drawdown	1	1	1	1	4/11	1 - 3 years	$

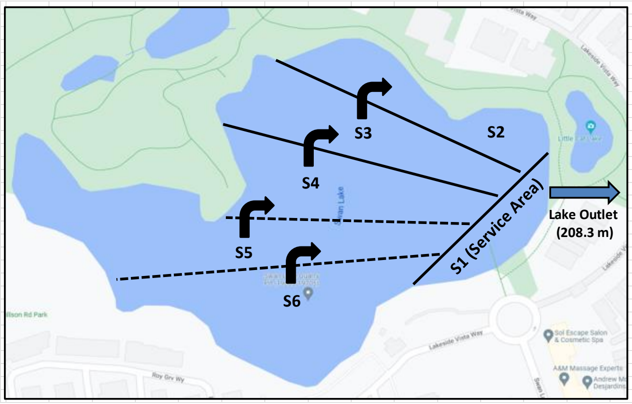
a) Recycling and Filtration Via the North Channel

Recycling of water via the North Channel as outlined in Appendix B will provide a basic means of enhancing oxygen levels. It is possible to add filtration materials such as:

1) In 2021, Fleming College[3] researchers suggested consideration of absorption material (such as Chlorocel, manufactured by Porocel) as a means for absorbing chloride from the water.
2) In 2022, researchers from York University[15] submitted a proposal to Markham to evaluate the effectiveness of carbon-based filters for removing phosphorus, nitrogen and chloride. Markham staff have indicated they plan further investigation of this concept.
3) A small industrial filtration unit outlined in the next section.
4) Expanding the existing bioswale elements of the North Channel and Turtle Inlet

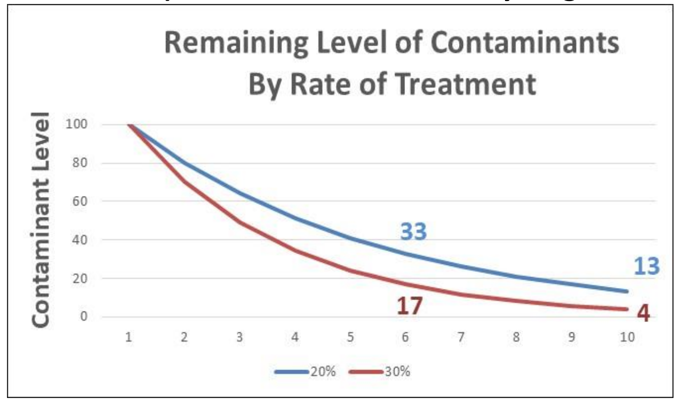
A high flow rate through the North Channel may be desired to maximize the benefits of lake circulation for oxygenation purposes. However, introducing a filtration process may require lower flow rates. The impact of filtration on the lake's water quality will be related to the effectiveness of the filtration process and the percentage of the lake that can be treated each growing season.

b) Filtration and Lake Partitioning



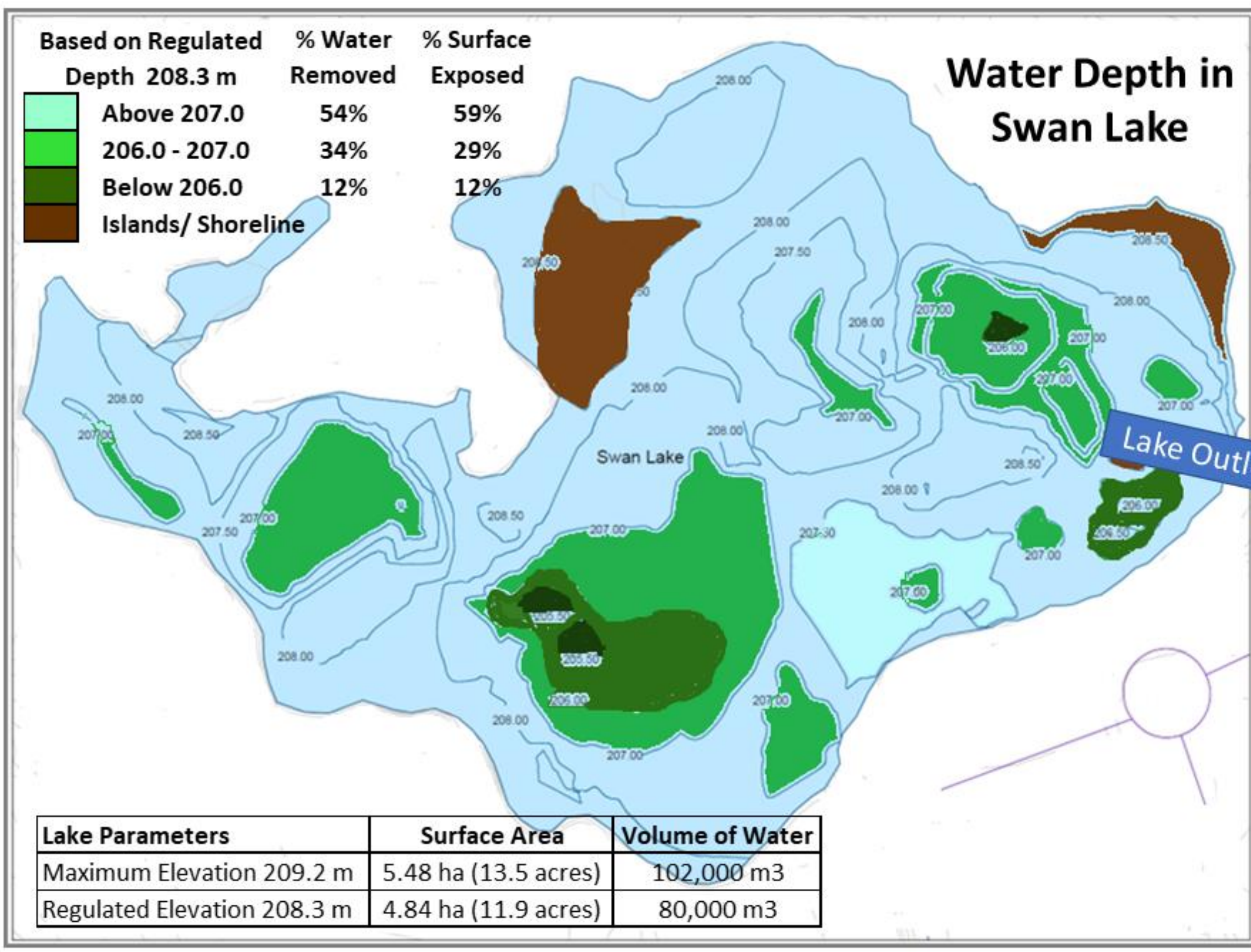
The more expensive industrial filtration option has the ability to restore the water within one season by partitioning sections of the lake and returning the clean water without mixing with the contaminated water. (See Appendix D)

c) Filtration and Lake Recycling



The recycling process using an industrial filtration system avoids the costs of partitioning but is less effective because it involves mixing the clean water back into the existing lake water and in effect retreating the diluted lake contents.

d) Drawdown of Lake Water



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

The lowest cost option appears to be a drawdown of the lake. With some minor modifications to the lake outlet, a gravity-driven drawdown to an elevation of 207.0 metres has the potential to remove 54% of the contaminants and expose 59% of the lakebed. With the addition of pumping capacity, it would be possible to remove all of the contaminated water within one season.

The lake water is expected to be restored over 1 – 3 seasons through precipitation and replenishment from the aquifer. If permitted by regulatory authorities, the replenishment could be accelerated by pumping water from the aquifer.

Drawdown to	**207.0 m**	**206.0 m**	**204.5 m**
Volume of Water Removed (m3) *	44,000	70,000	80,000
Area of Lakebed Exposed (m2) *	28,000	43,000	48,000
% of Water Removed	54%	88%	100%
% of Lakebed Exposed	59%	88%	100%
* Source: Swan Lake Long-term Plan November 2021, Page 5			

The drawdown would direct nutrient and chloride laden lake water into the stormwater system. Analysis suggests that the current design of the stormwater structure will support a drawdown over 30 – 60 days. Volume control mechanisms would provide the ability to control the rate of outflow from the lake. A technical analysis is required to confirm the analysis and appropriate outflow management process to minimize any downstream issues.

3) Comprehensive Water & Sediment Options

a. Partitioning, Industrial Filtration and Removal of Sediments
b. Drawdown and Removal of Sediments

These are the most comprehensive options but trigger additional issues and expenses primarily related to dealing with the sediments. There are four factors to consider in dealing with the sediments:

i. Sediment Quantity

The depth of the sediments is unknown, so a range of potential volumes was estimated based on an average depth of 20 cm – 35 cm based on estimates provided in an early report. The amount of the lakebed exposed depends on the technique utilized. A low-cost gravity fed drawdown of the lake to an elevation of 207.0 m. will expose approximately 59% of the lakebed. With pumps it would be possible to expose up to 100% of the lakebed. The more expensive partitioning option has the potential to expose up to 100% of the sediments.

It may be feasible to store 5,000 – 8,000 m^3 of sediment onsite raising the possibility that most of the sediments could be stored onsite if the lake were drawn down to 207.0 m. Any sediments removed in excess of the local storage capacity would have to be trucked offsite at greater costs.

Estimate of Sediment Volume (M3)						
Lake drawdown to	**207.0 m**		**206.0 m**		**204.5 m**	
Lake Bed Exposure (m2)	28000		43000		48000	
Average Sediment Depth	**20 cm**	**35 cm**	**20 cm**	**35 cm**	**20 cm**	**35 cm**
Sediment Volume	5,600	9,800	8,600	15,050	9,600	16,800
Onsite Storage Capacity	**% Stored Onsite**					
5,000 m3	89%	51%	58%	33%	52%	30%
8,000 m3	143%	82%	93%	53%	83%	48%

Testing will be required to determine the expected depth of the sediments and an estimate developed as to the onsite storage capacity.

ii. Sediment Quality

PetoMacCallum Limited oversaw the cleanup/remediation plan for the Swan Lake development which included reworking about 400,000 m^3 of soils onsite and removal of 5,000 m^3 of contaminated soil and debris plus removal of three underground storage tanks. They reported that there were some contaminants in the sediments that were in excess of the province's lowest quality benchmarks but that the level of contaminants was not harmful to aquatic or human health and could remain in place. This conclusion was supported by two other consultants. A summary of historical comments on sediment quality are provided in Appendix E.

Updated sediment testing will be required to determine if contaminants are a factor that would impact the onsite storage or removal options.

iii. Disturbing Former Dump Sites

There are former dumpsites along the southern (Block 9) and western shorelines (Block 15) of the lake that may contain additional contaminants so due to seepage there may be higher levels of contaminants in the sediment adjacent to these areas.

Removal of sediments from these areas would need to be managed to minimize any disruption to the shoreline. It may be feasible to design the onsite storage in a way to minimize the future risk of seepage from these sites.

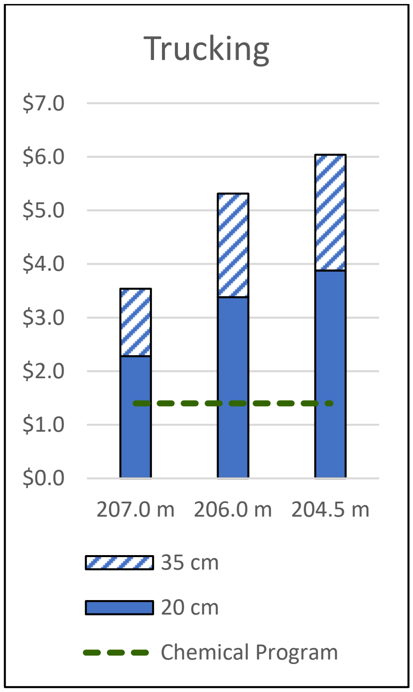
iv. Sediment Removal Costs

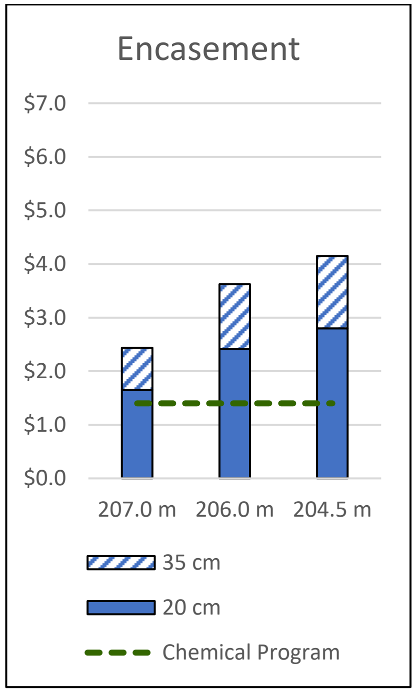
Three processes were considered in terms of managing the sediments:

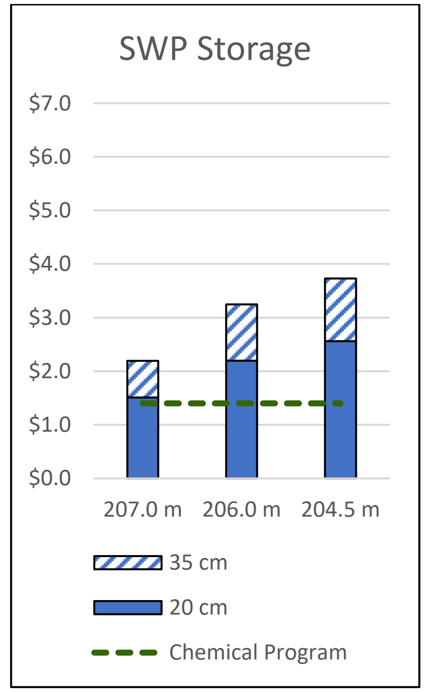
a) Offsite Disposal – trucking the sediments to a land fill site.
b) Storage onsite – using concrete encasements.
c) Storage onsite – using lower-cost stormwater pond techniques.

Cost estimates were development based on a basic project management cost of $0.6 - $1.0 million plus the costs for disposal or storage of the sediments. Sediment disposal costs and onsite storage costs were based on estimates outlined in a stormwater management guide developed by the Toronto and Region Conservation Area ("TRCA") and on information provided by Markham staff. Disposal costs including fees and trucking costs were assumed to be $300 per m^3, onsite concrete encasement to be $75 per m^3 and onsite storage using lower cost impermeable materials practices to be $25 per m³. If the risk of seepage from the former dump sites is seen as a significant issue, the concrete encasement option may provide a more secure way for storing the sediments. The cost estimates assume 50% of the sediments are stored onsite and 50% were trucked to a land fill site.

The following charts illustrate the costs of addressing the sediments relative to the $1.4 million budgeted for the chemical treatment program.







The development of the estimates of sediment volume and total project costs are outlined in detail in Appendix F and summarized in the table below.

Sediment Removal Options	Nutrients		Cl	O	Factors Addressed	Restoration Timeframe	Costs
	P	N					
a) Disposal Offsite (100%/0%)	1	1	1	1	4/11	1 year	$2.3 - $6.0 m
b) Concrete Encasement Onsite (50%/50%)	1	1	1	1	4/11	1 year	$1.7 - $4.2 m
c) SWM Storage Onsite (50%/50%)	1	1	1	1	4/11	1 year	$1.5 - $3.7 m

The estimates illustrate that the costs of removing the sediments may be significant however the costs may be justified:

a) If the costs are at least partially offset by a reduction in other costs, such as fewer chemical treatments and a reduction in ongoing monitoring costs.
b) If the additional costs provide a timelier improvement or greater certainty of improvement in water quality and a more stable environmental long-term outcome.
c) If the removal of the sediments increases the likelihood of a better outcome such as achieving a mesotrophic level of water quality, or
d) If the restoration of water quality will restore the ecological habitat and the community's use and pride in Swan Lake Park as the "Jewel of Markham".

VII) HOSTING A SOLUTION DESIGN WORKSHOP

The issues facing Swan Lake are complex and interrelated. The solution requires input from a multidisciplinary pool of talent. It has been suggested that often, in complex cases such as Swan Lake, an effective technique is to host a "Solution Design Workshop" which brings the various talents together to discuss the range of options and to narrow down the approach following which a plan is developed for a subsequent "peer review" by the workshop participants.

We recommend that Markham host a workshop in early 2024 to discuss the various restoration options. Skills in attendance would include: an independent facilitator with extensive restoration experience; limnologist (2); water resource engineer(s); someone experienced in management of sediments; fish and aquatic plant scientist(s); researchers; someone with broad project management experience on a similar project; representatives from City of Markham and Friends of Swan Lake Park.

Background Information Available for Consideration at the Workshop

We are fortunate in that there is extensive background information and data available on the issues facing Swan Lake.

The following existing information would be available for review by the participants prior to the workshop.

1) Swan Lake Long-term Management Plan, November 2021
2) 2023 Swan Lake Water Monitoring Report (with 2023 updated water quality measures).
3) Various analyses and reports provided by Freshwater Research.
4) Various reports provided by Friends of Swan Lake Park
5) Flow Diversion Study recommendations on feasibility of rerouting stormwater flows.
    a. Possible approaches:
        i. Altering local Swan Lake infrastructure and/or
        ii. Developing a solution in sync with upgrading of the system south of 16th Avenue in 2027-2028
    b. Expected impact of reducing annual inflows of road salt once implemented.
    c. Expected cost and potential timing of implementation.
6) Recommendations on the shoreline restoration.
    a. Original goals/ objectives and estimated costs of the design by TRCA/Markham Parks Operations
    b. Impact of rerouting stormwater flows on original design.
    c. Impact of onsite storage of sediments on original design.

Additional information that could be developed in 2023 and submitted to the workshop for consideration:

1) Review of feasibility/benefits of drawing down the lake water.
    a. Outline of issues/ concerns.
    b. Outline of regulatory approvals required/ issues/concerns.
    c. Alterations required to modify the lake outflow chamber (costs, flow management approaches.)
2) Review of the feasibility/benefits of removing the sediments
    a. An assessment of sediment quality and quality:
        i. Sediment analysis undertaken in 2020.
        ii. Possibly more extensive testing of samples taken in 2020.

iii. Possibly additional testing for contaminants.
iv. Estimate of sediment depth and volume of sediments within the lake.
b. Feasibility and estimate of volume that potentially could be stored onsite and cost parameters.
c. Estimate of project costs including offsite removal costs and onsite storage costs.

3) Recommendation on the planned chemical treatment for 2024 (Phoslock or PAC)
4) Reports on the research work undertaken by:
   a. 2021 Fleming College report on possible engineering techniques.
   b. AECOM review of the Fleming College research proposal on the use of calcium peroxide for oxygenation enhancement.
   c. York University research findings on the use of charcoal filters for removal of nutrients and chloride.
   d. University of Toronto research findings on the impact of circulation on the release of nutrients from the sediments.

Workshop Discussion Items

a) If the drawdown of the lake is feasible from an engineering perspective:
   i. What are the restoration benefits in terms of removal of nutrients and chloride?
   ii. Should a drawdown be only to 207.0 m – removing 54% of the water or should more be removed?
   iii. What are the issues/concerns relating to refilling of the lake?
   iv. Is this an approach that would have long-term benefit as a management tool to periodically clear out the buildup of nutrients and chloride. If so, what frequency?
b) Is removal of sediments feasible?
   ii. Would removal result in material improvement and/or greater certainty of water quality outcomes?
   iii. Are there any potential reductions in other costs?
   iv. When could/should removal occur (before/after realignment of stormwater routes)?
c) Should the chemical program be continued and at what frequency?
   i. Temporarily until sediment removal completed. Thereafter?
   ii. Permanently if sediments are not removed?
d) Are oxygenation techniques required?
   i. Are they helpful or harmful during the restoration phase?
   ii. Are they essential/beneficial for sustaining improved water quality post-restoration?
   iii. Recommended oxygenation techniques: 1) mechanical bubblers 2) circulation equipment 3) recycling via the North Channel?

Potential Outcome from Workshop

The recommendations of the workshop would provide the framework for the development of an updated comprehensive plan and provide Council and the community with guidance on four critical topics:

1) What level of water quality is achievable and sustainable and at what cost?
2) Is it worth investing to reroute the stormwater?
3) Is a drawdown of the lake beneficial and can it be managed safely?
4) Is it worth investing to remove the sediments?

Two possible outcomes are expected: A water-only restoration plan or a restoration plan that addresses the sediments. Two illustrative examples are provided.

Path #1: An illustration of a possible "Water Only" outcome

A water-treatment only option that would build upon the current geese management and chemical treatment program and likely incorporate an initial drawdown to address chloride loads in the lake plus a sustainable oxygenation program such as recycling via the North Channel

Path #1: Water Treatment Only	Factors Addressed	Restoration Timeframe	Costs	Benefits/Concerns
Geese, Fish Management & Monitoring	2/11	10 + years	$3.2 m	Includes monitoring costs of $0.9 m
Rerouting stormwater, maintenance	1/11	3 - 5 years	$0.7 m +	Essential. Excludes rerouting costs
Drawdown	4/11	1 - 3 years	$	Addresses chloride, Downstream, Refill
Recycling Via North Channel	1 - 4/11	10 + years	$ - $$	Additional costs if filtration added
Chemical (Phoslock/PAC)	**2.5/11**	**10 + years**	**$1.4 m**	**Addresses only Phosphorus**
Comprehensive Water Treatment Plan	**9/11**	**10 + years**	**$5.3 m +**	**Continuing sediment impact, uncertainty of success, timeline**
* Costs exclude Shoreline Restoration & Rerouting Stormwater				

Path #2: An illustration of a possible "Water and Sediment" outcome

A plan including a drawdown to reduce chloride combined with removal of some of the sediments plus a sustainable oxygenation program such as recycling via the North Channel may provide an opportunity to discontinue the chemical treatment program.

The core question to be answered is whether the potential additional costs of addressing the sediments materially increases the environmental outcomes and reduces other costs.

Path #2: Water & Sediment	Factors Addressed	Restoration Timeframe	Costs	Benefits/Concerns
Geese, Fish Management & Monitoring	2/11	10 + years	$3.2 m	Potential to reduce water monitoring costs
Rerouting stormwater	1/11	3 - 5 years	$0.7 m +	Essential. Excludes rerouting costs
Drawdown	4/11	1 - 3 years	$	Addresses chloride, Downstream, Refill
Recycling Via North Channel	1 /11	10 + years	$	Reduces need for additonal filtration
Sediment Removal & Storage (SW)	**7/11**	**1 year**	**$1.5 - $3.7 m**	**Shoreline Restoration Impact, Capacity**
Comprehensive Water & Sediment Plan	**11/11**	**10 + years**	**$5.4 - 7.6 m +**	**Faster aquatic recovery, greater assurance of success, potentially better results, potential to reduce monitoring costs**
* Costs exclude Shoreline Restoration & Rerouting Stormwater				

VIII) RECOMMENDATIONS

1) **That Markham host a Solution Design Workshop in early 2024 with the goal of providing guidance on the appropriate path forward for an updated long-term water quality plan.**

In preparation for the workshop the following activities should be approved:

a. Completion of current undertakings in 2023:
   i. Completion of the design phase of the shoreline restoration project.
   ii. Completion of the Flow Diversion Study into the feasibility, costs and timing of rerouting stormwater flows from the lake.
   iii. Expand the scope of the Flow Diversion Study to include a report on the technical feasibility of a drawdown of water from Swan Lake during periods of low or no precipitation.
   iv. Support for the York University research into means of removing nutrients and chloride**.**

b) Support research in 2023 into the following:
   i. University of Toronto research into whether oxygenation will increase phosphorus release from the sediments during restoration.
   ii. Research into the biological benefits of using a drawdown of the lake as a management tool during the restoration phase and as a future management tool for sustainability.
   iii. Research into the cost/benefits of the removal of sediments as a management tool.
   iv. Research into whether oxygenation processes are helpful or a hindrance during the restoration phase and whether they should be a component of a long-term sustainable plan.

3) **That following the Solution Design Workshop that staff submit a draft Comprehensive Water Quality Plan for a “Peer Review” by the Workshop participants before submission to Council for consideration and approval.**

REFERENCES:

Swan Lake Reports:

1) "Swan Lake Monitoring Report (March 2023)" – City of Markham
2) "Swan Lake Long-term Water Quality Plan", City of Markham, November 16, 2021
3) "Literature Review of Potential Engineering Solutions for the Restoration of Swan Lake", Barbara Siembida-Lösch, Fleming College, February 2021.
4) "A Pathway to Sustainable Water Quality for Swan Lake", Friends of Swan Lake Park, Dec. 2020
5) "Swan Lake Water Quality Management", Freshwater Research, July 17, 2020
6) "Geo-Environmental/Hydrogeological Investigation and Analysis Lake Water and Sediment Quality Assessment", PetoMacCallum Ltd., March 1994
7) "Report of Site Cleanup/Remediation Swan Lake Development", PetoMacCallum Ltd., Sept. 1995
8) "Environmental Assessment Swan Lake Block 15, Proposed Parkland", Barenco, March 2000
9) "Environmental Quality Assessment of Sediment Samples, Swan Lake, Block 9", Gartner Lee Limited, February 2003
10) "Review of Environmental Reports and Assessment of Proposed Land Severance Block 9 of Swan Lake", Jacques Whitford Environmental Limited, May 23, 2003
11) "Environmental Quality Assessment of Swan Lake, Block 9", Gartner Lee Limited, Jan. 2006
12) "Risk Assessment for Block 9", Water and Earth Sciences Associates, March 2006
13) "Swan Lake Sediment Analysis, Summary Report", Dr. Nowak Institut, October 23, 2020
14) Research Proposal on Use of Oxygen Releasing Compounds, Dr. Barbara Siembida-Lösch, Centre for Water and Wastewater Technologies, Fleming College, April 2022
15) Research into Removal of Nutrients and Chloride from Swan Lake, Dr. Rama Pulicharla, Dr. Satindar K Brar, York University, May 2, 2022
16) Research Proposal into Nutrient Release from Sediments, Dr. Amy Bilton, University of Toronto
17) "Rules for Soil Management and Excess Soil Quality Standards, Ontario
18) "Calcium Peroxide and Biochar Proposals – Review", Tammy Karst-Riddock, AECOM, April 18, 2023
19) Markham Sewer Use By-law 2014-71

Selective Academic References

A1 T. Shatwell, J. Kohler, "Decreased nitrogen loading controls summer cyanobacterial blooms without promoting nitrogen-fixing taxa: Long-term response of a shallow lake", Limnology and Oceanography, 2019

A2 Stephen C Maberly, Jo-anne Pitt, P. Sian Davies, "Nitrogen and phosphorus limitation and the management of small productive lakes", Taylor & Francis Online, March 23, 2020

A3 Xiaodan Jin, Yiliang He, Bo Zhang, "Impact of Sulfate and Chloride on Sediment Phosphorus Release in the Yangtze Estuary Reservoir, China" , 2013

A4 Jovana Radosavljevic, Stephanie Slowinski, Mahyar Shafii, "Salinization as a driver of eutrophication symptoms in an urban lake (Lake Wilcox, Ontario)", Science of the Total Environment 2022

A5 Alexandra McClymont, "The Effect of Increasing Chloride Concentration and Temperatures on Freshwater Zooplankton Communities" , Queens University, February 2020

A6 R. Gachter and B. Wehrli, "Ten Years of Artificial Mixing and Oxygenation: No Effect on Internal Phosphorus Loading of Two Eutrophic Lakes", October 15, 1998.

Appendix A: Focused Solutions

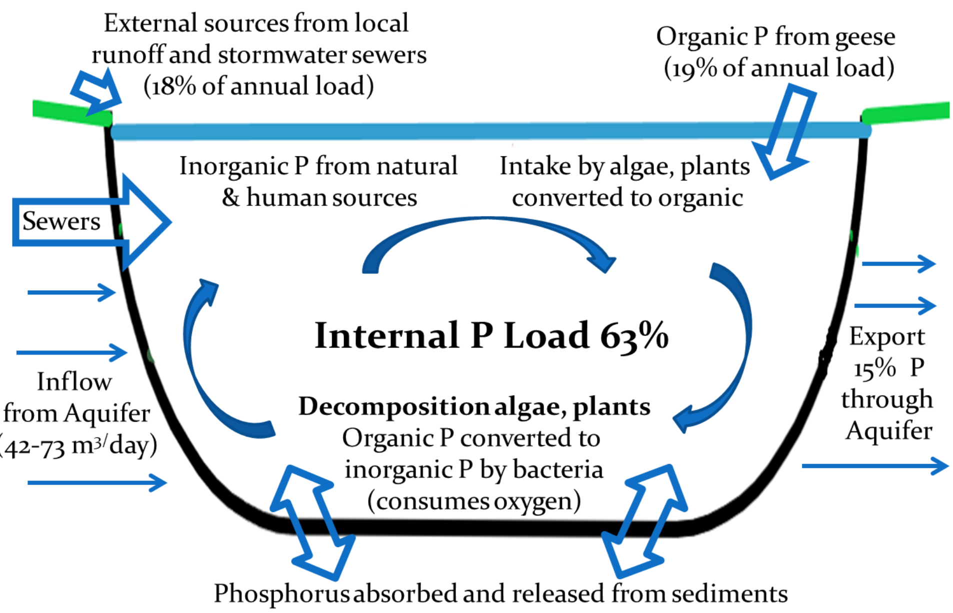
a) Algae Removal Options

A variety of techniques for targeting algae and cyanobacteria were reviewed by Freshwater Research[5] and considered to be ineffective.

Equipment, such as the Aecom unit shown here, are capable of harvesting concentrated amounts of algae.

Freshwater Research concluded that the high-water content and low concentration of algae within Swan Lake make this approach ineffective as a management tool.

b) Nutrient Focused Programs: Phosphorus and Nitrogen



The Phosphorus Cycle in Swan Lake (2017 – 2018)

Nutrients, such as nitrogen ("N") and phosphorus ("P"), are essential for plant and animal growth and nourishment.

Excess nutrients can cause overstimulation of growth of aquatic plants and algae. Excessive growth of these organisms block sun light to deeper waters and use up dissolved oxygen as they decompose.

Goose feces contain both phosphorus and nitrogen. Studies have shown that the contribution of nitrogen and phosphorus attributed to waterfowl can account for as much as 40% of the nitrogen and 85% of the phosphorus input to a lake. Markham has introduced a successful geese management program that has reduced the number of resident and migratory geese visiting Swan Lake.

Other than the years immediately after the Phoslock treatment in 2013 and the PAC treatment n 2021, phosphorus and nitrogen levels in Swan Lake are consistently reported to be within the hypereutrophic range.

Freshwater Research describes Swan Like as "polymictic" because of its relatively shallow depth.

In a 2019 study[A1], Shatwell and Kohler note that "currently there is a lack of scientific consensus about whether eutrophication is best managed by controlling P alone, or by controlling both N and P". Their study reviewed 37-years of data on a German lake during periods of reduced phosphorus and nitrogen loading and concluded that "dual N and P control can be an effective strategy to mitigate eutrophication. Particularly in polymictic lakes where summer internal P-loading and denitrification rates are potentially high, the lower N-loading can induce stronger summer N-limitation and in turn effectively control cyanobacterial blooms in the long term."

Another study released in 2020 by Maberly, Pitt and Davies[A2], of shallow lakes in England concluded that "even in P-limited sites, once input of P has been reduced, further ecological benefit of reducing N at targeted sites should be explored". The study noted that a Policy Forum Review in Science concluded that "amelioration of the negative impacts of nutrient enrichment should be made by control and reduction of both N and P."

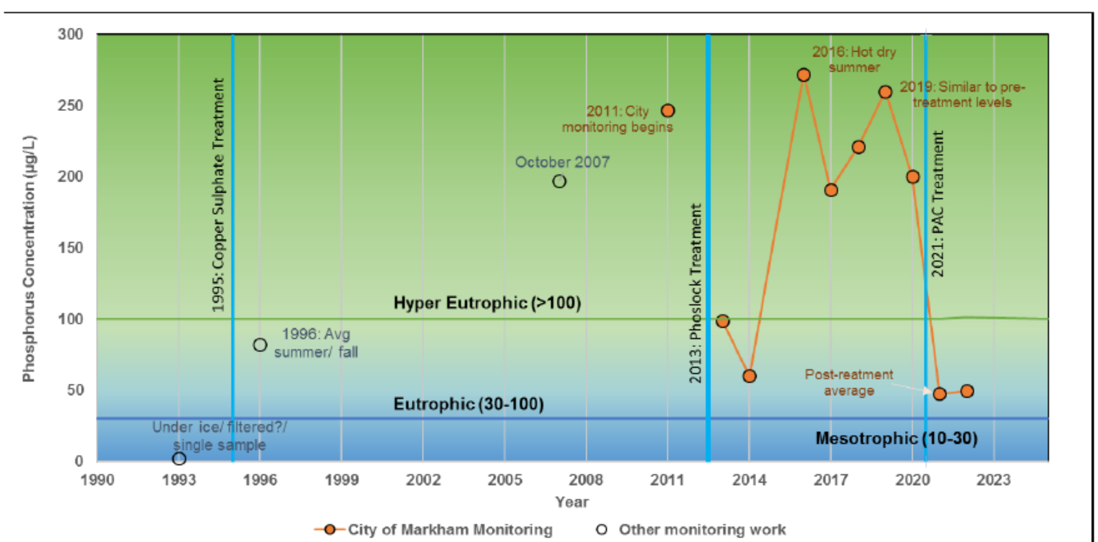
Swan Lake's Phosphorus Focused Program

The focus of the Swan Lake Long-term Management Plan is on reducing phosphorus as the primary nutrient by adding Phoslock or Poly Aluminum Chloride ("PAC") every few years. In 1995, a treatment of Copper Sulphate was applied.

An application of 25.2 tonnes of Phoslock was applied in 2013 and there was a reduction in phosphorus for two years. In 2021, Freshwater Research outlined the benefits of more frequent applications of Phoslock and subsequently a program was implemented to apply Phoslock in 2021 with a follow up application planned for 2024. Due to import restrictions Phoslock was not available in 2021 so an application of 13 tonnes of PAC was applied in August 2021. Recent analysis of the 2022 water quality suggests that some improvement in phosphorus levels in 2021 and 2022 to eutrophic levels following the PAC treatment in July 2021.

The following chart from the 2022 monitoring report (Appendix G) illustrates the impact of the three phosphorus treatment programs administered. Indications are that the benefits are short-lived.

Figure 13: Trophic State Classification for Swan Lake based on Phosphorus Concentration



Is a Nitrogen Focused Program Needed?
Nitrogen, in the forms of nitrate, nitrite, or ammonium, is a nutrient needed for plant growth but is also one of the core nutrients that can contribute to excessive growth of algae.

Lake sediments represent an important source of nitrogen. Nitrogen is released from the sediments in the form of ammonium which can then be transformed into forms that are readily usable for algal growth. The 2022 monitoring report (Appendix G) notes that:

> "Total the nitrogen concentrations the growing season averaged 0.60 mg/L (below the 1.2 mg/L threshold for a hyper-eutrophic condition. In 2022, Ammonia and nitrate concentrations (the forms available for uptake by biota) were generally very low (except in April), and nitrogen was mainly present as organic matter."

The chemicals used to control phosphorus do not directly impact nitrogen levels and at present there is no program focused on addressing nitrogen levels in Swan Lake.

As noted above, recent research suggests that an effective restoration program needs to consider the impact of both phosphorus and nitrogen triggering the following questions:

1) What options other than geese management are available for reducing nitrogen levels in Swan Lake?
   a. Is there a chemical program that can help manage nitrogen levels in Swan Lake?
   b. Would the drawdown of the lake materially reduce nitrogen levels?
   c. Would removal of sediments materially contribute to a reduction of nitrogen levels in Swan Lake?
2) Can we achieve mesotrophic levels of water quality without dealing with nitrogen levels?

c) Chloride Focused Options: Desalination

Chloride levels in Swan Lake are very high and are 4x-6x the safe level for aquatic life. The high levels undermine restoration of the lake in at least two ways:

1) Researchers[A3] believe that chloride enhances the release of phosphorus from the sediments which in turn spurs algae growth. A recent study [A4] of Lake Wilcox in Richmond Hill associated an increase in algae to an increase in chloride levels.
2) Other research[A5] concludes that chloride kills lower-level aquatic life (zooplankton) that consumes algae and is a natural ally in controlling algae.

There are no simple chemical treatment processes for removing chloride arising from road salt. Investigation is underway to minimize the future inflow of road salt, but it is expected that while it may be possible to significantly reduce the inflows there will likely be continuing inflows into Swan Lake because of its role as a flood control mechanism.

There is an estimated 40 tonnes of chloride within the water in Swan Lake. The amount of chloride that is now stored within the sediments but could potentially be released is unknown. Three approaches were considered for the removal of the 40+ tonnes of chloride currently active in Swan Lake water:

1) Use of desalination equipment outline below.
2) Drawdown of lake water as outlined in Appendix C.
3) Use of filtration techniques as outlined in Appendix D.

Addressing the chloride in the sediments would require removal of the sediments or a continuing program to remove chloride from the water.

Desalination Equipment

Equipment and processes have been developed to remove salt from water, primarily for the purpose of generating drinking water.

The approaches range from low-cost wind and solar driven devices designed for use in remote villages as illustrated here, to multi-billion-dollar plants for generating large volumes of drinking water for major cities.

To remove 40+ tonnes of chloride already in Swan Lake will likely require sizable processing equipment which suggests that a more comprehensive treatment process such as industrial filtration or a drawdown which address other elements as well as chloride would be more viable solutions for restoration.

d) Oxygenation Options

Dissolved oxygen (DO) is a measure of how much oxygen is dissolved in the water - the amount of oxygen available to living aquatic organisms. Dissolved oxygen in surface water is used by all forms of aquatic life; therefore, it is measured to assess the "health" of lakes and streams.

Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, whereas stagnant water bodies such as Swan Lake contain less.

Bacteria in water can consume oxygen when organic matter, such as algae, decays. Thus, the decay of excess organic material in lakes can cause an oxygen-deficient situation that can cause a water body to "die." Aquatic life can have a hard time in stagnant water that has a lot of rotting, organic material in it, especially in summer when dissolved-oxygen levels are at a seasonal low. Water near the surface of the lake is too warm for aquatic life, while water near the bottom has too little oxygen.

It is expected that the current chemical treatment process, which is focused on reducing phosphorus levels will indirectly improve oxygen levels by reducing the algae in the lake and thereby reducing the consumption of oxygen in the autumn as the algae decays.

Investigation is required into the best options for improving oxygen levels in Swan Lake. There are two dimensions to the issue:

i. Are improved oxygen levels helpful or a hindrance to the restoration process?
ii. Once restoration is achieved, are processes to improve oxygen levels essential to sustaining the restored water quality?

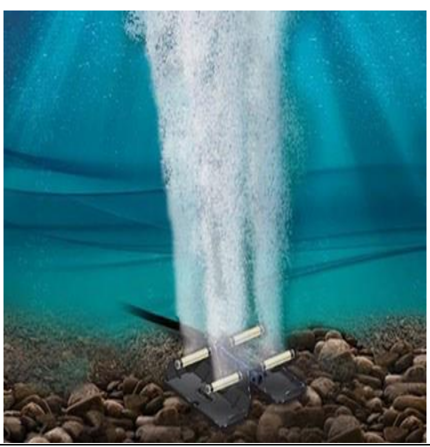
Several of the processes, such as drawdown, desalination or industrial filtration provide an indirect opportunity to add oxygen to the water as it is returned to the lake. These processes tend to provide a one-time benefit during the process but do not address the long-term challenges of sustaining restored oxygen levels.

Three possible options were considered:

a) A proposal by Fleming College[14] on the use of calcium peroxide as a means to stimulate oxygen levels is under review by Markham staff. Staff have concluded that the process may have potential but is still at a very early stage of research and is not worth pursing at this time. It is recommended that this review be shared with the participants in the proposed workshop.
b) Permanent recycling via the North Channel as outlined in Appendix B.
c) Installation of oxygenation equipment.

Oxygenation Equipment

There are several styles of equipment options for directly adding oxygen to lakes and ponds. These approaches are aimed at reducing the internal sources of phosphorus and can have a material impact on increasing dissolved oxygen levels. The equipment options include the ability to not interfere with the stratification of the different layers of water or alternatively to intentionally mix the layers. Further analysis is required to assess the best options in a post-restoration environment. Fountains tend to provide only surface level aeration. The fountain that had been in use until recently in Swan Lake was considered decorative, providing only minimal aeration benefit.

Bubblers	Solar Bee® Lake Circulators	U of Toronto Research
Bubblers add oxygen but tend to mix the layers.	Active lake circulation can be limited to only the top layer or to treat the bottom water.	Researchers have designed a low-cost wind powered aeration device for use in fishponds in remote areas.
		

Oxygenation through mechanical means such as circulators has been rejected by Freshwater Research, as ineffective during the restoration phase because the sediment demand for oxygen is so high and increased temperatures at the lower levels may also add to the increased release of phosphorus.

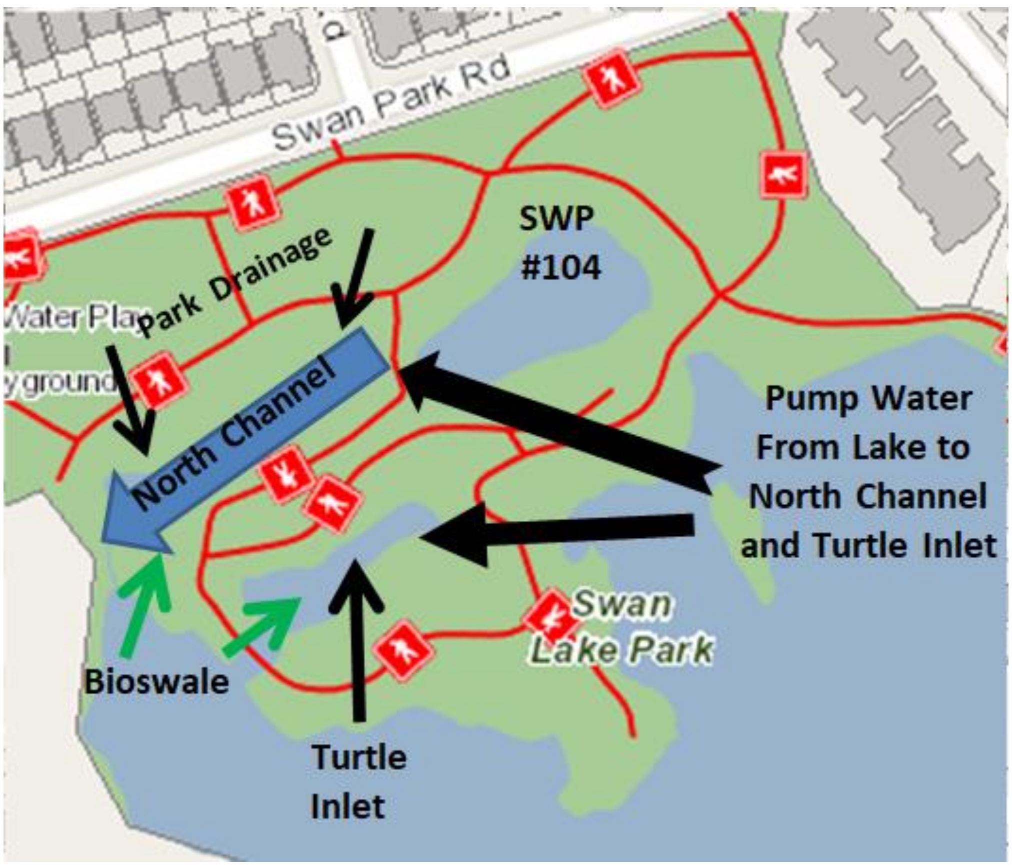
Consideration needs to be given as to whether increasing the release of phosphorus from the sediments may in fact be beneficial when done in combination with a chemical treatment program such as Phoslock or PAC.

Appendix B: Recycling Through the North Channel

Swan Lake is a stagnant body of water with no natural surface level inflows or outflows and has a very long hydraulic detention time ("HDT").

Circulation is considered one of the primary methods for increasing oxygen levels. Fleming College[3] indicated that a lake mixing strategy may need to be developed as a tool in the control and prevention of excessive algal growth. The report notes that as a general rule, an HDT between 20 – 30 days at least 80% of the time is recommended and cites reports indicating the most sensitive lakes are those with a detention time greater than 30 days.

Removing water from the lake and returning it to the lake oxygen enhanced with possibly fewer nutrients could provide a natural enhancement to the water quality in the lake and reduce the dependency on future chemical treatments. This could be accomplished by recycling lake water through the North Channel, a dry channel along the north end of Swan Lake that serves to drain stormwater from the north end of the park. A small portion of the channel is a bioswale which it may be possible to extend. It also may be feasible to circulate water from the lake into Turtle Inlet, creating a decorative waterfall.



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

Turtle Inlet is a small, shallow inlet that has potential to be enhanced as a bioswale.

Pulling from and returning water to the lake will create circulation throughout the lake. Concern has been raised that the circulation will lead to more frequent mixing of the cool lower water with the warmer surface level waters resulting in more nutrients being released from the sediments and potentially stimulating further algae growth. However, one study[A6] indicated that increasing lower-level oxygen content had no effect on the release of nutrients from the sediment.

Consideration must be given as to whether increased mixing is a detriment to the restoration effort. Potentially the possible release of nutrients from the sediments, if any, may in fact be beneficial in combination with a regular chemical program designed to reduce the phosphorus contribution from the sediments.

Circulation: A Tool for Sustaining Restoration Efforts
Once the water quality is restored the challenge remains to sustain the improved water quality. Without circulation, Swan Lake will continue to be a stagnant body of water and face the inherent challenges.

Recycling provides a low-cost, perpetual oxygenation process. Whether or not recycling is beneficial during the restoration phase, recycling and filtering via the North Channel and should be considered as an inherent component of a long-term sustainable plan for lake management.

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

a) If the emphasis is primarily oxygenation and reducing the hydraulic detention time in the lake, then a high-volume pump may be required.
b) If the emphasis is a combination of filtration and oxygenation, then pumping lower volumes in line with the capabilities of the filtration process will be needed.

Lake Turnover (80,000 m3) April - October (214 days)		
Pump Size	**1 HP**	**1.5 HP**
Capacity (m3/24 hr)	**50**	**200**
100%	13%	54%
50%	7%	27%

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

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

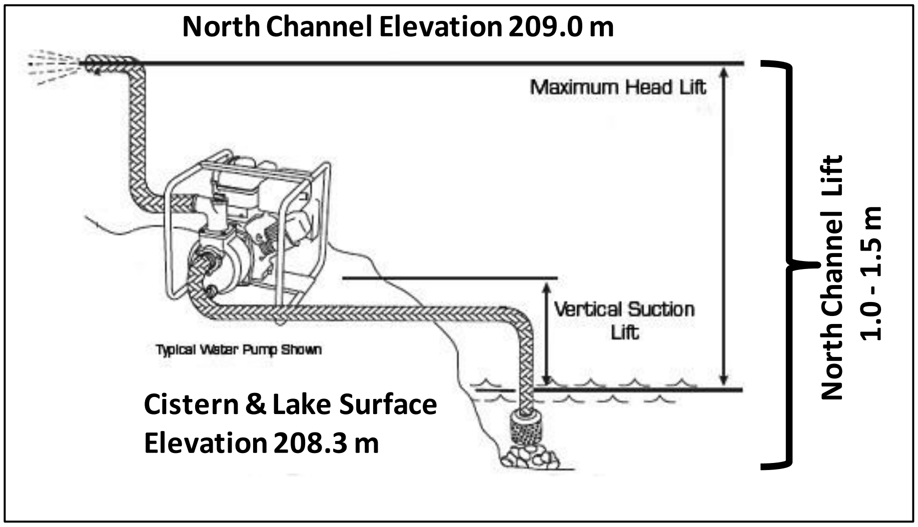
Driven by either solar sources or by repurposing the existing windmill on the north pond, assuming 50% efficiency, the small pumps would have the capability to recycle 7% - 27% of the 80,000 m^3 of lake water over the summer months.

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

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

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

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



The North Channel is at an elevation of 209.0 m. or 0.7 m. above the regulated lake level. Depending on the location of the intake head within the cistern, the maximum head lift height to the North Channel surface is expected to be 1.0 – 1.5 m.

Repurposing the Existing Windmill

It may be possible to repurpose the existing windmill and to add solar panels as a low-cost energy source for supporting a “cottage-style” pump.

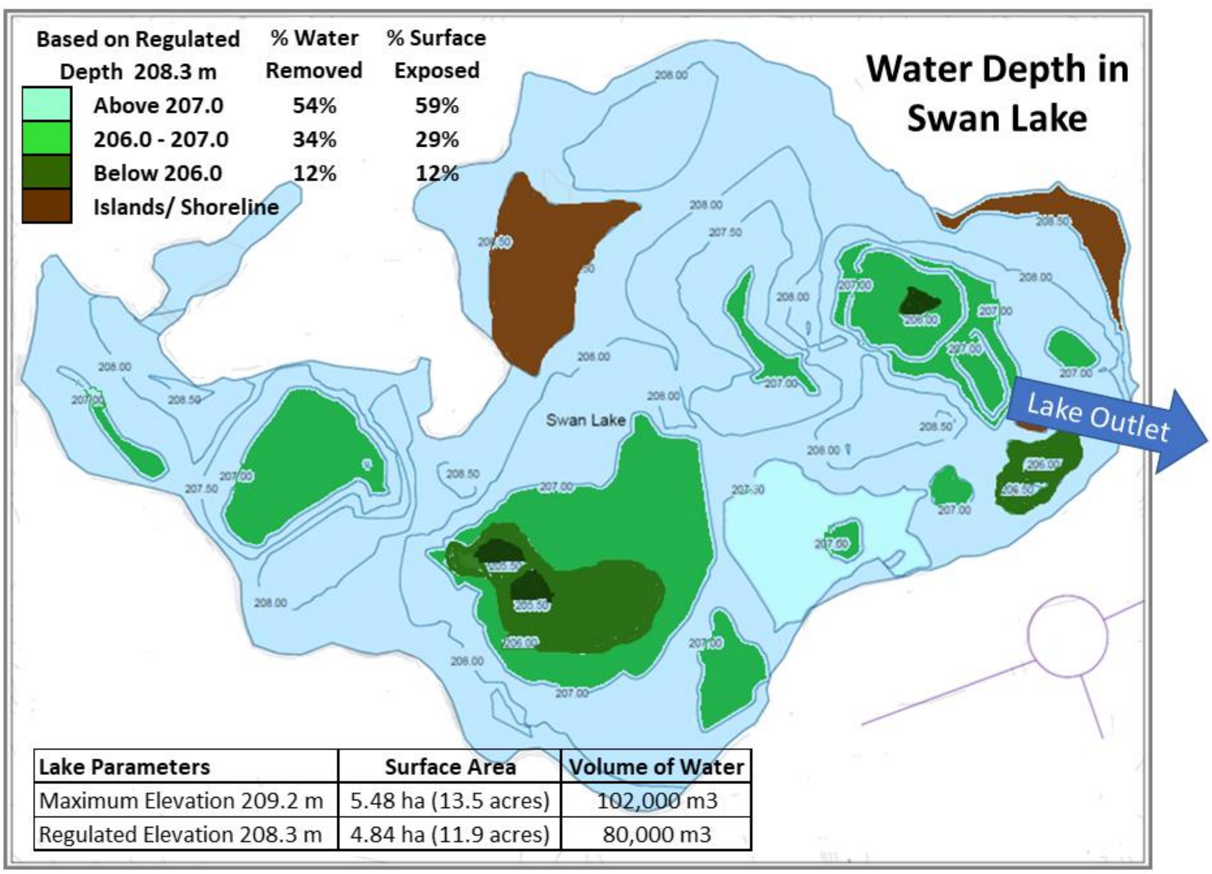
Appendix C: Controlled Winter Drawdown of Swan Lake

Swan Lake is a very shallow lake. Its depth is regulated to an elevation of 208.3 m. by a concrete control structure on the south-eastern shoreline. There is an outlet pipe near the bottom of the chamber at an elevation of 207.0 m, 1.3 m below the top edge of the chamber, making it feasible to develop a low cost, controlled gravity-driven drawdown to 207.0 m.

The 2021 Swan Lake Long-term Plan provided data on the depth and volume of water in Swan Lake and the lakebed exposed at various depths.

Drawdown to	207.0 m	206.0 m	204.5 m
Volume of Water Removed (m3) *	44,000	70,000	80,000
Area of Lakebed Exposed (m2) *	28,000	43,000	48,000
% of Water Removed	54%	88%	100%
% of Lakebed Exposed	59%	88%	100%
* Source: Swan Lake Long-term Plan November 2021, Page 5			

Reducing the lake depth by 1.3 m to 207.0 m would remove over 54% of the contaminated water and expose all the light blue areas in the chart below – suggesting that approximately 59% of the lake bottom sediments would be exposed thus providing an opportunity for the treatment and/or removal of the sediments.



Additional efforts could be undertaken to pump water down to 206.0 m which would remove 88% of the water and expose 88% of the sediments. A full drawdown would occur at 204.5 m.

A drawdown of water from the lake would be categorized as a “dewatering activity” under Markham’s Sewer Use By-law 2014-71 which regulates quality standards for water entering the sewer system. Swan Lake water would appear to satisfy the By-law requirement that water entering the storm sewer system not be categorized as “contaminated” as defined by Table 2 within the By-law and that it falls within the acceptable pH range of 6.0 – 9.0. Notably Table 2 excludes a standard for chloride. Approval may be required to discharge the high chloride content of Swan Lake water into the downstream system.

Removal of water contaminated with nutrients and chloride would refresh the water within the lake with cleaner water from the aquifer and through precipitation. In the 1970’s, once quarry operations ceased, the lake filled up naturally. As it may take 2-3 seasons for the lake to naturally refill, this process could be accelerated by pumping water into the lake from the local aquifer. A previous report noted that the static ground water level was about 9 metres below grade in Block 15, which is elevated about 3 metres above the lake level suggesting the aquifer is 5 – 6 metres below the lake surface. An analysis of the hydrology and hydrogeology involved in refilling the lake is required as well as an investigation of any possible regulatory issues related to drawing water from the aquifer.

Managed Drawdown Option

At its regulated elevation of 208.3 m, Swan Lake contains 80,000 m^3 of water. A drawdown to 207.0 m would remove approximately 44,000 m^3 or 54% of the total water volume in the lake through the downstream storm sewer system.

Since the lake outflow pipe is 1.3 m below the regulated lake surface, it should be possible to draw the lake water down by 1.3 m without the use of pumps. Pumps would be needed to remove water from areas where the water does not flow freely towards the lake outlet at 207.0 m and for removing water below 207.0 m.

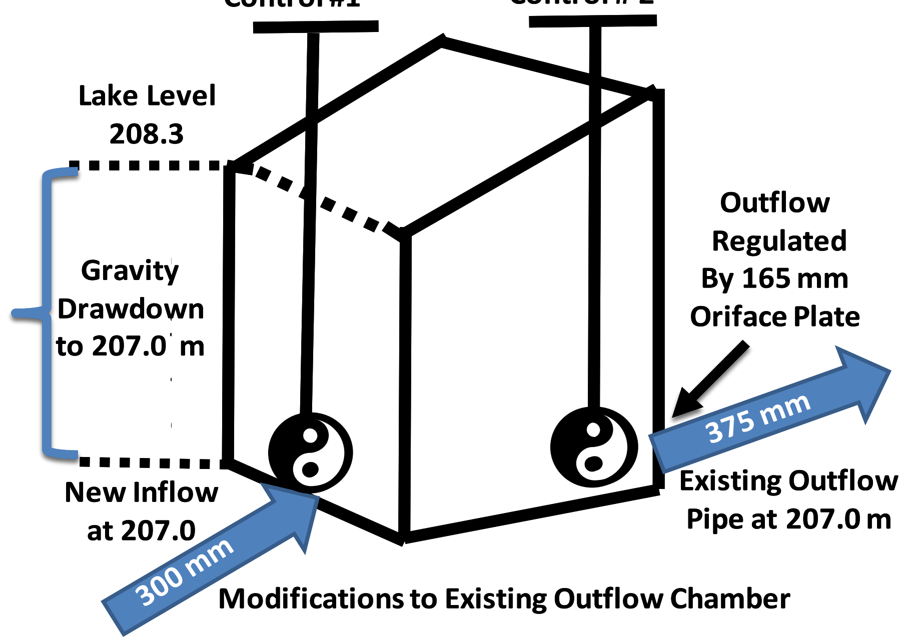
Lake Outflow Grate **Inflow from East Pond Bypass**

Two basic modifications would be required to support the gravity-driven drawdown. These modifications would not reduce the existing flood protection elements within the original design and in fact there is an opportunity to improve the flood protection mechanism by installing an additional outlet control mechanism. They include:

1. The lake is very shallow near the lake outlet. The first modification required would be to dig a 1.3 m deep trench from the lake outlet area about 10 - 20 metres towards one of the deeper areas so the lake can drain naturally down to 207.0 m. Sloping the sides of the trench would help minimize any erosion activity along the length of the trench. Near the outlet chamber, installation of 2-3 large stones should help stabilize the side slopes.
2. The second modification would be to create a new 300 mm opening in the upstream wall to enable flows into the chamber at the 207.0 m level.

   To control the flows through this new opening a Sluice Control Gate (#1) would be required. The gate would be opened only during the drawdown process – either fully or only partially depending on the rate of flow desired for the drawdown. It may be necessary to provide a platform on the existing chamber to provide operators with easy and safe access to the sluice control gate mechanisms.

Illustration of a Circular Sluice Control Device



Modifications to Existing Outflow Chamber

Though not necessary for the drawdown, installation of a second sluice control gate (#2) would provide the city with a means for stopping outflows from the lake and help alleviate downstream issues during periods of future flooding.

System Capacity Restrictions

Outflows from the Swan Lake and Swan Lake Village stormwater system are regulated at two levels by use of orifice plates. The first stage of regulating flows is at the source – at the East Stormwater Pond and at the lake outlet. Additional protection is provided at the 16th Avenue outlet where the combined pond, lake and Foundation Collector System flows leave the area and proceed south of 16th Avenue.

Orifice plates are used to reduce average flows leaving an area and to reduce surges in the outflow. An orifice plate consists of a large medal plate that is placed over a large pipe with a hole smaller than the pipe.

At the lake outlet, the orifice plate covers the 375 mm stormwater pipe, and the cutout is 165 mm in diameter. The lake level is 1.3 m above the outlet. The flow rate and volume of water that can flow through the small orifice is influenced by the water pressure. For the lake and pond this is primarily determined by the depth of water above the outlet (the "head").

The East Pond is regulated to stay at an elevation of 208.3 m but could increase by 0.5 m to an elevation of 208.8 m. during normal operations.

Detailed information is available on the expected outflows from the East Pond based on the water depth. The following table provides some estimates for the lake outlet and for the outlet to 16th Avenue based on use of an on-line calculator for flows through an orifice using the parameters specified for the East Pond. More detailed calculations would be part of a comprehensive drainage study.

	Diameter of SW Pipe	Diameter of Orifice	Area of Orifice (m2)	Depth of Water (m) (Head)		Discharge Rate (m3/s)		Discharge Volume (m3) Per Day (24 hr)	
				Max	Avg	Max	Avg	Max	Avg
East Pond Outlet	250 mm	66 mm	0.0034	1.6	0.5	0.012	0.006	1,037	518
Lake Outlet	375 mm	165 mm	0.0214	1.3	0.7	0.067	0.049	5,789	4,234
Combined Flows								6,826	4,752
16th Avenue Outlet	450 mm	190 mm	0.0284	1.0	0.5	0.078	0.055	6,739	4,752

The summary indicates that combined flows from the East Pond outlet system and the lake outlet system would support daily output volumes of 4,752 – 6,826 m^3, comparable to the flow rate supported at the 16th Avenue system. The maximum flow release from the lake outlet alone is approximately 85% of maximum outflow rate supported at 16th Avenue, so during periods of no rainfall an unrestricted release from the lake is within the system design limits for flows entering the area south of 16th Avenue.

Days to Release Water From Lake

Total Volume (m3)	Lake Discharge Rate (m3) Per Day: Avg	Lake Discharge Rate (m3) Per Day: Max
	4,234	5,789
44,000	10.4	7.6
70,000	16.5	12.1
80,000	18.9	13.8

Due to the 165 mm orifice plate, outflows from the lake are limited to a maximum of 5,789 m^3 per day.

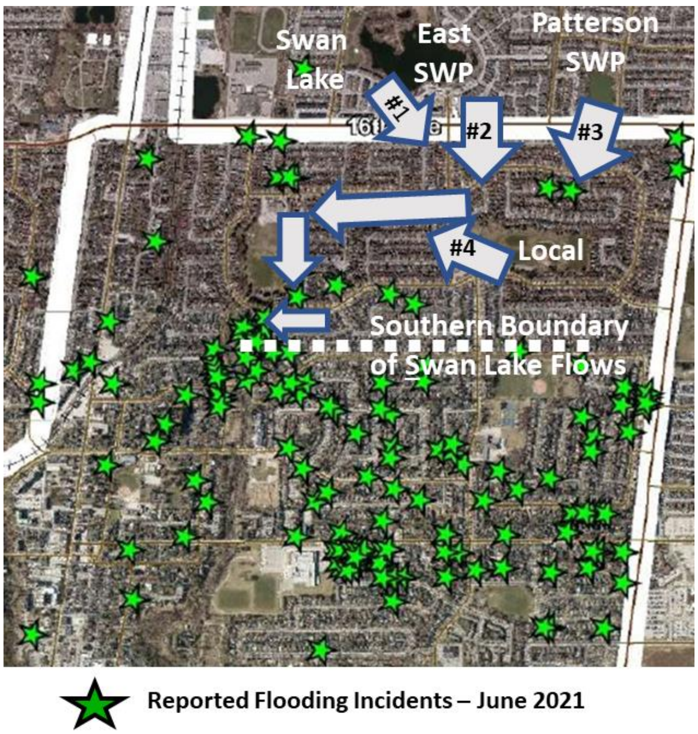
Releasing 4,000 – 5,800 m^3 every day suggests the initial release of 44,000 m^3 could be accomplished over 8 – 10 days if there are no rainfall events. The entire lake (80,000 m^3) could be drawn down in 14 – 19 days during periods of no other rainfall.

Even if the sluice gates were used to reduce the outflow to 2,500 m^3 day, full drawdown of the lake can be accomplished in 30 – 40 days. In the event of pending rain, the sluice gates provide the opportunity to completely stop the outflow from the lake at any time. The above analysis suggests that a managed daily release of lake water from 2,500 – 5,800 m^3 during periods of no rain is well within the design parameters of the stormwater system.

Areas of Concern South of 16th Avenue

Stormwater and lake outlet flows from the Swan Lake Park and Swan Lake Village flow southward through a residential area south of 16th Avenue before flowing into Mount Joy Creek in Paramount Park at Fincham Avenue and Paramount Road.

The area south of 16th Avenue down to Highway #7 has been designated by Markham as an area at risk for basement flooding and plans are in place to expand the stormwater system south of 16th Avenue in 2028 or later. Concern has been expressed about moving additional lake water into this area, particularly before the area stormwater system is expanded.



Stormwater from two stormwater ponds and water from Swan Lake join with flows from a residential area bounded on the north by 16th Avenue and on the south by Ramona Boulevard before entering Mount Joy Creek near Paramount Park.

As of June 2021, there have been only a few incidents of basement flooding reported in the servicing area.

A managed release of 2,500 – 5,000 m^3 of Swan Lake water during periods of low rainfall when there is no stormwater in the system south of 16th Avenue should avoid any downstream complications.

A technical assessment is required to determine whether a controlled drawdown of Swan Lake is feasible and if it can be done in a manner that avoids downstream issues.

Appendix D: Comprehensive Water Treatment Options

Three comprehensive water treatment options that influence 4 factors were reviewed:

I) Drawdown of the lake
II) Recycling via the North Channel
III) Industrial Filtration (i) recycling (ii) partitioning

Comprehensive Water Based	Nutrients P	Nutrients N	Cl	O	Factors Addressed	Restoration Timeframe	Costs
a) Drawdown	1	1	1	1	4/11	1 - 3 years	$
b) Recycling & Filtration via North Channel	1	1	1	1	4/11	10+ years	$$
c) Industrial Filtration (Recycling)	1	1	1	1	4/11	1 year	$$$
d) Industrial Filtration (Partitioning)	1	1	1	1	4/11	1 year	$$$$

I) Winter Drawdown

Drawdown, outlined in detail in Appendix B, involves the removal of a large volume of water from the lake and will remove a significant portion of the active contaminants in the lake water.

A drawdown may be an effective technique for the removal of chloride in particular. Depending on the success of rerouting stormwater flows from the lake, additional drawdowns may be required in the future to manage chloride content. To minimize the impact on aquatic life, a drawdown would be planned during the winter months. It is likely that only partial drawdowns will be feasible in the future if the aquatic life rebounds.

A drawdown is one of the lowest cost options and should impact the water borne content of phosphorus, nitrogen and chloride while the refill process should improve oxygen content.

Three primary benefits associated with drawdown:

1) Low cost.
2) Significant reduction of water contaminants over one season.
3) Exposing sediments provides an opportunity to address the contaminants in the sediments.

II) North Channel Filtration Options

Recycling lake water via the North Channel has the potential as a low cost, sustainable tool for oxygenation.

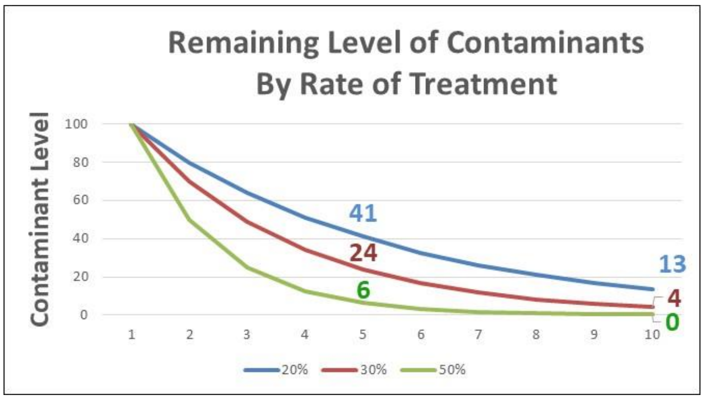
Adding filtration mechanisms may also be an effective means to remove nutrients as part of the restoration process if the drawdown process is not used. As a restoration tool the process is likely to take several years to have a material impact on water quality. The process may be a viable alternative as a low-cost sustainable means for removing contaminants as part of the on-going sustainable process post-restoration.

Some possible filtration options:

1. In 2021, Fleming College[3] researchers suggested consideration of absorption material (such as Chlorocel, manufactured by Porocel) as a means for absorbing chloride.

1) In 2022, researchers from York University[15] submitted a proposal to Markham to evaluate the effectiveness of carbon-based filters for removing phosphorus, nitrogen, and chloride. Markham staff have indicated that this process may have merit and recommends further investigation.
2) A small industrial filtration unit outlined in the next section.
3) Expanding the existing bioswale elements of the North Channel and Turtle Inlet

A high flow rate may be required to maximize the benefits of circulation for oxygenation purposes. However, introducing a filtration process may require lower flow rates. The impact of filtration on the lake's water quality will be related to the effectiveness of the filtration process and the percentage of the lake that can be treated.

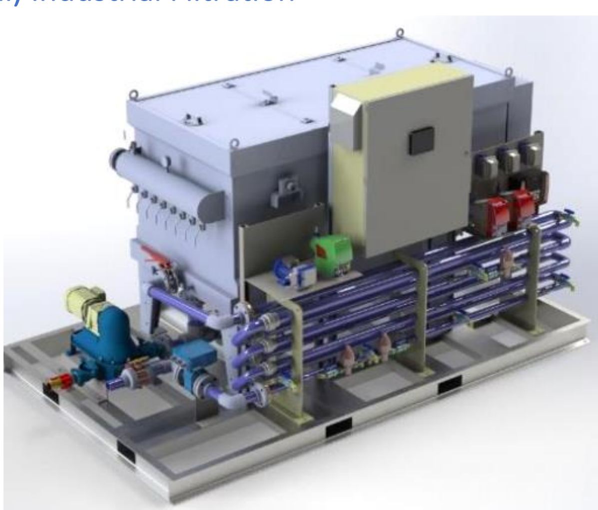


The adjacent chart illustrates that if 20% of the lake can be circulated through the channel filtration process each year and the cleaner water returned to the lake, after 5 years the nutrients in the lake could be reduced to 41% of the original levels (assuming no new inflows of contaminants).

If 50% of the lake could be filtered each year the contaminants could be brought down into the range of 6% or original levels after 5 years.

An industrial filtration unit could handle higher flow rates and may warrant consideration as a primary tool for restoration. Filtration mats or a natural bioswale are expected to be able to process lower flow rates and may be better suited for use as a long-term tool for maintaining restored water.

iii) Industrial Filtration



Veolia's ACTIFLO System

There is an established industry providing water filtration equipment to chemical and mining companies and municipalities utilizing a variety of treatment processes.

The systems are capable of producing drinking water or water suitable for release back into natural water bodies.

The equipment is typically used in permanent installations, but some equipment is available on a rental basis for site clean-up activities.

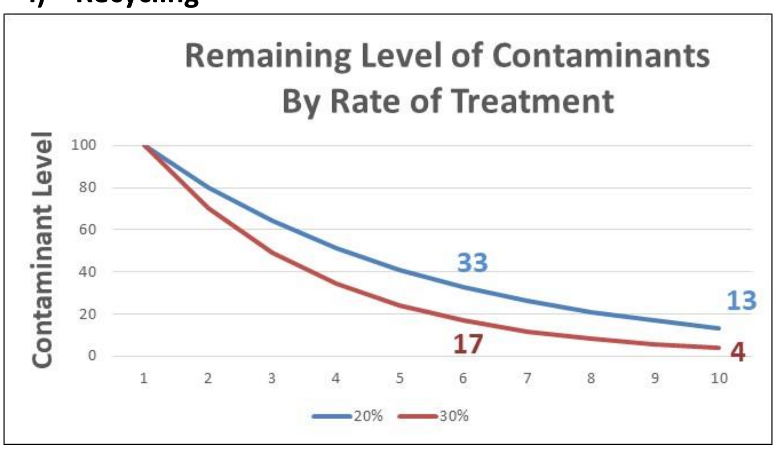
The following table summaries a sample of information available on various suppliers' websites.

Filtration Equipment Suppliers	Throughput m3/ hr	Days to Filter 80,000 m3		Equipment Purchase
		8 hr days	24 hr days	
H2Flow (Rental)				
a) Skid Mounted DAF Pilot	5	2,000	670	
b) Containerized DAF Pilot	10	1,000	335	
Samco Illustration				
Microfiltration (MF) and	2.3 - 4.5	2,200 - 4,400	700 - 1,500	< US $100,000
Ultrafiltration (UF) system	23 - 45	220 - 440	70 - 150	US$150 - 450k
Samco Illustration				
Nanofiltration (NF) and Reverse	1 - 2.3	4,400 - 8,800	1,500 - 2,900	< US $60,000
Osmosis systems	68	150	50	US $2 million

The permanent installation of a small scale and lower cost system (US$100,000) filtering 2 – 10 m^3/hr. could be installed in the North Channel and would be capable of processing approximately 10% - 30% of the lake volume each year.

The entire lake volume could be filtered within 1 year by renting one of the larger systems through either recycling or by partitioning the lake.

i) Recycling



Industrial units are capable of processing 20% - 30% of the lake volume per month.

By returning the cleaner water immediately back into the lake, the contaminants in the lake could be reduced to 17% - 33% of the original levels after 6 months.

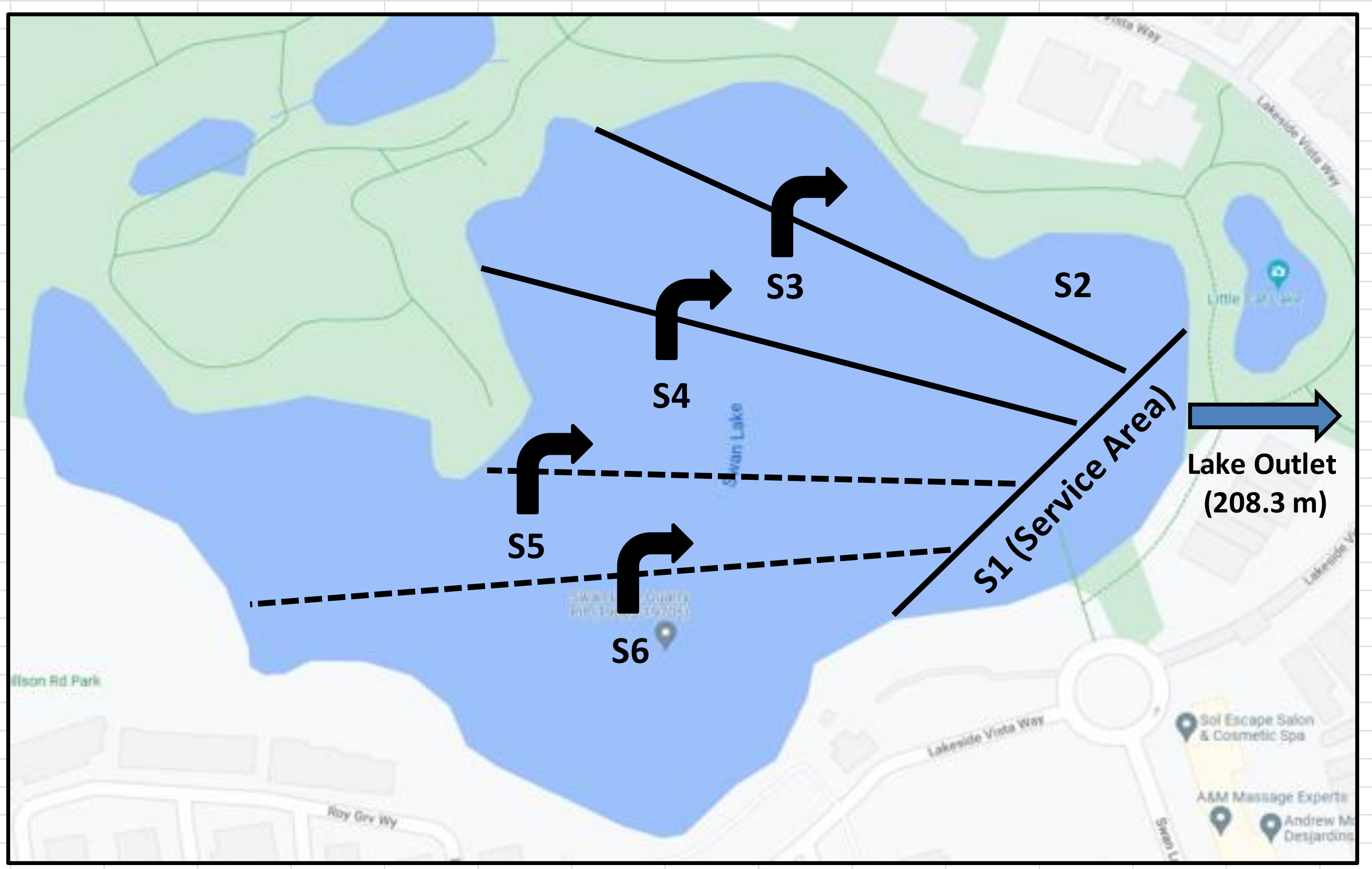
The large-scale filtration equipment has the potential to have a significant impact on water quality within one season. The costs of renting the large-scale equipment needs to be compared to the relatively low cost of a draw down which could reduce the contaminants by 50% or more.

Consideration should be given as to whether a stirring of the sediments during the filtration process would release more contaminants from the sediments increase the effectiveness of the filtration process.

ii) Partitioning

Partitioning the lake is a more expensive option than recycling filtered water or a drawdown but may be warranted in the event a drawdown of the lake is not permitted or deemed feasible. Partitioning would provide two benefits:

1) a timely means of eliminating up to 100% of the water-born contaminants.
2) provides the opportunity for sediment removal.



The process, including removal of sediments, is summarized as follows:

Step #1: Partition two sections of the lake. S1 to serve as a service area for the duration of the process. Pump untreated water from S1 and S2 back into the main lake (S4).

Step #2: Remove sediments from S1 & S2.

Step #3: Partition section S3. Remove chloride & nutrients from water in S3 and pump treated water into S2. Remove sediments from S3.

Step #4: Partition section S4. Treat water in S4 and pump treated water into S3. Barrier between S3 and S2 can be removed and reused. Once completed remove sediments from S4.

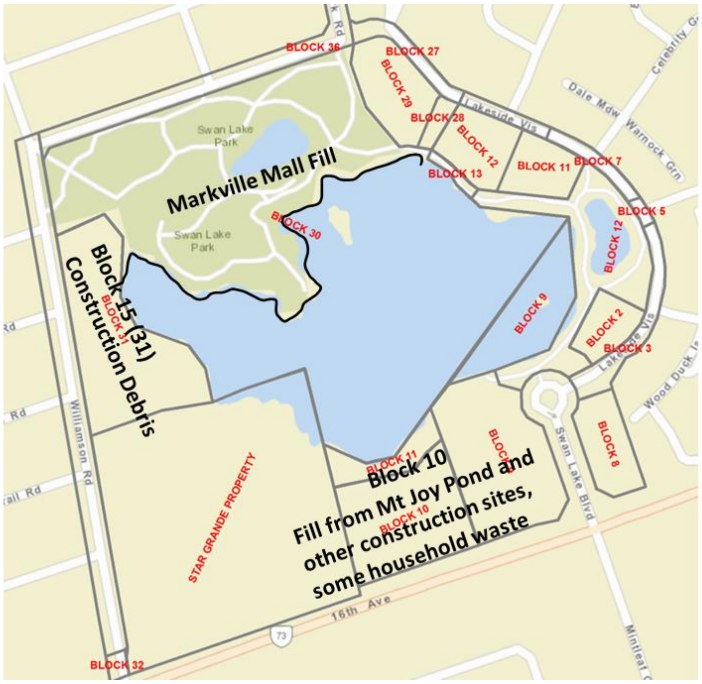
Step #5-6: Repeat until entire lake is treated.

Appendix F provides a summary of the options for managing the sediments.

Appendix E: Historical Assessment of Lake Sediments

Dumping of Fills and Household Waste

In a report dated September 1995, PetoMacCallum Ltd. identified areas where distinct stockpiles of fill materials were located:



1) Fill with construction debris apparently from indiscriminate dumping during the early 1980s was stockpiled along the west shore of the lake.
2) Fill from a 1983 pond excavation at the Mount Joy Community Centre and possibly fill from other construction sites were stockpiled in the southern parts and stockpiled on the south shore of the lake.
3) In 1998, fill comprising sandy silt from construction of the Markville Mall was stockpiled beyond the north shore.
4) Small berms consisting of stripped topsoil and native materials were created in the north part of the lake.

Other reports note the dumping of household waste along the southern shoreline. The Ontario government classified the site as a “waste disposal site" in 1984 and ordered operations to cease.

Historical Sediment Analysis

Extensive analysis of the sediments and soils were undertaken during the early stages of development. Analysis was based on Ontario’s Provincial Sediment Quality Guidelines (“PSQG”) which were designed to protect the community of organisms found in aquatic sediments.

At that time, the guidelines provided for a “Low Effect Level” (LEL) and a “Severe Effect Level” (SEL). Exceedance of the LEL had no requirement for management action.

In a report[6] dated March 1994, PetoMacCallum Consulting Engineers summarized its assessment of the potential impact of chemical quality of the lake water and sediments on aquatic life and benthic organisms. The report noted that in some test areas lake sediment had levels marginally exceeding the province’s “lowest level effect” guidelines with one exception. In borehole #206, measured concentrations of chromium, copper, lead, mercury, zinc, and phosphorus considerably exceeded the province’s “lowest effect” criteria. The report recommended that:

> “Based on these results, the fill materials in the vicinity of borehole 206 (to an approximate depth of 1.3 m below the lake bottom) are considered to be a source of lake water contamination from continued leaching. It is therefore recommended that these materials be dredged out or be capped over with clay fill during the proposed shoreline rehabilitation grading and filling activities.”

In a review dated October 2, 1995, Gartner Lee Limited commented that they agreed "that this sediment, while mildly contaminated, should not cause a problem to lake water quality".

We have not been able to confirm if the area in the vicinity of borehole 206 was dredged or capped with clay.

Remediation Efforts: Block 10 and Block 15

Remediation work was undertaken over the years for Block 10, site of the original Amica building and for Block 15 (originally known as Block 31). In both areas, methane barriers were installed to minimize migration of methane to adjacent properties.

Block 15 was filled with excess soil and construction debris during the early 1980's. Potential sources of contaminants also included petroleum related impacts from truck traffic in the 1980's and the rail spur line that was built in the 1870's. Block 15 became new parkland in 2019.

Subsequent Assessment of the Shoreline and Lake Sediments: Block 9

Block 9 was initially formed in 1995 to align exposure for undefined risk and liabilities associated with the sediment impacts. The area consists of the new Amica building and extends along the shoreline from the dock area to the northern portion of the East Pond. As of 2023, this area remains under private control.

In February 2003, Gartner Lee Limited[9] reported that the contaminants in the sediments in Block 9, along the south-eastern shoreline, are not directly related to past activities:

> *"Our review led to the conclusion that the present-day sediment quality in Swan Lake **is not related to past activities or historic contaminants on the lands surrounding the site.** [emphasis added]. We 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. Sediment quality was typical of that in other aquatic systems in Southern Ontario. We therefore recommend that the sediments be left in place as part of the lake system and that this could be done without threat to the aquatic environment."*

This recommendation was accepted by the Town of Markham's advisor Jacques Whitford Environmental Limited[10] in 2003 which stated that:

> ***"As the contaminants identified are only slightly above the LEL (Low Effect Level of the MOE's Provincial Sediment Quality Guidelines), it is anticipated that there would be no detrimental effect and leaving the sediments in place would be acceptable."****[emphasis added]*

A "Risk Assessment for Block 9" report dated March 2006 by Water and Earth Sciences Associates Ltd ("WESA")[12] noted that relative to Provincial guidelines there was one Chemical of Concern (COCs) related to human health and six Chemicals of Concern related to aquatic life within Swan Lake.

The chemical analysis reported uranium concentrations between 20 – 32 µg/g, compared to expected background concentrations of up 10 µg/g however the report notes that the chemical analysis used is not an accredited method for uranium and that the laboratory had indicated that the results do not warrant a high level of confidence. The report notes that at the reported level if a person were to ingest and have dermal contact with the sediment on a daily basis that the estimated risks would still be well below the maximum acceptable levels for human health for the intended use as parkland.

The six Chemicals of Concern related to aquatic life were calcium, copper, sulphur, uranium, petroleum hydrocarbons (Fraction 3) and total organic carbon. The analysis involved comparing these levels to various standards, objectives and guidelines intended to be protective of ecological receptors as well as "background" concentrations of chemicals in the environment. The maximum measured concentrations were then compared to ecological toxicity reference values. The report concluded:

> *"This shows the risks due to copper are acceptable, there is no basis for assessing calcium, sulphur or uranium and impacts are possible for Fraction 3 but warrant a low degree of confidence, and impacts are possible for total organic carbon, but other data (notably dissolved oxygen levels) indicate that the organic carbon is not causing impacts at Swan Lake."*
>
> ***" The main finding of the risk assessment is that risk management measures are not needed to reduce potential health risks to human health or to ecological receptors. This is premised on Block 9 and the rest of Swan Lake continuing to be used as a visual amenity for the community and as a storm water management facility. If activities at the lake were to change and present the potential for materially greater exposures, then a new risk assessment might to required to determine the necessity to remove, treat or otherwise manage the sediment****.[emphasis added]*

The WESA report notes that if the sediment in Block 9 were to be removed, then those involved in such activity would have greater opportunities for exposure than those considered in the risk assessment. The report outlines a proposed three step risk management plan for the protection of workers and the safe management of the sediments.

2020 Assessment of Sediments

During the fall of 2020, additional samples of the sediments were taken and tested with a focus on phosphorus content in preparation for a planned second treatment of Phoslock. An initial treatment of Phoslock, which contains lanthanum was completed in 2013.

The samples were analysed by the Institut Dr. Nowak[13], and their report described the general sediment quality as:

> *3.1 General sediment quality*
>
> *The sediment samples were analyzed for general sediment characteristics such as the dry weight, the loss on ignition at 550°C, and their elemental composition.*
>
> *The sediment character was dominated by aluminosilicates with low organic content as indicated by the high dry weight percentages (average DS 52%) and low LOIs (average 3,6%). Metal concentrations of iron, manganese and calcium were comparably low (averages Fe 13500 mg/kg DW; Mn 335 mg/kg DW). Lanthanum concentrations were elevated (173 mg/kg DW), because of treatments with lanthanum modified bentonite in the past. Also sulfur concentrations were low, in line with the low LOI results.*

Phosphorus concentrations were moderate, with an average of 700 mg/kg DW, ranging from 1050 mg/kg DW (Site 10, 0-5 cm) up to 420 mg/kg DW (Site 10, 5-10 cm). Phosphorus concentrations seem to be correlated to LOI, which stands for the proportion of organic matter.

Updated Sediment Guidelines

In 2008, the Ontario government updated its sediment guidelines to be consistent with the Federal guidelines for the Great Lakes. The updated Ontario guidelines note that “sediment chemistry is often used only as an initial screening tool “ and that other tools “such as sediment bioassays, benthic community evaluation and biomagnification potential are crucial in the assessment of sediments for dredging, cleanup or monitoring.”

In 2020, Ontario released guidelines[17] called Rules for Soil Management and Excess Soil Quality Standards for the management of sediments.

If the Swan Lake sediments are to be disturbed, then a more comprehensive review of the sediments, particularly Block 9, will be required to determine whether there are any concerns under the new Ontario guidelines and a risk mitigation plan will be required for the safe management of the sediments.

Appendix F: Sediment Removal Options

Limitation of Cleaning or Drawing Down the Lake Water

Aquatic life is undermined by the excessive amount of chloride and the low levels of oxygen in the water. Industrial filtration of the lake water or the drawdown of the lake will have a significant impact on reducing chloride levels in the water and the restored water should have a higher oxygen content.

The significance of the sediments as a storage area for chloride is not known but the sediments are known to be an active storage facility for phosphorus and nitrogen and thus a significant continuing contributor of nutrients that will stimulate future algae growth. When the algae die in the fall, the process consumes oxygen thus unless the phosphorus and nitrogen are removed from the sediments, issues with algae and low oxygen levels can be expected to continue.

Recent research studies [A1, A2] have concluded that it is important to address both phosphorus and nitrogen.

The current chemical program readily impacts the phosphorus in the water column, but repeated treatments are required to neutralize the phosphorus within the sediments. The current long-term water quality plan assumes repeated chemical treatments over the next 25 years will be required just to maintain the lake at an oligotrophic level. A provision of $1.4 million has been included in the life-cycle reserve fund for chemical treatments.

Removal of the sediments would significantly reduce the challenges of restoring water quality in Swan Lake.

Efforts are underway to minimize the inflow of road salt by rerouting some of the stormwater flows away from the lake. Even if successful, inflows of road salt will be a long-term factor undermining the environmental health of the lake. Canada Geese will continue to contribute phosphorus and nitrogen to the lake. Even if the sediments are removed there may still be the need for future partial drawdowns of the water or continuing chemical treatments unless other programs such as oxygenation, restocking of algae eating fish and the restoration of aquatic plants prove to be effective management tools.

Quality of Sediments and Risk of Seepage

Appendix E provides a summary of the historical assessments of the sediments. An updated review of the Swan Lake sediments will be required to determine whether there are any concerns under the new Ontario guidelines that may impact the options outlined below.

Consideration will also have to be given the impact of Ontario's "Rules for Soil Management and Excess Soil Quality Standards" [17] on the management options outlined below.

In addition, the Swan Lake Long-Term Management Plan raised concerns about the potential for contaminants to seep into the lake from the various landfill sites along the shoreline. Options for storing sediments along the shoreline have the potential to help mitigate this potential risk.

Quantity of Sediments

Water filled the former gravel pit in the 1970's. It existed as a self-contained pond with no outlet until stormwater connections were added in the mid 1990's. Sediment has been building over its 50-year existence as a pond and chloride from road salt over the last 25 years.

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

One early report on the sediments noted that sediment depth ranged from 0.15 m to 0.35 m. and that they were deeper along the southern shoreline due to prevailing wind action. The 2020 sediment analysis reported that the lakebed was hard, with limited amount of sediment to collect in most areas. For that analysis, samples were taken up to 10 cm.

The 2021 Swan Lake Long-term Plan provided data on the depth and volume of water in Swan Lake and the lakebed exposed at various depths. It is estimated that a drawdown of the lake to 207.0 m will remove 54% of the water and expose 59% of the lakebed. Additional efforts could be undertaken to pump water down to 206.0 m which removes 88% of the water and exposes 88% of the sediments. Full drainage would occur at 204.5 m.

Drawdown to	207.0 m	206.0 m	204.5 m
Volume of Water Removed (m3) *	44,000	70,000	80,000
Area of Lakebed Exposed (m2) *	28,000	43,000	48,000
% of Water Removed	54%	88%	100%
% of Lakebed Exposed	59%	88%	100%
Average Sediment Depth	**Sediment Volume (m3)**		
20 cm	5,600	8,600	9,600
35 cm	9,800	15,050	16,800
* Source: Swan Lake Long-term Plan November 2021, Page 5			

If the lake water is drawn down to 207.0 m., it is estimated that the volume of sediment exposed ranges between 5,600 m^3 (if sediment averages 20 cm deep) and 9,800 m^3 (if sediment averages 35 cm deep).

Drawing the water down to 206.0 m will expose 8,600 m^3 of sediment (if sediment is 20 cm deep) or 15,050 m^3 (if sediment is 35 cm deep). A full draw down would expose 9,600 – 16,800 m^3.

Four options were considered:

1) Do nothing, leave the sediments in place. Deal over time with the release of nutrients and other contaminants in the sediments.
2) Remove elements of concern onsite and return sediments to the lakebed.
3) Remove and truck the sediments to another site.
4) Remove the sediments and store them around the shoreline of Swan Lake.

Common project costs, which included collecting and drying of sediments and general management costs, were assumed to be $0.6 million for a drawdown to 207.0. For removal of additional water to 206.0 m, common project costs were increased to $0.8 million to reflect the need for pumps and additional challenges in dealing with irregular terrain on the lakebed surface. To fully drain the lake to 204.5 m, common project costs were assumed to be $1.0 million to address the additional challenges.

Storage and removal costs were added to the common project costs based on estimates of storage and removal costs and volume of sediments. The following summary illustrates the relative costs of the alternatives considered.

Option # 1: Leave Sediments in Place

Leaving the sediments in place is clearly the lowest cost short-term option but it would require continuation of the current chemical treatment program which is budgeted to be $1.4 million over the next 25 years. This option represents the least effective restoration technique because sediments are a known storage house for phosphorus, nitrogen and chloride but it provides a cost benchmark from which other alternatives can be assessed.

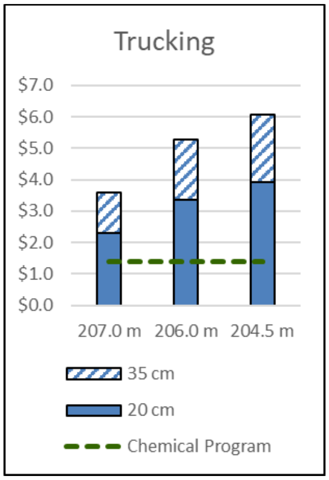
Option #2: Remove Contaminants and Return to Lakebed ("In situ" treatment)

It may be feasible to remove some of the contaminants on site and return the cleaned sediments to the lakebed. The effectiveness and the relative cost of this option would need to be determined and compared to the costs of the alternative solutions. A cost benchmark was not available, but it is assumed this approach will be more expensive than storing the sediments on site but cheaper than removal by truck.

Option #3: Truck Sediments to a Land-fill Location

Sediment removal and relocation is a relatively common practice when cleaning stormwater ponds. A 2016 guide prepared by the Toronto and Region Conservation Authority summarized the process and expected costs associated with cleaning stormwater ponds. Markham typically cleans 1 - 2 stormwater ponds per year and estimates removal costs of $300 per m^3 for projects of up to 2,000 m^3. The TRCA guide quotes on-site storage rates of $15 m^3. The amount of sediment in Swan Lake is more than 5x the typical volume removed from a stormwater pond so lower rates may be attainable. The following calculations used $300 per m^3 for trucking to an off-site landfill and $25 m^3 for onsite storage.

Removal to Offsite Storage							
Lake drawdown to		**207.0 m**		**206.0 m**		**204.5 m**	
Average Sediment Depth		**20 cm**	**35 cm**	**20 cm**	**35 cm**	**20 cm**	**35 cm**
Sediment Volume		5,600	9,800	8,600	15,050	9,600	16,800
# Truckloads @ 10 cu m		**560**	**980**	**860**	**1,505**	**960**	**1,680**
Project Costs		$0.6	$0.6	$0.8	$0.8	$1.0	$1.0
Removal Costs	$300.00	$1.7	$2.9	$2.6	$4.5	$2.9	$5.0
Total Cost		**$2.3**	**$3.5**	**$3.4**	**$5.3**	**$3.9**	**$6.0**



Utilizing dump trucks that can carry 10 m^3 of sediment to remove the sediment would require 560 – 1,680 truckloads depending on the extent of the drawdown and the depth of the sediments.

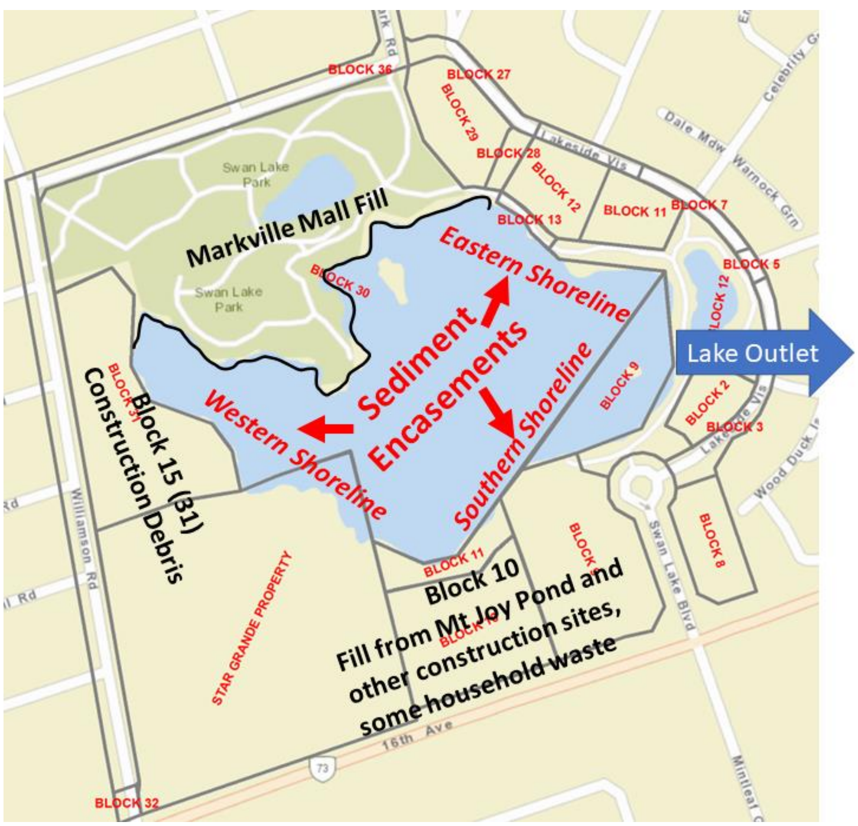
Assuming project management costs of $0.6 million and removal costs of $300 per m^3, the total project and removal costs could be in the range of $2.3 - $3.5 million if the lake is drawn down to 207.0 m which is above the $1.4 million budgeted for the chemical program.

Costs for total drawdown and removal would range between $3.9 - $6.0 million.

Option #4: Encase the Sediments within Swan Lake

To avoid the costs of trucking and relocation of the sediments, a more cost-effective method would be to gather the sediments and encase the sediments along the shoreline of Swan Lake.

Design work on restoring the shoreline is already underway to curb the resident population of Canada Geese. Use of the shoreline for storage of sediments would need to incorporate the objectives of the shoreline restoration program but the costs outlined below may permit reduction in some of the costs planned for the shoreline restoration.



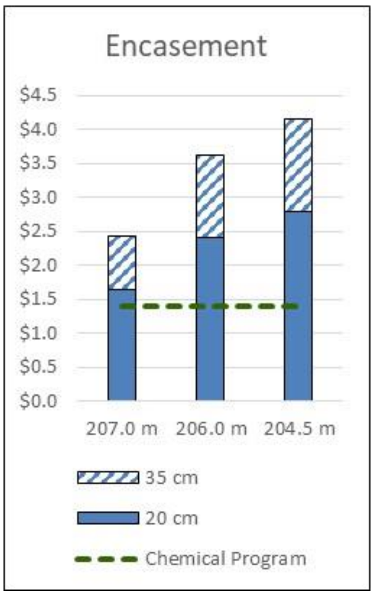
Enclosing the shoreline has a potential additional benefit.

Concern has been expressed about possible seepage from former dump sites around the lake. The impermeable seals or concrete encasements should minimize the chance of seepage of contaminants from the former sites and remove another possible complication.

Two possible approaches were considered for storing the sediments on site:

a) Concrete Encasement

Concrete Encasement Along Swan Lake Shoreline						
Lake drawdown to	**207.0 m**		**206.0 m**		**204.5 m**	
Average Sediment Depth	**20 cm**	**35 cm**	**20 cm**	**35 cm**	**20 cm**	**35 cm**
Sediment Volume	5,600	9,800	8,600	15,050	9,600	16,800
Project Costs	$0.6	$0.6	$0.8	$0.8	$1.0	$1.0
Removal Costs (50%) $300.00	$0.8	$1.5	$1.3	$2.3	$1.4	$2.5
Onsite Storage (50%) $75.00	$0.2	$0.4	$0.3	$0.6	$0.4	$0.6
Total Cost	**$1.7**	**$2.4**	**$2.4**	**$3.6**	**$2.8**	**$4.2**



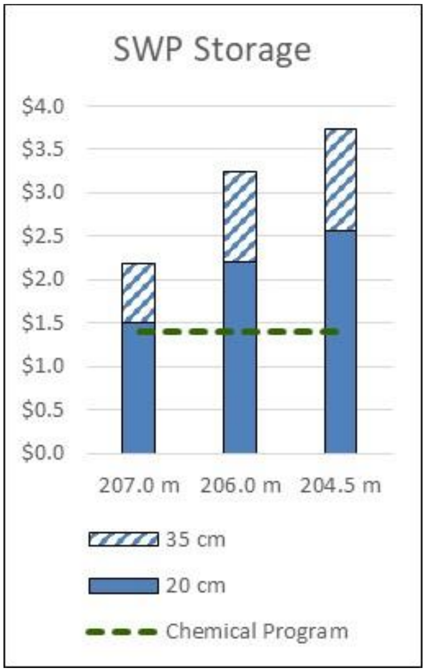
One option is to create concrete encasement areas as part of the shoreline to hold the sediments. Given the higher construction costs, we have assumed a cost equal to 25% of the removal costs ($75). We also assumed 50% onsite storage and 50% removal to a landfill site providing an estimate of $1.7 - $2.4 million for a drawdown to 207.0 m.

Depending on the extent of the drawdown, the costs are slightly or significantly greater than the costs of the planned chemical program. The additional costs of the concrete encasement may be justified if it is found to provide greater protection to seepage from former dump sites or provides some benefits to the shoreline restoration program.

b) Sediment Storage Using Stormwater Pond Techniques

Costs Using SWP Approach Along Swan Lake Shoreline						
Lake drawdown to	**207.0 m**		**206.0 m**		**204.5 m**	
Average Sediment Depth	**20 cm**	**35 cm**	**20 cm**	**35 cm**	**20 cm**	**35 cm**
Sediment Volume	5,600	9,800	8,600	15,050	9,600	16,800
Project Costs	$0.6	$0.6	$0.8	$0.8	$1.0	$1.0
Removal Costs (50%) $300.00	$0.8	$1.5	$1.3	$2.3	$1.4	$2.5
Onsite Storage (50%) $25.00	$0.1	$0.1	$0.1	$0.2	$0.1	$0.2
Total Cost	**$1.5**	**$2.2**	**$2.2**	**$3.2**	**$2.6**	**$3.7**

Another option is to use a process like that used to store stormwater pond sediments on site. A layer of impermeable plastic would be laid down and the sediments placed on top and then covered with another impermeable layer, providing a sealed container to minimize leeching. Alternatively, the sediment could be put into impermeable bags. Landscaping can then be added.



The TRCA guideline suggested \$15 per m^3 for onsite storage of sediments removed from a stormwater pond. For our analysis, we have assumed \$25 per m^3 for onsite storage and assumed 50% of the sediment must be removed to a landfill site at a cost of \$300 per m^3.

Costs are estimated to range from \$1.5 - \$3.7 million. Onsite storage is the lowest cost option. A removal of 50% of the sediment would provide a more comprehensive solution at costs equal to or slightly greater than the chemical program.

This analysis suggests that the lake could be drained down to 207.0 m (exposing 59% of the lakebed,) and all sediments stored for less than the cost of the chemical program. The limiting factor may be the ability to find sufficient storage along the shoreline so a full drawdown may require removal of some portion of the sediments.

If onsite storage can be found for 5,000 m^3, then 51% - 89% of the sediments exposed during a drawdown to 207.0 m could be stored onsite or 33% - 58% if the drawdown is to 206.0 m. Onsite storage of 8,000 m^3, would be sufficient to store 48% - 83% of the sediments for a drawdown to 204.5 m.

Estimate of Sediment Volume (M3)						
Lake drawdown to	**207.0 m**		**206.0 m**		**204.5 m**	
Lake Bed Exposure (m2)	28000		43000		48000	
Average Sediment Depth	**20 cm**	**35 cm**	**20 cm**	**35 cm**	**20 cm**	**35 cm**
Sediment Volume	5,600	9,800	8,600	15,050	9,600	16,800
Onsite Storage Capacity	**% Stored Onsite**					
5,000 m3	89%	51%	58%	33%	52%	30%
8,000 m3	143%	82%	93%	53%	83%	48%

Comparison of Options

The cost of having to remove or store the sediments must be considered in the context of whether the treatment would substantially displace the ongoing costs of the current chemical program. The sediments have built up over the 50-year history of Swan Lake. The core question becomes even if the option of removal or encasement of the sediments is more costly, would it provide a more sustainable solution over the next 25–50 years and provide the potential to maintain the lake at an improved and sustainable mesotrophic level.

	Nutrients		**Cl**	**O**	**Factors Addressed**	**Restoration Timeframe**	**Costs**
Sediment Removal Options	**P**	**N**					
a) Disposal Offsite (100%/0%)	1	1	1	1	4/11	1 year	\$2.3 - \$6.0 m
b) Concrete Encasement Onsite (50%/50%)	1	1	1	1	4/11	1 year	\$1.7 - \$4.2 m
c) SWM Storage Onsite (50%/50%)	1	1	1	1	4/11	1 year	\$1.5 - \$3.7 m

Appendix G: Executive Summary 2022 Water Quality Monitoring Report

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Executive Summary

Background

Swan Lake is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road. Swan Lake has an approximate area of 5.5 ha and a maximum water depth of 4.5 m (from the edge of the Lake at 210 MASL). A gravel pit in the 1960s and 1970s, Swan Lake is currently a community feature with multiple trails and urban development surrounding it.

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

In 2019, the City of Markham conducted a study to define a Water Quality Management Strategy for Swan Lake. The Strategy, finalized in July 2020, recommended a chemical treatment in 2021.

In August 2021, 13 tonnes of Poly Aluminum Chloride (PAC) were applied to the Lake in a controlled manner over several days.

The Swan Lake Long-Term Management Plan was received by the Markham Sub Committee in November 2021 and approved by the Council in December 2021. It describes a phased adaptive approach, including provisions for chemical treatment every three years. Activities planned for 2022 included enhanced geese management, fish removal, water quality monitoring, and investigation of additional measures to improve water quality in the Lake.

Water quality monitoring of Swan Lake has been conducted almost annually since the first treatment in 2013 to track water quality and the continued effectiveness of the treatment. The collected data presented in this report is part of the ongoing monitoring program that will allow for continuous assessment of the water quality in Swan Lake and will be used to implement and adapt the Long-Term Management Plan for Swan Lake.

In 2022, sampling for chloride measurement was also conducted at several locations to determine the relative contribution of each source to the Lake.

This report discusses observations at the monitored stations in the Lake and several runoff stations throughout 2022.

Results- Lake Water Quality

Water quality is regularly monitored at two shoreline sites: the Dock and the Bridge, on a bi-weekly basis (from April to November). Samples and measurements are taken at 0.5 m or 1m increments for the depth of the lake. A level logger is used to record the water level in the Lake.

The following paragraphs provide the monitoring results for the 2022 monitoring period, as well as annual summaries of available data from 2011 to 2022. The figures include plots of measured dissolved oxygen (DO), water clarity, phosphorus concentration, chloride concentration, and geese count.

Targets

Phosphorus concentration and clarity were compared to the eutrophication thresholds and/or the interim targets developed for Swan Lake through the 2019 Water Quality Management Strategy. For DO and chloride, Federal and/or Provincial water quality Guidelines or Objectives are shown for perspective. It should be noted 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), Temperature, and pH

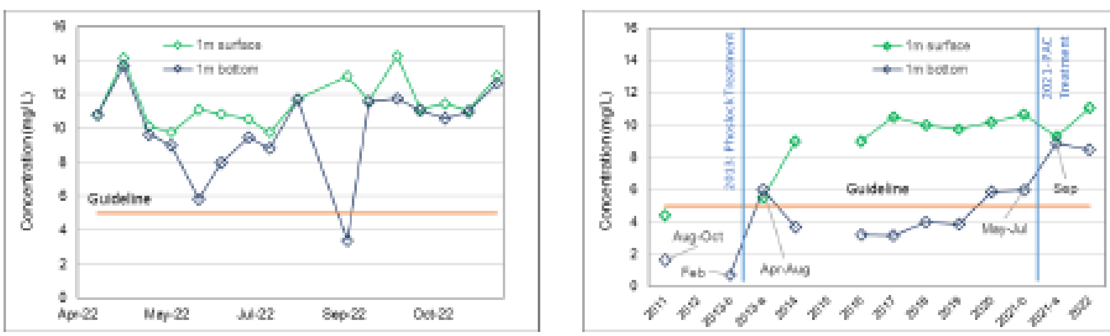
The minimum dissolved oxygen concentration required for the protection of warm water fish is 5 mg/L for water temperatures up to 20 °C, and 4 mg/L for temperatures above 20 °C. DO concentrations for the 1m from the surface and 1m from the bottom layers are shown below.

Measured day-time surface concentrations were above the DO guideline throughout 2022 (above 9.5 mg/L). DO concentration at the bottom layer was also above the guideline, except for two measurements at 2.2 and 3.4 mg/L, which occurred on dates when the water column was thermally stratified.

Lower DO 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.

Although measured DO levels did not indicate anoxia during the sampling events, its decline at the bottom of the water column could suggest that if the stratification persisted, it could have led to anoxic episodes (at night when respiration occurs), contributing to the release of nutrients from the sediments. Such potential occurrence would, however, be less severe than pre-treatment conditions as implied from the annual trend of day-time surface and bottom concentrations.

Figure ES-2: 2022 Monitoring Results and 2011-2022 Annual Results- Dissolved Oxygen



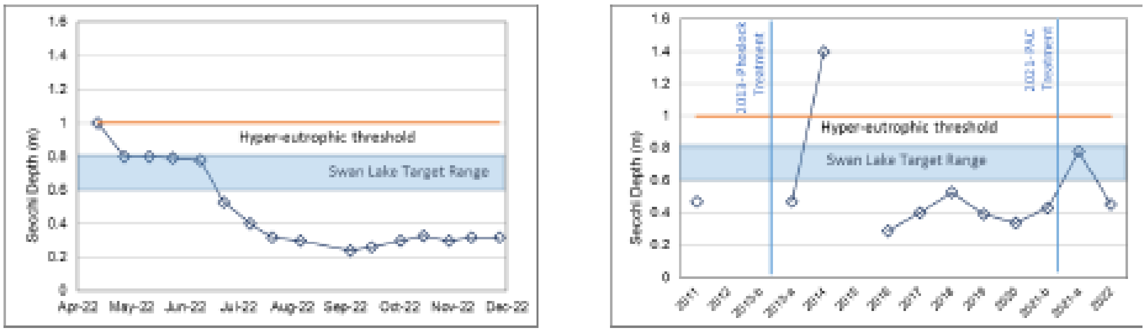
Note 1: DO concentrations are shown at 1 m from the surface (average of 0.5 and 1 m) and 1 m from the bottom (average of two bottom depths).
Note 2: Historical data are shown for the average growing period (June-Sep) unless otherwise indicated.

pH measured at the lab ranged from 7.5 to 9.4 throughout the year. High pH is consistent with high levels of algae. Algae take up carbon dioxide, a weak acid, from the water for photosynthesis, causing the water to become more basic (higher pH).

Water Transparency (Secchi Depth)

Secchi depth represents water transparency, which declines when the algae level increases. In the trophic state classification scheme, growing period average water clarity of under 1 m is the threshold for a hyper-eutrophic condition. The proposed interim target for Swan Lake is 0.6-0.8 m based on correlation with the phosphorus target. In 2022, water clarity was above 0.5 m until the end of June but dropped to below 0.4 m for the remainder of the monitoring period.

Figure ES-3: 2022 Monitoring Results and 2011-2022 Annual Results- Secchi Depth

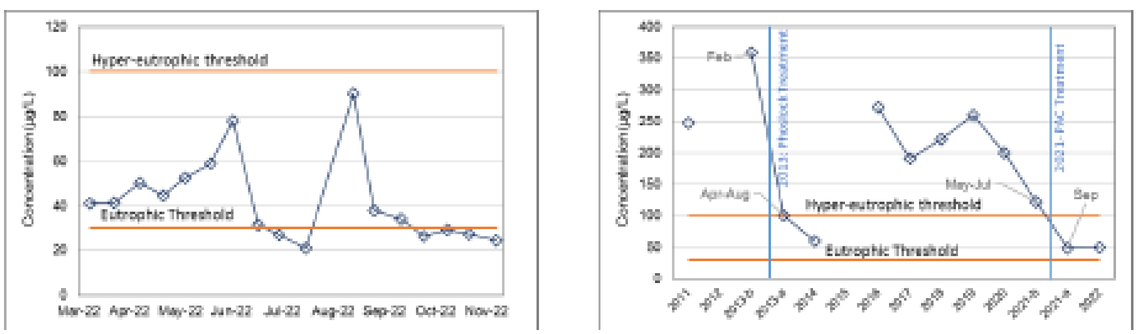


Phosphorus and Nitrogen Concentrations

Phosphorus concentration is the most important indicator of the trophic state in Swan Lake. It is an indication of how prone the Lake is to algae growth.

Phosphorus concentrations above 100 µg/L represent a hyper-eutrophic condition, which lead to high algae concentrations. Total phosphorus concentration in the top 0.5 and 1.5 m depths averaged under 50 µg/L during the growing season (under the 100 µg/L threshold for a hyper-eutrophic condition, and below the interim target of 50-100 µg/L). There was significant improvement in phosphorus concentrations after treatment by Phoslock and PAC.

Figure ES-1: 2022 Monitoring Results and 2011-2022 Annual Results- Total Phosphorus



Note 1: The 2022 values are averages of samples collected at 0.5 and 1.5 m from the surface.
Note 2: Annual concentrations are summaries of the growing period (June-Sep) unless otherwise indicated.

Total nitrogen concentrations over the growing season averaged about 0.60 mg/L (below the 1.2 mg/L threshold for a hyper-eutrophic condition). In 2022, ammonia and nitrate concentrations (the forms available for uptake by biota) were generally very low (except in April), and nitrogen was mainly present as organic matter.

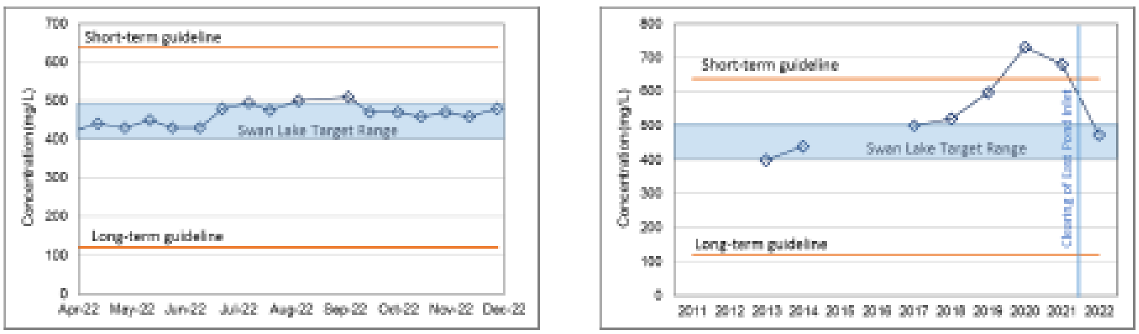
Chloride Concentration

Chloride concentration has been increasing in urban lakes as a result of de-icer application for winter maintenance of roads and walkways. 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.

Chloride guidelines developed for generic environmental data include a long-term guideline (120 mg/L) and a short-term guideline (640 mg/L). The long-term guideline has been developed to protect all organisms (present in Canadian aquatic systems) against negative effects during chronic indefinite exposure. The short-term guideline aims to protect most species against lethality during a sudden hike in chloride concentration for an acute 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. The interim target for chloride is 400-500 mg/L consistent with 2013-2014 values.

In 2022, chloride levels reduced considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake. The lower water level in the summer may have resulted in more concentrated amount of chloride starting from end of June.

Figure ES-4: 2022 Monitoring Results and 2011-2022 Annual Results- Chloride



In 2022, water samples were collected from various inlets to the Lake and analyzed for chloride. The mass balance established using these data is documented in a separate report.

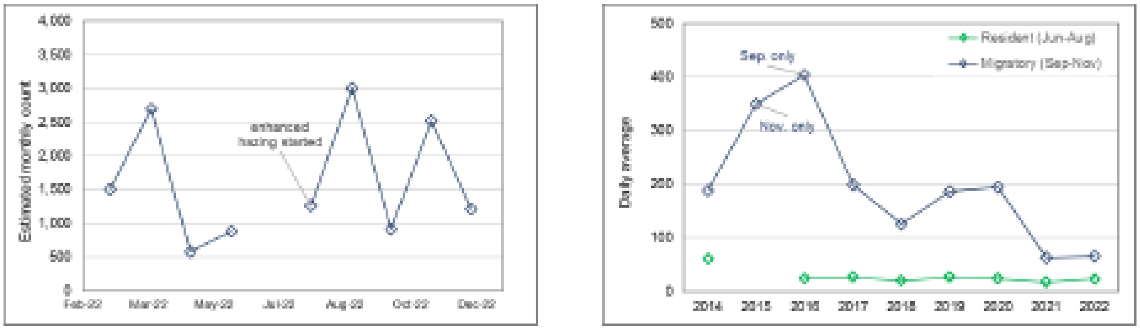
Geese Count

Geese are the primary external source of nutrients in the Lake. Therefore, active geese management is completed annually. The geese control program started in 2014, focusing on resident geese. The program extended to the management of migratory geese in 2016.

The 2022 program included a hazing program in the Spring, with an expanded version starting in mid-August to mid-December, nest management and geese relocation, the installation of nine strobe lights on the Lake and adjacent stormwater ponds, and geese count program.

In 2022, the increased hazing efforts were very effective in reducing the number of migratory geese visiting the Lake, similar to those achieved in 2021 when the extended program started. The strobe lights did not have any noticeable impact on the counts. The geese count data helped provide more certainty in the results, and were used to more effectively schedule hazing efforts.

Figure ES-5: 2022 Monitoring Results and 2011-2022 Annual Results- Geese Count



Note 1: 2022 data are the sum of counts in each month, compensated for days with no count.
Note 2: Annual trends are shown as daily averages of counts over June-August and September to November, representing resident and migratory geese, respectively.

Other management activities completed in 2022 included a fish inventory, the removal of bottom-dwelling fish to reduce sediment disturbance, and Phragmites management through spraying and physical removal.

Algal Growth

In 2022, limited surface scums were observed along the shoreline around the Dock, as well as in the northern bay at the Bridge site. While the Lake was dominated by phytoplankton from late June, surface scums were not widespread.

Samples were collected and sent to the laboratory for phytoplankton and cyanobacteria. Test results showed lower diversity and higher total counts compared to 2021.

Several algal blooms with potentially toxic cyanobacteria were observed in years before 2011; however, testing completed before 2011 and following treatment (2013-2016) did not detect any Microcystin in the water. In 2016, a bloom was tested and resulted in a Microcystin concentration of 73 µg/L. Extended blooms were observed at several sites in 2018; however, cell density was at half of WHO's threshold for significantly increased human health risk. These results suggest that in most years, toxin-producing cyanobacteria are not the dominant form of phytoplankton in Swan Lake. In recent years, Abraxis tests have resulted in Microcystin levels below the recreational limit (20 µg/L, recently updated to 10 µg/L).

Summary and Recommendations

Overall, the management activities in 2021/2022 that focused on the significant nutrient loadings identified in the water quality improvement study (i.e., chemical treatment and fish management to reduce internal loads and geese management to reduce external loads), were effective at improving water quality in the Lake as shown in reduced phosphorus concentrations and improved dissolved oxygen levels. These improvements represent a positive step towards improving the aquatic habitat in the Lake and meeting the long-term water quality goals.

In 2022, chloride levels decreased considerably compared to 2021, likely due to clearing the blockage at the East Pond inlet, which resulted in lower catchment flows from the inlet bypass to the Lake.

While internal and external source controls successfully reduced nutrient concentrations, the Lake was dominated by phytoplankton, and water clarity did not improve. This could be partly due to the absence of submerged aquatic vegetation (SAV), which has been replaced by phytoplankton (algae) due to low water clarity.

The 2023 monitoring program will follow the recommendation of the Long-Term Management Plan. Additional measures will be investigated for the return of SAVs to the Lake, as well as strategies to reduce chloride concentration in the Lake.

Appendix H: Summary of Swan Lake Long-term Management Plan (2021)

In December 2021, Markham Council approved a Long-term Water Management Plan (the "Plan") for Swan Lake. The Plan is based on an evolving "adaptive" management approach and focuses on the reduction of algae through actions to reduce phosphorus as the critical nutrient spurring the algal growth. Following are extracts and summaries of the long-term plan.

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

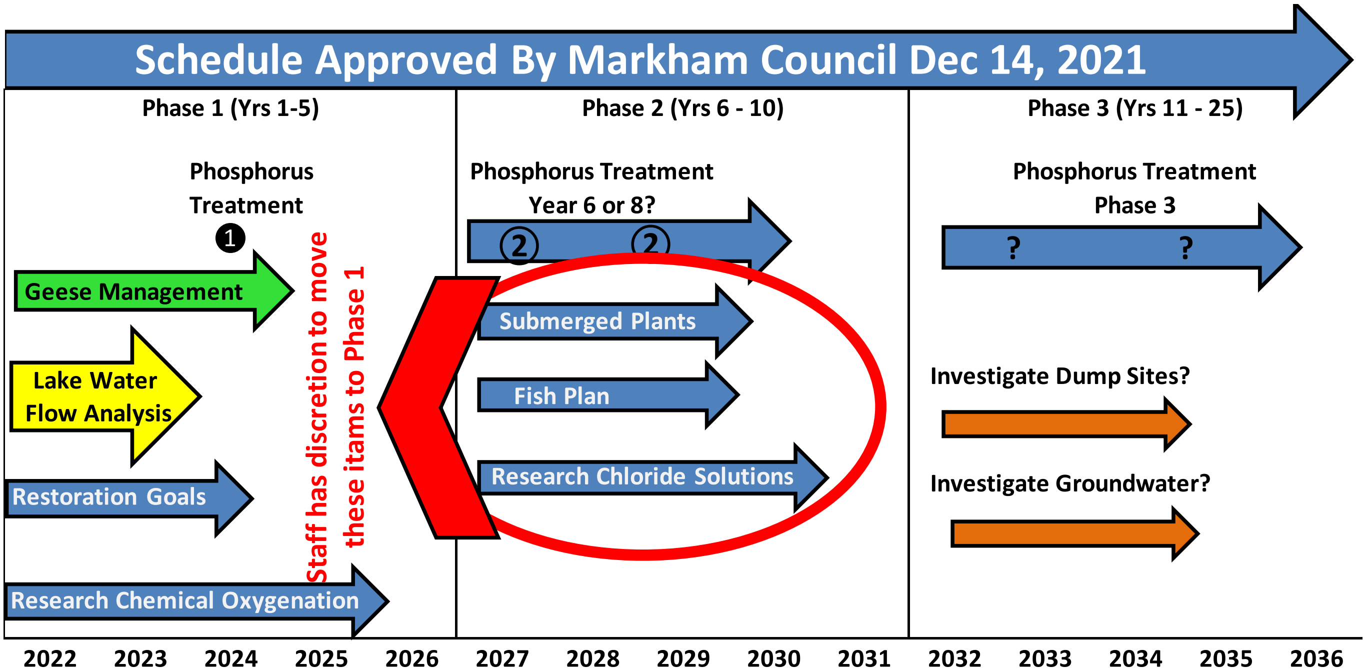
Parameter	Current Values	Interim Target	Objective and Rationale
Total phosphorus (µg/L)	>200	50–100	Current value: the average of growing season TP values in the period since 2016 has been 200. Interim target: will provide a low eutrophic condition in the first year after treatment increasing to eutrophic 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	

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



Review #1 (Year 2 - 3)

1) Monitor success of 2021 treatment
2) Decision on Lake Flow Analysis
3) Decision on "Restoration" goals
4) Decision on oxygenation options
5) Decision on timing of next treatment

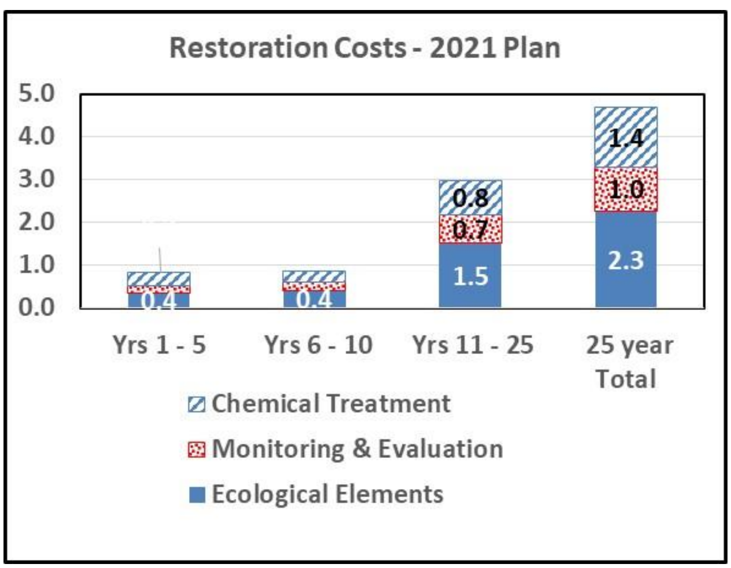
Review #2 (Year 5 - 6)

1) Assess targets and program
2) Decision on plants, fish
3) Decision on chloride options

Review #3 (Year 10)

1) Assess targets and program
2) Decision on Dump Sites
3) Decision on Groundwater

Restoration Costs



The Plan provides for $4.7 million for water quality restoration over the next 25 years.

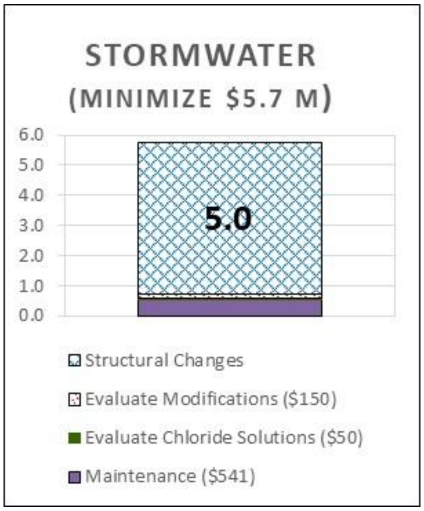
The budget provision in Markham's Life-Cycle Reserve Fund includes $2.3 million (49%) for Ecological Elements including geese management and restoration of fish and aquatic plants.

Another $1.0 million (22%) is provided for water quality monitoring and site testing and $1.4 million (29%) for ongoing chemical treatment program for phosphorus.

The current plan does not include estimates of the costs for restoring the shoreline but provides an outline of potential additional costs related to rerouting stormwater flows and addressing potential issues related to former dump sites.

Stormwater Management Costs

In addition to the water quality program, the long-term budget includes $541,000 for future stormwater pond management and $50,000 for investigation into options for removal of chloride.

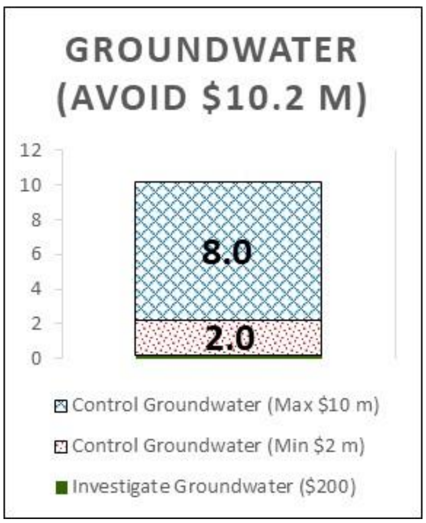


Finding a cost-effective approach for reducing stormwater inflows is an essential component of a restoration program.

Markham Council recently approved $150,000 for investigation into the feasibility of rerouting the stormwater away from the lake. Results are expected in 2024.

The long-term plan indicates a potential cost of $5 million for rerouting stormwater flows. It is expected that the technical investigation underway will provide a refinement to this estimate in 2024.

Potential Dump Site Related Costs



If it is determined that seepage from the old dump sites is undermining restoration success, the plan has indicated that costs for addressing groundwater issues could be in the range of $2.0 - $10.0 million.

Development of a comprehensive plan for restoration should endeavour to minimize or avoid issues that may trigger costs related to the dump sites. Storage of sediments along the shoreline near the dump sites could possibly reduce the risk of seepage from the dump sites.

The following table outlines the specific budget allocations in the life-cycle fund.

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

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

Core
Complementary
Alternative

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		
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
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
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.

Experimental Plan for Aeration System Field Testing at Swan Lake

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May 9, 2023

1.0 - Experimental Goal

Swan lake is a former rock quarry located in the Greensborough community of Markham, ON. While restoration over the past years has led to increased wildlife in and around the lake, hypoxic (low oxygen) water conditions prevent it from sustainably supporting an aquatic ecosystem. The primary goal of this experiment is to determine if the wind-powered aeration system previously developed by the Water and Energy Research Lab is a viable option for addressing the persistent hypoxic conditions within Swan lake and contributing to long-term restoration plan for the site. The specific objectives of the study are to measure the impact of the aeration system on dissolved oxygen levels within the lake, determine the consistency of the system's operation based on local wind conditions, and evaluate the long-term robustness of the system in this setting.

2.0 - Site description

Swan Lake is located in a residential community and is surrounded by a park with partial sheltering from trees along the north shore (Figure 1). Its overall dimensions are 375m by 250m with a depth of up to 4.5m [1]. This is an artificial lake created from a former gravel quarry with no natural inflows or outflows, resulting in stagnant water conditions.

Figure 1: Swan Lake overview

The water quality of the lake is heavily eutrophic with high turbidity and dense algae/aquatic vegetation. Previous water chemistry studies have reported dissolved oxygen (DO) concentrations under 3mg/L [2], making it uninhabitable for fish and most other aquatic species.

3.0 - Introduction to aeration system

The Water and Energy Research Lab at the University of Toronto has previously developed a wind-powered aeration system for passively aerating in-ground reservoirs. The current system consists of a vertical-axis wind turbine coupled to a sub-surface impeller (Figure 2). The impeller, mounted within a draft tube, generates vertical circulation of water throughout the reservoir when driven by the turbine, leading to increased concentration and distribution of dissolved oxygen throughout the water body. The turbine is positioned ~1.5m above the water surface and is mounted on a floating baseboard $2m^2$ in area. The base of the draft tube extends approximately 1m below the surface.

The system was primarily designed for supporting aquaculture operations, although it is potentially suitable for other applications involving aeration of outdoor ponds and reservoirs. In the summer of 2022, a prototype of the wind-powered aeration system was tested in a small aquaculture tailing pond where it raised dissolved oxygen levels by 18% compared to a control area and reduced the stratification of dissolved oxygen between the upper and lower pond depths.

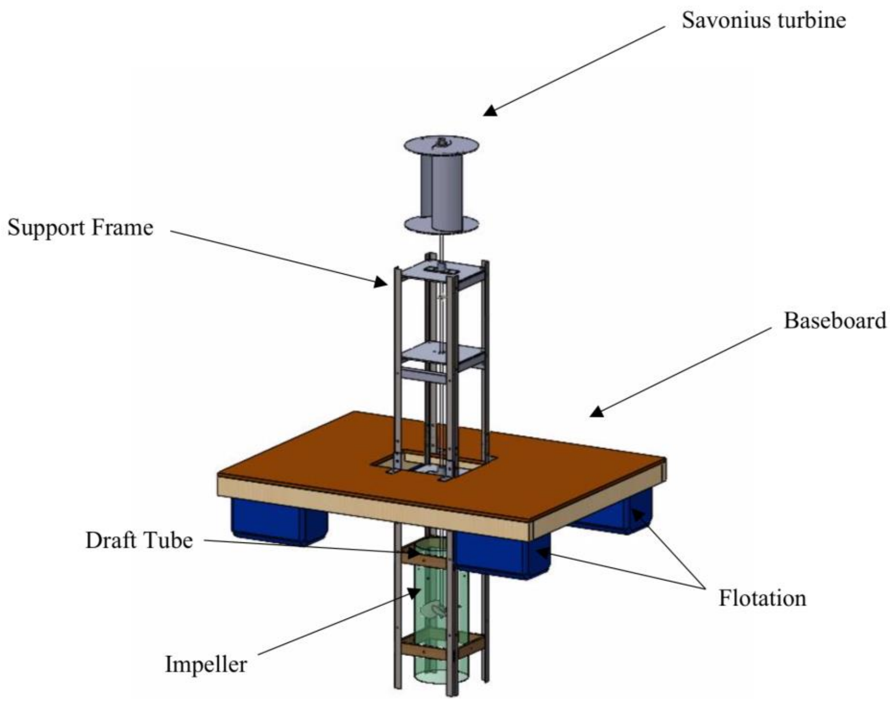

Figure 2: Overview of wind-powered aeration system components

4.0 Proposed Experiment Plan

4.1 Partition of test and control areas

Swan Lake is relatively large and in practice may require a modular installation of the aeration system order to generate the desired impact. To more readily measure the impact of a single device within this setting, it is proposed to partition off a smaller area of the lake for the test. The partition will utilize three dividers walls to section off two 30x30m areas of the north-east corner of the lake. One section will be used as the test area in which the system will be installed, and the other will serve as a control.

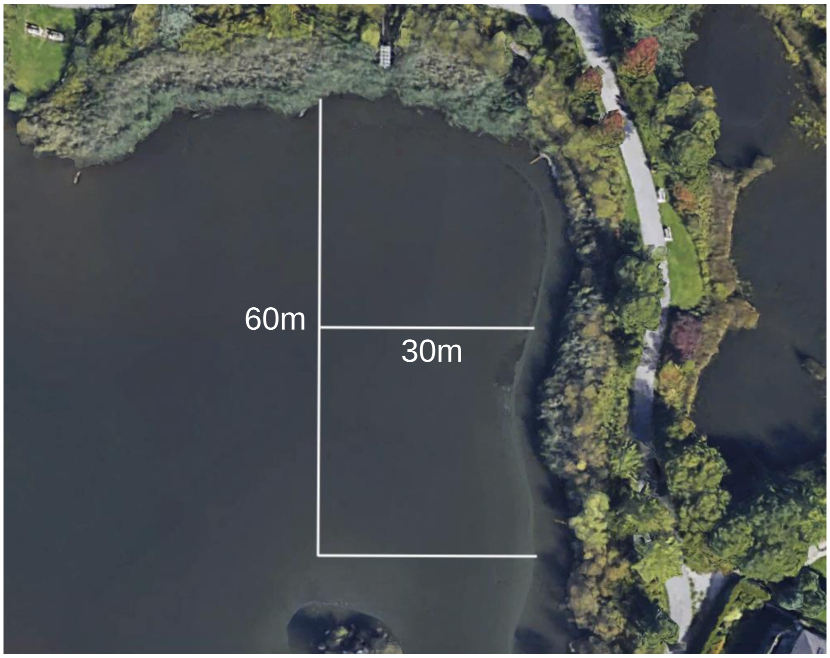

Figure 3: Proposed layout of partitioned test areas

Figure 4: Similar divider configuration from previous field experiment

The divider is constructed from heavy-duty plastic drop sheet to limit transfer of water and oxygen from the test and control areas to the surrounding lake. The divider will be supported at the surface by a float line and secured using ground stakes at the edge of the lake. The lower edge of the liner will be weighted using sandbags to sink into the sediment at the bottom of the reservoir.

4.2 Description of sensors

For monitoring the environmental conditions of the lake, surroundings, and the mechanical performance of the turbine throughout the duration of the experiment, sensors will be assembled and positioned as listed in Table 1.

Table 1: Sensor list for field experiment

Sensors	**Metric**	**Number and position**
DO sensor	Dissolved O_2 (mg/L)	3 - At reservoir surface 3 - At reservoir bottom (in each partitioned area)
Water temperature	Temperature (°C)	12 - Built into DO sensors
Anemometer	Wind Speed (m/s)	1 – Within test area (at height of turbine)
Pyranometer	Solar Irradiance (W/m^2)	1 - Adjacent to lake
Ambient Temperature	Temperature (°C)	1 - Adjacent to lake
Hall effect sensor	Shaft Speed (RPM)	1 – Mounted on turbine shaft

The rotational speed of the turbine will be monitored with a magnet mounted on the turbine shaft, which once per rotation will trigger a hall effect sensor. A microcontroller will be used to collect shaft speed data and save it to an SD card. This sensor box will be installed on the floating baseboard of the aeration system and will be powered by a 12V battery regularly charged with a 20W solar panel.

A separate weather station will be positioned at the side of the lake for monitoring ambient temperature, solar irradiance, and wind speed. The anemometer and pyranometer will be mounted on a pole in the lake, while ambient temperature will be monitored from the shore. All environmental sensors will log data to an SD card and will be powered by a solar panel as with the shaft speed sensor. Although not provisioned in this current plan, there may also be plans for periodic water sampling to evaluate the impacts of the circulation on other water quality parameters, such as nitrates, phosphates, and TDS.

4.3 Test Procedure

Following installation of the divider sheets, 6 dissolved oxygen sensors will be installed in the test and control areas as shown in Figure 5. At each point indicated two DO sensors are to be installed: one 20cm below the surface, and another 20cm from the bottom of the lake so that the distribution of oxygen across the water column can be measured. The DO sensors will be left for 3-weeks prior to installation of the aeration system to establish baseline dissolved oxygen concentration values.

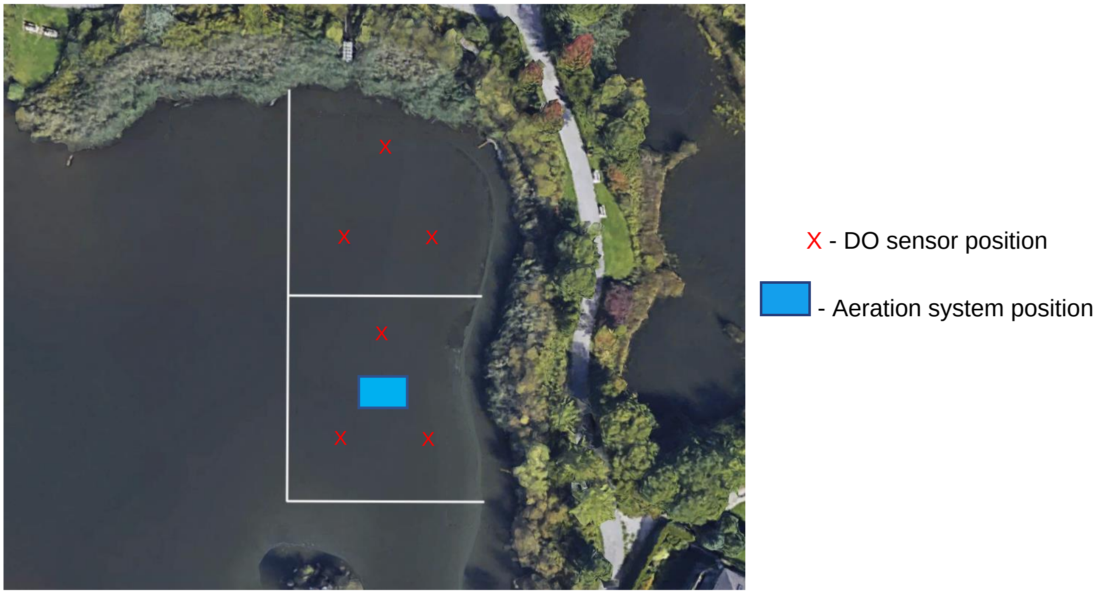

Figure 5: Position of aeration system and DO sensors

After 3-weeks, the aeration system is to be installed and anchored at the indicated location in Figure 5 and will remain in place for 1 month to evaluate its long-term effect on water conditions in the lake. After the 1 month, the aeration system will be changed to the other partitioned area to minimize any bias which may occur due to environmental conditions. At regular intervals over test period, the system will be inspected for any damage or fouling which may have occurred and the data from each sensor box will be collected. The DO sensors are also to be regularly inspected and cleaned to ensure measurement accuracy. The aeration system, dividers, and sensors will be removed from the lake following completion of the experiment.

Works Cited

[1] R. Muir and Z. Parhizgari, "Swan Lake: Long Term Management Plan," Markham, 2021.
[2] Friends of Swan Lake Park, "Pathway to Sustainability," Markham, 2020.