Friends of Swan Lake Park

A PATHWAY TO SUSTAINABLE WATER QUALITY FOR SWAN LAKE

December 15, 2020

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EXECUTIVE SUMMARY

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.

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 and the erosion of sustainable terrestrial habitat in Swan Lake Park due to the unchecked intrusion of invasive plants.

The environmental elements in the Park are all interconnected and interdependent on each other. Once water quality gets out of balance, aquatic life and aquatic plants are directly impacted while other elements are negatively affected by the deteriorating aquatic conditions. Our June 2020 report, “Pathway to Sustainability”, details the issues facing Swan Lake and Swan Lake Park and is available on our website at www.friendsofswanlakepark.ca.

Over 27 years, Swan Lake and the surrounding land has evolved from an inactive, obscure gravel pit to the centre piece of the thriving Greensborough community. In 2020, the City of Markham Council recognized the need to address a variety of the issues in the Park and authorized three programs that will immediately address some of the critical issues:

1) Approved a treatment of Phoslock for Swan Lake in spring of 2021, a chemical treatment that will help minimize the current excessive amounts of phosphorus in Swan Lake;
2) An enhanced geese management program that will reduce one of the primary sources of excess phosphorus and nitrogen entering Swan Lake each year;
3) A Park Refresh program that will address some of the invasive plant species in the Park and will include a review of options for redesigning the shoreline areas to reduce the attractiveness to Canada Geese while improving public viewing access.

Council asked staff to report back in 2021 on two important topics: 1) a “Park Improvement” program and 2) the establishment of long term water quality guidelines for Swan Lake.

Discussions on Park Improvement are inter-related to water quality objectives. The original objective, set out by the developers and accepted by Markham officials at that time, was for Swan Lake to provide community engagement for water based sports, sports fishing and ice skating. These objectives were never realized and due to the current poor water quality could not be supported today. Only the hardiest of fish species can survive in Swan Lake and due to the presence of cyanobacteria, the water presents a health risk to both humans and small animals.

In July 2020, Markham staff released two reports that provide the technical background on the water quality issues in Swan Lake. The attached appendices contain the Executive Summary of each report as well as a list of questions we have related to these reports.

The report by Freshwater Research (Appendix C), Markham's water quality consultant, concludes by recommending a 5 year Phoslock treatment cycle beginning in 2021 and addresses some of the issues associated with other phosphorus treatment options. It does not however provide guidance on what complementary efforts should be undertaken, within the context of an ongoing Phoslock treatment program, to address low oxygen levels and to reduce excessive levels of nitrogen and chloride.

This report, which draws upon the information provided in the technical reports issued by Markham, was created by Friends of Swan Lake Park to facilitate discussion around addressing these other critical issues impacting water quality that need to be addressed if Swan Lake is to be environmentally stabilized. It also provides a framework for a discussion that ties water quality to the broader objectives of the community role of Swan Lake as illustrated in the table below.

Lake Conditions and Community Options Associated With Trophic States

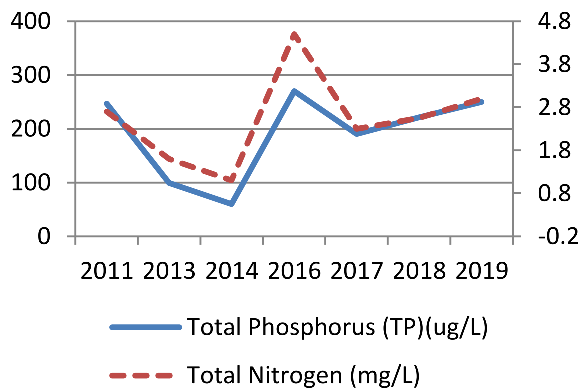
TROPHIC STATE	AQUATIC ENVIRONMENT	COMMUNITY OPTIONS
Oligotrophic	Lack of plant nutrients keep productivity low, lake contains oxygen at all depths, clear water.	Swimming, paddle sports, wide range of fish options.
Mesotrophic	Moderate plant productivity, lower levels may lack oxygen in summer, moderately 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.**

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. Frequent chemical treatments will be required to stabilize Swan Lake as eutrophic.

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.

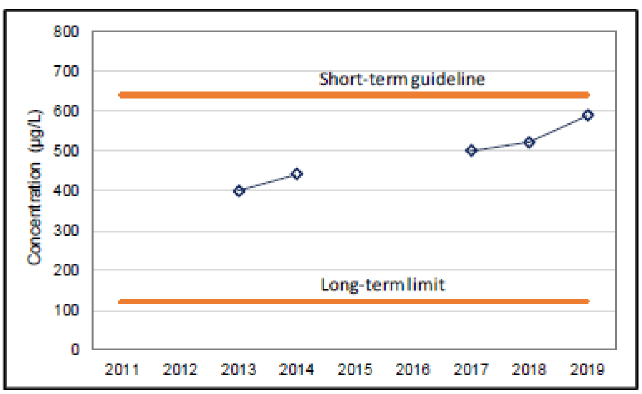
The Phoslock treatment planned for spring of 2021 is an essential first step towards containing the deteriorating water quality issues in Swan Lake. However, Phoslock only addresses phosphorus. Establishment of a stable water quality environment in Swan Lake requires an action plan that addresses the three other major contributors to the poor water quality conditions in Swan Lake:

1) Excessive nitrogen levels



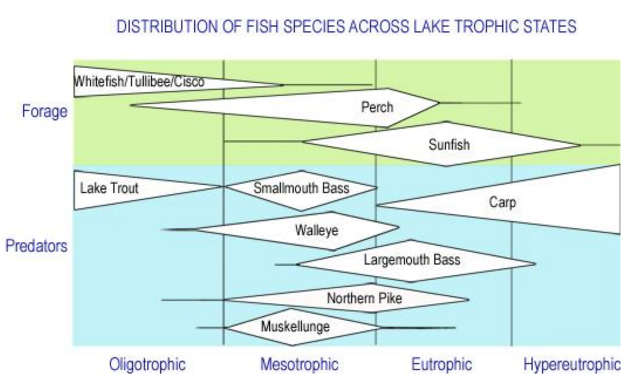
Nitrogen, like phosphorus, is an important nutrient for aquatic life but the excessive amounts in Swan Lake are sufficient to fuel and support excessive algae levels even if phosphorus were eliminated. A program to contain algae must also address the excessive nitrogen levels.

2) Excessive chloride (road salt) levels



Chloride levels in Swan Lake are 4-5 times higher than the long term Federal standards. Three road surfaces adjacent to Swan Lake drain directly into the lake. The excessive chloride (from road salt) is sufficient to kill small fish and eliminate zooplankton in the water, natural elements that consume algae. Restoring a healthy zooplankton colony is a building block for a naturally sustainable aquatic environment.

3) Low oxygen levels



Low levels of dissolved oxygen reduce aquatic and plant life in the lake and draw phosphorus from the sediments. Improved levels of oxygen are essential to restoration of aquatic animal and plant life that in turn can contribute to a balanced aquatic environment.

Section 6, outlines several approaches that may help improve oxygen levels.

Water Quality Goals

	Eutrophic Classification Measures				
	Algae Measures (1)		Nutrient Measures (1)		Dissolved
	Chlorophyll (µg/L)	Clarity (3) (meters)	Phosphorus (µg/L)	Nitrogen (µg/L)	Oxygen (2) (mg/L)
Eutrophic Range	9.1 - 25	1 - 2	31 - 100	0.65 - 1.2	5 - 11
Remediation Trigger	25	1	100	1.2	5
Midpoint Goal	17	1.5	65	0.93	8
2014 Actual (Post Phoslock)	**12.6**	**1.4**	**60**	**1.1**	**<2.5**

Note: 1) Freshwater Research 2) Fondriest Environmental 3) Water clarity as indicated by Seechi Depth

The 2013 Phoslock treatment was successful in achieving or exceeding the mid-point eutrophic state goals in 2014 for the key measures of algae (chlorophyll and clarity) and for phosphorus. Nitrogen levels improved to the eutrophic levels however there was no improvement in oxygen levels.

We believe the mid-point eutrophic level could be maintained over a three year period by adopting a three year Phoslock treatment cycle combined with continued aggressive geese management.

Phoslock that does not bind immediately with phosphorus remains active. Therefore, if feasible, consideration should be given to adding additional quantities of Phoslock in 2021, perhaps enough to offset 1-2 years' worth of the incoming phosphorus from external sources.

The ideal sustainable solution is to reach the point where Swan Lake can be categorized as a mesotrophic lake but that objective is likely only feasible if efforts are successful in lowering nutrient sources such as phosphorus and nitrogen and establishing a healthy aquatic environment by improving oxygen levels and reducing chloride levels.

Additional Actions Required in a Post Phoslock Setting

Phoslock targets the critical goal of reducing phosphorus already in the lake while the Geese Management program should help reduce the major external source of phosphorus and nitrogen.

We are not aware of any planned changes in stormwater management design or practices in and around the park; however improvement in stormwater management practices could have a significant direct impact on the volume of contaminants entering the lake. We recommend a high priority be given to investigating ways to reroute the stormwater drainage on Swan Lake Boulevard and the Amica property away from Swan Lake and that there be closer monitoring of the water quality and maintenance of the oil/grit separators and the two stormwater ponds.

The current programs do not directly address three other important issues: 1) Need to improve oxygen levels and 2) the need to reduce nitrogen levels, and 3) the need to reduce chloride levels.

	BENEFITS DERIVED			
	Phosphorus Reduction	Nitrogen Reduction	Chloride Reduction	Improved Oxygen
CURRENT ACTIONS				
• Phoslock	√			
• Geese Management	√	√		
• Stormwater Maintenance	?	?	?	
ADDITIONAL OPTIONS				
• Nitrogen Treatment		√		
• Chloride Treatment			√	
• Direct Oxygenation	√			√
• Indirect Oxygenation & Purification	√	√		√
• Purification by Extraction	√	√	√	

The above table illustrates the areas impacted by the current programs. In Section 6, we outline some additional programs that could address the core issues and minimize the dependency on Phoslock.

Proposed Six Year Action Plan

We believe the following comprehensive six year program could stabilize Swan Lake as a eutrophic lake and provide a basis of assessing whether attaining mesotrophic status is feasible.

The proposed plan is based upon a 3-year Phoslock treatment cycle supported by continued efforts to reduce incoming phosphorus and nitrogen through aggressive geese management. In parallel, additional actions are taken to reduce nitrogen and chloride levels and to improve oxygen levels.

A) Reparation Phase - Years 1-3 (2021 – 2023)

During the initial 3 year Reparation Phase, efforts should be undertaken to manage the four key issues identified: excessive phosphorus, excessive nitrogen, excessive chloride and low oxygen levels.

Investigation is required into what solutions are feasible and optimal for the complex issues in Swan Lake. Investigation is undertaken in 2021, providing time to implement any identified solutions within the initial three year cycle.

B) Monitoring Phase Years 4 – 6 (2024 – 2026)

Another Phoslock treatment would be applied in the spring of 2024, including additional dosage if feasible, setting the stage for a 3-year monitoring period to assess the success of the new initiatives.

C) Reassessment 2026

A reassessment in 2026 of the success over the Monitoring Phase will determine the effectiveness of the various efforts. Another Phoslock treatment should be planned for the spring of 2027 and a determination made if it is feasible to move to a 5-year Phoslock treatment cycle thereafter.

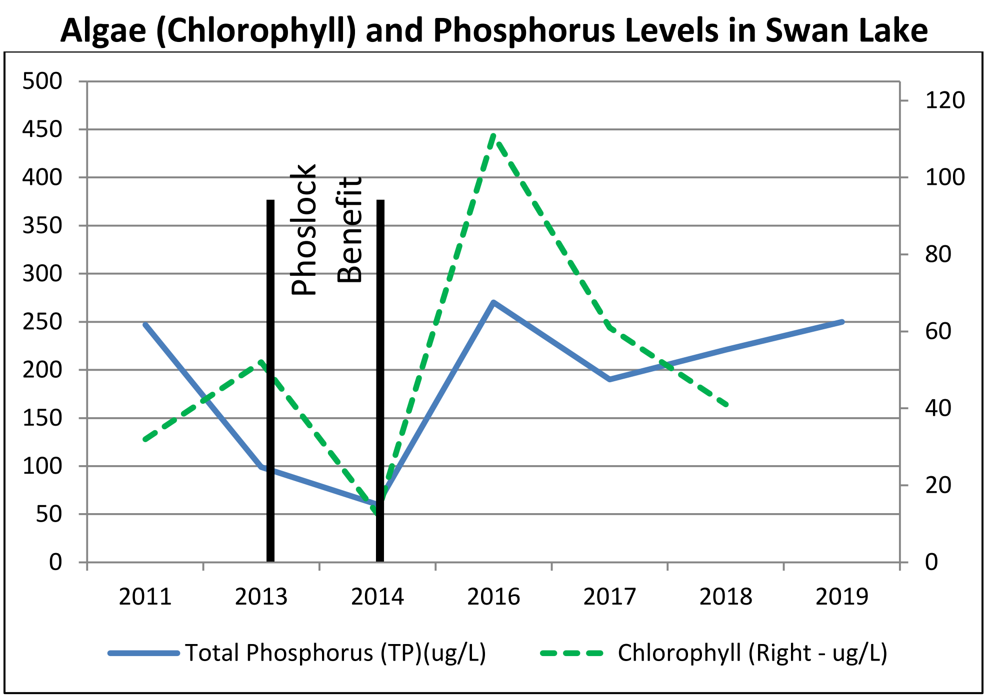
1) PHOSPHORUS AND PHOSLOCK

Based on water samples taken in 2005, a series of environmental studies of Swan Lake dated 2006 were prepared in preparation for the residential development around Swan Lake. These reports describe Swan Lake as having a "healthy warm water fish community". One report noted that the level of phosphorus in the Lake was high and would require monitoring. It recommended efforts be undertaken to identify and minimize the sources of the phosphorus, which were assumed to be related primarily to the intake of stormwater. A treatment of Copper Sulfate was applied in 1995 to reduce algae levels.

Over the following years, water quality continued to deteriorate to the point that there were regular sightings of algae blooms and cyanobacteria with fish kills recorded in 2012-2013.

An application of Phoslock (25 tonnes) was applied in April 2013 to reduce the impact of phosphorus in the sediments. There was initial success however the effects lasted only two years. By 2016 phosphorus levels had returned to levels in excess of those prior to the Phoslock treatment.

The following chart illustrates the short term drop in algae levels (as measured by chlorophyll) following the Phoslock treatment in 2013. Chlorophyll, a green pigment in plants used for photosynthesis, is considered a good indicator of the total quantity of algae in a lake.



Of note is the degree to which chlorophyll levels bounced back relative to the increase in phosphorus levels following the Phoslock treatment in 2013 but declined thereafter. Perhaps the hot dry summer in 2016 followed by relatively wet, cool summers in 2017 and 2018 were factors or perhaps the bounce back can be attributed to nitrogen, the other primary nutrient available in Swan Lake.

Sizing the Phoslock Treatment

Eight years after the initial treatment, a second dosage of Phoslock is planned for the spring of 2021.

Phoslock is a modified clay product made from naturally occurring products lanthanum and bentonite. Lanthanum binds with phosphorus to produce lanthanum phosphate. Lanthanum phosphate is very insoluble and therefore once bound phosphorus remains locked up within the bentonite. Phoslock settles on the sediment and so long as there are active lanthanum sites it will continue to react with any phosphorus either released from the sediment or present in the water.

In October 2019, lake bottom sediments were analyzed to assist in defining the appropriate size of the Phoslock treatment planned for 2021. A preliminary budget was based on an estimate of 35 tonnes, an increase from the previous 25 tonne treatment in 2013. The final dosage will be determined following the analysis of the sediments.

Since Phoslock can remain active after the application date, it begs the question of whether it is feasible to adopt a “proactive” program by adding additional amounts of Phoslock to address the expected annual influx of 30 kg or more of phosphorus contributed by external sources each year.

Adding additional quantities of Phoslock may provide greater environmental stability over the treatment period. By adding additional amounts of Phoslock in 2021, is it possible to extend the environmental benefits by 1-2 years?

Concerns about Phoslock

Phoslock is a focused solution – it directly reduces phosphorus levels but has no direct impact on nitrogen or chloride. By reducing algae levels it can have an indirect impact of the loss of dissolved oxygen attributed to decaying algae.

Phoslock is estimated to cost up to 50% more than traditional chemical applications such as aluminum compounds. The need for frequent periodic treatments means that the additional long term costs are significant. Do the benefits of Phoslock clearly justify the additional costs?

The manufacturer notes that Phoslock has been the subject of extensive ecotoxicity and other testing however some experts have expressed concern that there is not enough experience to be completely comfortable with the long term impact under continued use. Freshwater Research notes that it would be prudent to time the Phoslock treatment so as not to interfere with egg laying stages for amphibians and turtles, so there is some level of concern about possible environmental impact.

Therefore while Phoslock may provide an effective immediate solution for reducing phosphorus levels, more investigation should be undertaken to find complementary effective solutions that will minimize the future dependency on Phoslock for both financial and environmental reasons.

2) NITROGEN LEVELS

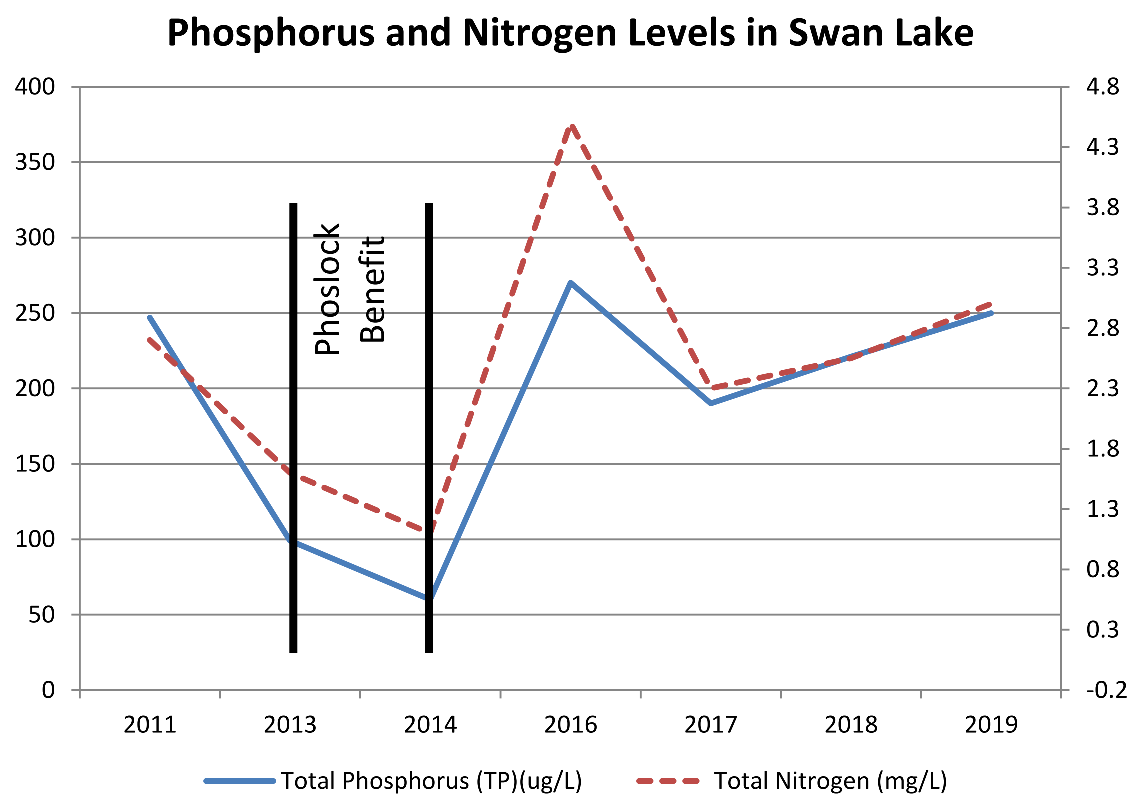
Nutrients, such as nitrogen and phosphorus, are essential for plant and animal growth and nourishment. Nitrogen, in the forms of nitrate, nitrite, or ammonium, is a nutrient needed for plant growth.

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

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.

Freshwater Research notes that Phoslock does not directly treat nitrogen or low oxygen levels. It also notes that nitrogen is not released from anoxic sediments like phosphorus so that the increases each fall are most likely attributed to the arrival of migrating geese.

The following chart illustrates the drop in nitrogen levels In relation to the changes in phosphorus levels following the Phoslock treatment in 2013.

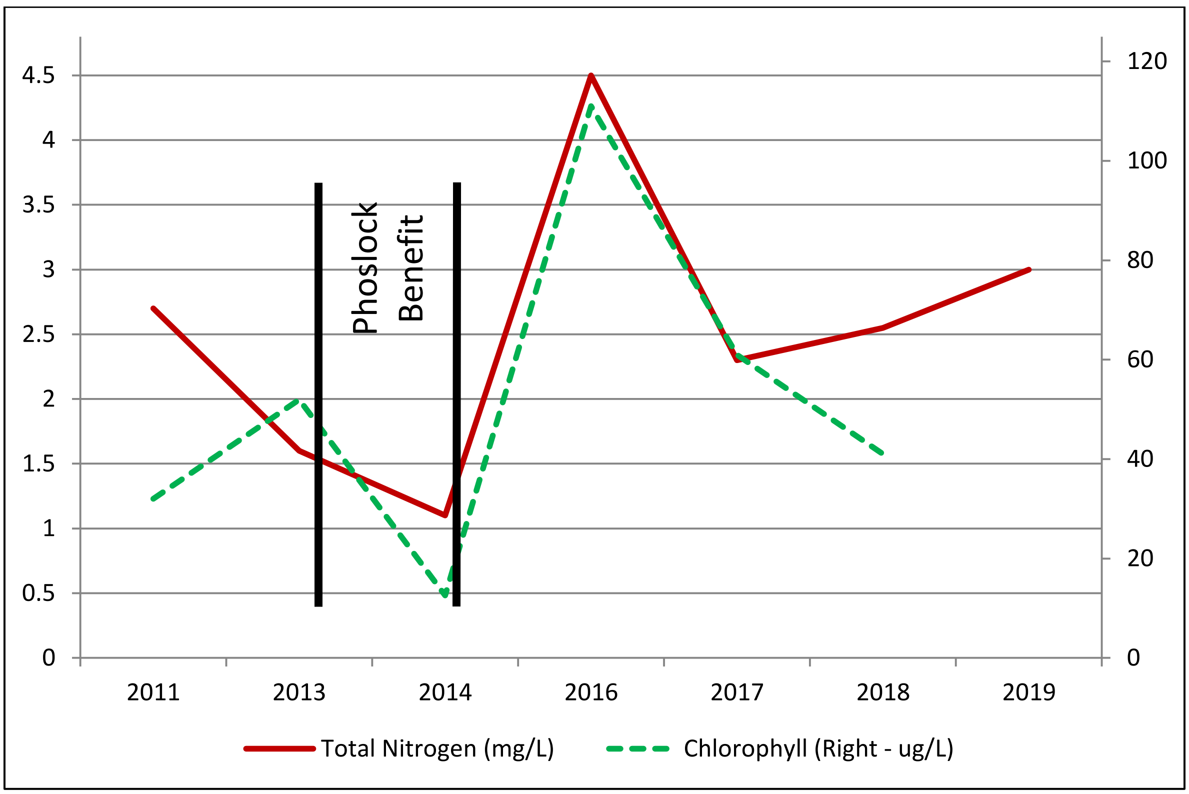


If Phoslock has no direct impact on nitrogen, why did nitrogen levels drop in 2013-2014? Perhaps the layer of clay associated with Phoslock also serves to trap nitrogen in the sediments.

The following chart suggests that nitrogen levels may have been a contributor to the rapid return of algae in Swan Lake following the Phoslock treatment in 2013.

Following the Phoslock treatment, the rise in algae is in line with the rise in nitrogen levels. While 2016 was a hot, dry summer, perhaps at this point nitrogen had become the dominant nutrient and a primary factor in the increase in algae.

Algae (Chlorophyll) and Nitrogen Levels in Swan Lake



Nitrogen is one of the core nutrients that can contribute to the growth of algae. So if a successful program were undertaken to eliminate phosphorus as the primary nutrient, say by adding Phoslock each year, at what point would nitrogen kick in and become the primary contributor to algae growth and thereby undermine the contributions of Phoslock?

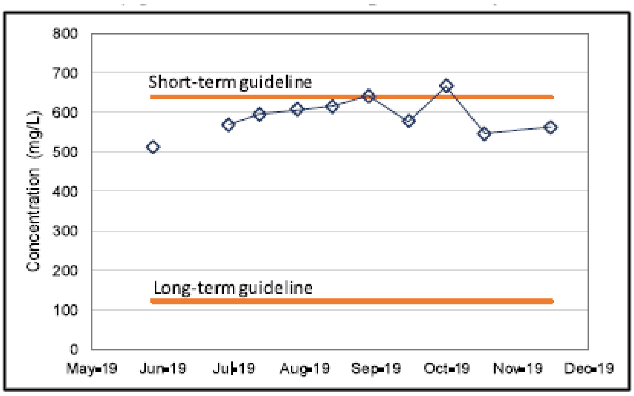
What options are available for reducing nitrogen levels in Swan Lake?

Can we achieve mesotrophic levels of water quality without dealing with nitrogen levels?

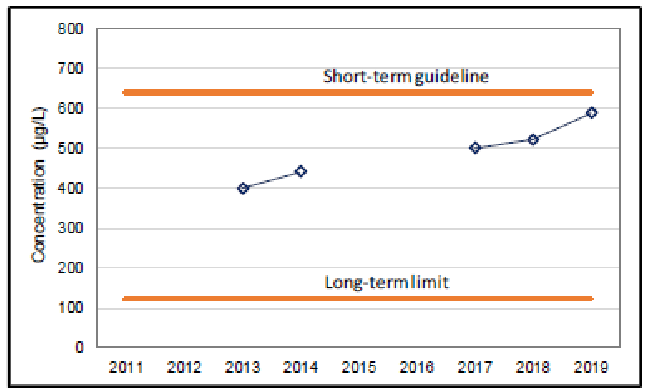
3) IMPACT OF EXCESSIVE CHLORIDE LEVELS ON AQUATIC LIFE

Swan Lake contains an excessive amount of chloride that Freshwater Research attributes to winter de-icing operations. Chloride does not break down and will accumulate within the lake over time, impairing the health of aquatic plants and many forms of aquatic species.

The following charts provided by Markham Environmental Services illustrate that the average annual chloride level in Swan Lake in 2019 was 5x the long term Canadian Water Quality Guidelines for the Protection of Aquatic Life – Chloride[1] of 120 mg/L and that each month in 2019 the chloride levels approached or exceeded the short-term guideline of 640 mg/L.



Short-term Levels of Chloride 2019



Average Annual Levels of Chloride

The long-term chloride guidelines were established based on the sensitivity of 28 different species to chloride levels. The observed levels of chloride in Swan Lake in 2019 are well in excess of a safe environment for 44% of the species on which the federal guidelines were based, including small fish such as the Fathead Minnow, which was identified as an original species in Swan Lake.

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

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

Research by McClymont[2] concludes that the CWQ Guidelines are too high to adequately protect zooplankton communities. The study's findings were that "At the CWQG (120 mg Cl/L), zooplankton abundances and biomasses were reduced by 30% - 77% …" and notes that other studies have

[1] http://ceqg-rcqe.ccme.ca/download/en/337/
[2] The Effects of Increasing Chloride Concentration and Temperatures on Freshwater Zooplankton Communities, A.C. McClymont, Queen's University, 2020

associated lower zooplankton levels with increased phytoplankton abundance and increased frequency of harmful algal blooms and the risk of cyanobacteria. In 2019, the chloride levels in Swan Lake were 600 mg/L, far above the levels at which zooplankton can survive.

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

Levels of chloride in Swan Lake are consistently well above the CWQ Guidelines. Reduction in chloride levels and restoration of a healthy zooplankton community and a robust stock of small algae eating fish could provide a meaningful contribution to the control of algal growth and cyanobacteria in Swan Lake. Perhaps overstocking with algae eating fish may compensate for the loss of zooplankton.

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

Sources of Chloride

The core questions become 1) How is road salt getting into Swan Lake?, 2) What can be done to restrict or reduce the amount entering the lake, and 3) What can be done to treat the amounts already in Swan Lake?

The likely primary sources of road salt are the three adjacent road surfaces where stormwater drains directly into Swan Lake after passing through oil/grit separators plus stormwater overflow from the stormwater system that feeds into the two adjacent stormwater ponds.

The locations of the three adjacent road surfaces that drain into Swan Lake via oil/grit separators are:

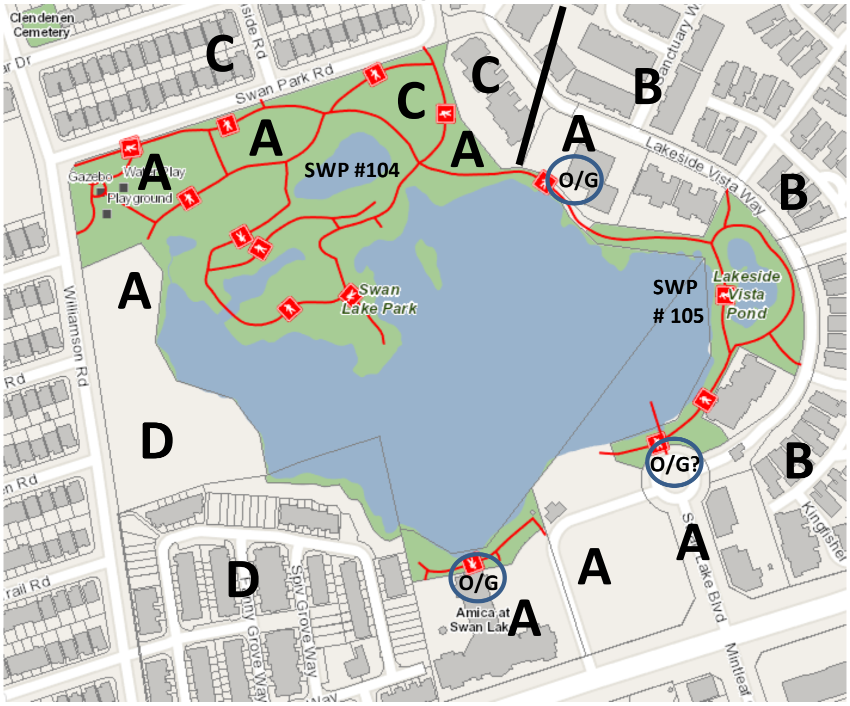
1) At the traffic circle on Swan Lake Boulevard (Stormceptor STC2000 specified, though the existence cannot be confirmed);
2) On the Amica property (a Stormceptor STC750);
3) The parking lot at the Swan Club in Swan Lake Village (a Stormceptor 300i).

The owners responsible for these oil/grit separators are expected to provide regular cleaning to ensure they are operating as designed. We are told that the city has no record of the cleaning record for any of the oil/grit separators. We were able to confirm that the oil/grit separator at the Swan Club was cleaned in 2020. We recommend that Markham determine if the other oil/grit separators are in need of cleaning.

Properly maintained oil/grit separators are designed to reduce contaminants entering Swan Lake; however, since chlorides are soluble in water, oil/grit separators provide virtually no ability to prevent chlorides from road salt from entering the lake.

The other likely contributors of road salt are the two stormwater ponds. The water balance model developed by city of Markham staff (Appendix C of the Freshwater Research report) assumes that these ponds are operating to their design.

Stormwater Drainage in Swan Lake Park



Drainage A) To Swan Lake B) To SWP #105 C) To SWP #104 D) To Williamson Road

The water balance model concludes that the large eastern stormwater pond (#105) is a regular contributor to Swan Lake implying this is a likely source for both phosphorus and road salt.

Both stormwater ponds are served by splitters that divert stormwater runoff during heavy rainfall events directly into Swan Lake. Any chloride, phosphorus or other contaminants absorbed by the excess stormwater bypassing the stormwater ponds goes directly into Swan Lake.

We were told that the water in the stormwater ponds is not tested by the city and that Markham does not know if the ponds are in compliance with the original maintenance obligations, so it is not known if these ponds are contributors of chloride or other contaminants to Swan Lake.

Freshwater Research noted that the stormwater ponds could be monitored for nutrient output. We would recommend that, in addition to monitoring the water quality in the ponds, the quality of the water bypassing the stormwater ponds via the overflow splitters should also be monitored.

Improved maintenance of the stormwater systems may not materially alter the chloride levels so other solutions to minimize chloride contributions may be necessary:

1) Minimize or ban the use of road salt in the three areas draining directly into Swan Lake;
2) Minimize or ban the use of road salt in all areas draining into the stormwater ponds;
3) Redirect the stormwater flows in the traffic circle and Amica parking areas to the stormwater systems along 16th Avenue or to the eastern stormwater pond;
4) Determine if there are effective chemical solutions that could be applied to Swan Lake that would neutralize the chloride already in Swan Lake.

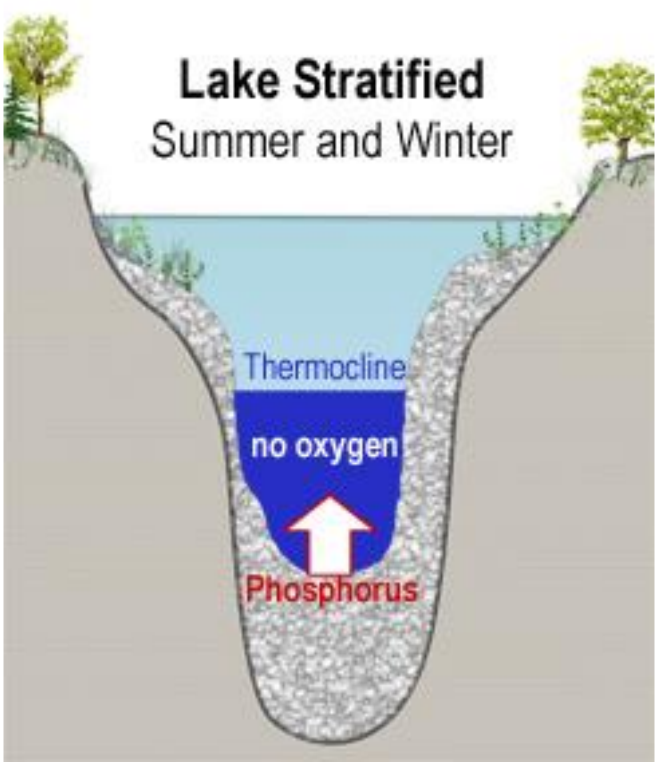
4) IMPROVING DISSOLVED OXYGEN LEVELS IN SWAN LAKE

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.

In lakes, oxygen is only added near the surface because that’s where the plants are and where diffusion from the atmosphere occurs. In the summer and winter, Swan Lake is usually separated into a top layer and a bottom layer called stratification. During stratification, the bottom of the lake becomes anoxic, void of oxygen. Anoxia occurs because respiration and decomposition takes place at the bottom of the lake and use up oxygen. The oxygen can’t be replenished at the bottom of the lake because it is cut off from the top of the lake by the thermal barriers. In the spring and fall when the lake mixes again, oxygen gets replenished at the bottom of the lake.



Source: RMB Labs

If the bottom of the lake becomes anoxic, the aquatic life either dies or moves up from the bottom to where there is oxygen. For example, in late summer fish usually move closer to the surface because there is no oxygen available at the bottom of the lake. In shallow lakes in the summer and winter, the entire lake can become anoxic, causing a fish kill.

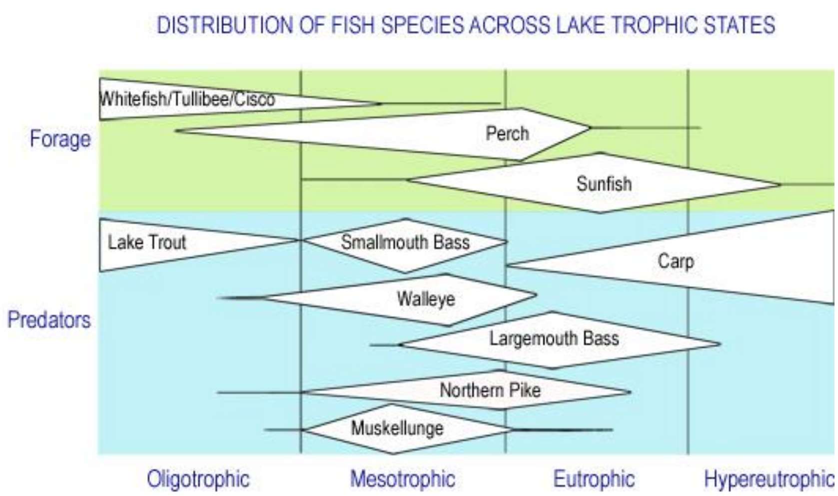
When the bottom of a lake is anoxic (usually in late summer and late winter), chemical processes at the sediment/water interface cause phosphorus to be released from the sediments. When the lake mixes again, this increased phosphorus fuels algae growth. This phenomenon is called internal loading because phosphorus is entering the lake from within the lake (from the sediment).

A) Dissolved Oxygen and Fish in Swan Lake

The original design of Swan Lake included environmental elements to support a healthy fish habitat. Early reports cite Swan Lake as supporting pumpkinseed sunfish, black crappie, fathead minnows and largemouth bass (believed to have been stocked prior to 1992 by TRCA). Many fish died prior to the Phoslock treatment in 2013.

Levels of dissolved oxygen in Swan Lake are typically below 3 mg/L. Only the hardiest of fish can survive at such low levels. Current sightings report carp, goldfish, catfish and minnows.

The following chart from RMB Environmental Labs illusrates the limited range of large fish that can survive in the poor hypereutrophic conditions in Swan Lake. A much greater variety, including smallmouth bass and perch can survive in mesotrophic conditions.



In concert with the Phoslock program, Freshwater Research has recommended that Markham introduce a program to rid Swan Lake of bottom feeding fish, such as carp and goldfish, that break up the clay barrier and thus contribute to phosphorus release from the sediments and back into the lake.

Freshwater Research recommends that Markham engage a fish specialist to advise on the type of fish that should be considered for restocking the lake. The suggested three categories are:

1) Species that do not consume zooplankton, since one of the objectives is to maximize zooplankton
2) Small fish that eat insects and mosquitos
3) Predator fish that can help keep carp and goldfish in check

If one of the community goals is to support sport fishing, the selection will need to include sport fish, such as largemouth bass, that could survive in at least eutrophic conditions. If the high chloride levels make it impossible to support a healthy zooplankton colony then the focus may also have to include small fish that consume algae as their primary food source given the lack of zooplankton.

Perhaps there is the potential to leverage Swan Lake's needs into a broader solution for the numerous stormwater ponds throughout the region. Ontario sponsors a fish hatchery program. If Swan Lake were overstocked with fish that address its immediate needs this could provide a source of fish for stocking stormwater ponds, helping to address regional problems such as algae and mosquito control.

B) Oxygenation and Stratification

Improving oxygen levels in Swan Lake should reduce phosphorus release from the sediments (internal loading) and reduce the amount of Phoslock required in the future. The challenge becomes finding a means to improve oxygenation levels in Swan Lake ideally in a manner that supports the phosphorus management challenges.

Freshwater Research notes that Swan Lake thermally stratifies during the summer despite its shallow depth. This pattern of stratification and anoxia (lack of dissolved oxygen) remained similar after the Phoslock treatment.

The hypolimnetic area is the lower layer of water that is non-circulating and remains cooler than the surface layer. Freshwater Research notes that "hypolimnetic aeration or oxygenation coupled with a chemical to absorb phosphorus, such as iron and aluminum, have consistently decreased internal load and delivered positive effects on tropic state".

This conclusion suggests that in sync with an ongoing treatment program using Phoslock (rather than aluminum), there are successful oxygenation techniques that could aid in the management of phosphorus levels in Swan Lake while enhancing the environment for aquatic species. Freshwater Research suggests that the challenge is finding an economic solution.

One of the challenges in identifying the appropriate oxygenation solution relates to whether the objective should be to maintain levels of stratification or whether it is better to mix the layers in the lake. The lake naturally mixes midsummer so the natural stratification is considered relatively weak.

Two paths require investigation: A) Direct Oxygenation B) Indirect Oxygenation

A) Direct Oxygenation

Oxygenation equipment can be added to Swan Lake. 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 Phoslock environment.

B) Indirect Oxygenation

Indirect options for oxygenation include i) the removal of phosphorus laden water from the lake to be replaced by freshwater via the aquifer or ii) the recycling of lake water via the north channel through a bioswale or floating islands.

Investigation is required into the best options for improving oxygen levels in Swan Lake. An effective program to improve oxygen levels in Swan Lake should have two primary objectives:

1) Improve and stabilize the aquatic environment in the Lake
2) Reduce, or at least not worsen, the phosphorus management challenges

5) OXYGENATION AND NATURAL PURIFICATION OPTIONS

A) Direct Oxygenation

There are several styles of equipment options for directly adding oxygen to lakes and ponds.

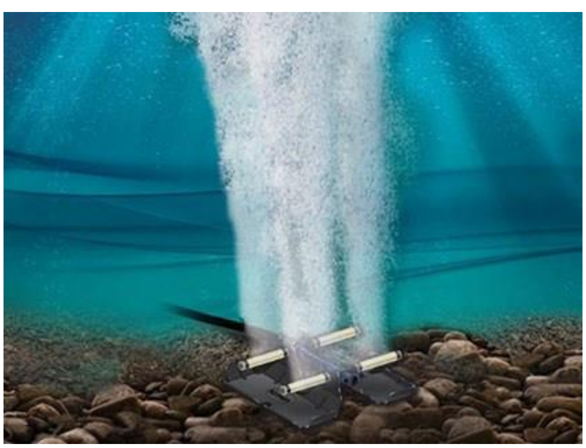
Fountains tend to provide only surface level aeration. The fountain that had been in use until recently in Swan Lake was considered decorative, providing only minimal benefit as an aerator.

Bubblers add oxygen but tend to mix the layers. Water circulators stir the water and increase oxygen levels.

These approaches are aimed at addressing the internal sources of phosphorus and can have a material impact on increasing dissolved oxygen levels.

The manufacturers cite the following benefits:

- Prevents and controls cyanobacteria (blue-green algae) blooms.
- Improves dissolved oxygen (DO) and pH levels throughout the circulation zone.
- Reduces invasive aquatic weeds and filamentous algae.

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

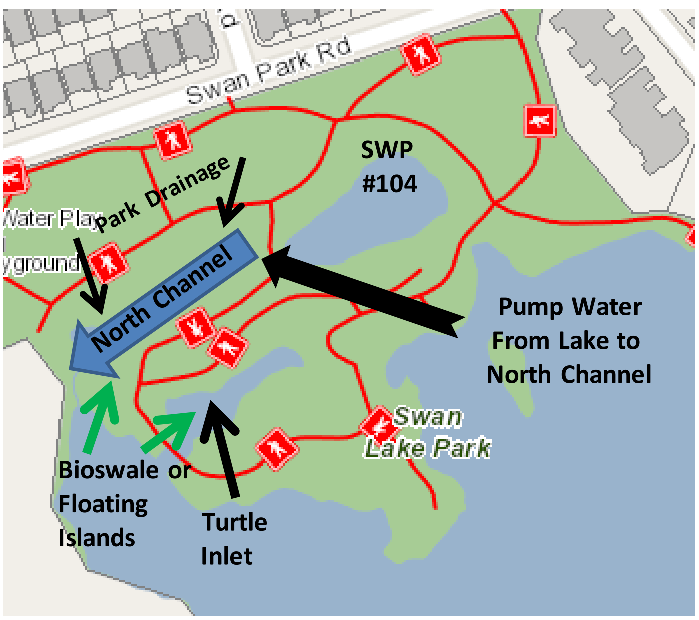
Specialists caution that it is important to tailor the use of this type of equipment to the specific situations in the lake.

B) Indirect Oxygenation and Purification: Recycling Lake Water

Swan Lake is a stagnant pond. There are no natural surface level inflows or outflows. 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.

Pulling from and returning water to the lake would create circulation of water within the lake that will be beneficial in mixing nutrients within the lake. Before being returned to the lake, the water could be enhanced in two ways: first, by naturally adding oxygen to the returning water by having it flow over waterfalls or rough stones and by using proven biological techniques to filter out some of the phosphorus and nitrogen before returning it to the lake.

Circulating Water Through the North Channel



The North Channel, about 50 metres long, is designed as an emergency spillway for overflow from the north stormwater pond; 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 areas.

As noted above, pumping of water from the lake through the North Channel will provide a basic level of circulation in the Lake. The volume of the circulation will be dependent on the capacity of the pumps deployed.

A small ½ HP pump, driven either by solar sources or by repurposing the existing windmill on the north pond, would have the capability to recycle 13% of the water volume within Swan Lake. Perhaps it may be possible increase capacity by installing an historic windmill from one of the local farms.

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 50% of the lake water through the North Channel each season. In addition to higher oxygen levels throughout the lake, the increased circulation should lead to a greater mixing of the warmer and cooler waters, adding to the oxygen content near the sediment and thus reducing the amount of phosphorus drawn from the sediments.

Bioswales and Floating Islands: North Channel and Turtle Inlet

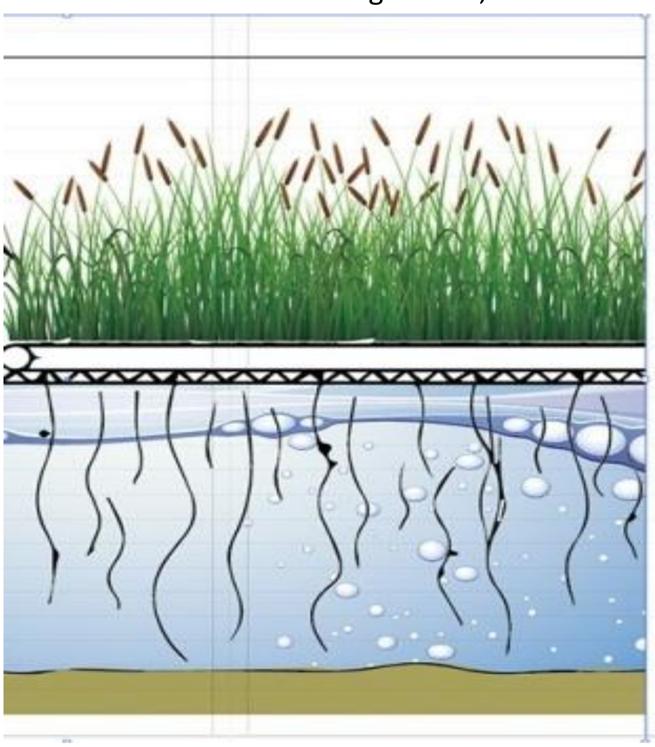
Phosphorus and nitrogen could be removed from the water recycled through the North Channel by passing the water through a bioswale or an area containing floating islands.

Bioswales are ditch-like areas that contain plants that can help control and absorb nutrients. They are commonly used for stormwater management control but they have the added benefit of absorbing nutrients from the water flow.

The North Channel currently serves as a nominal bioswale but could be enhanced. One concept is to plant more nutrient absorbing plants, such as bulrushes, or installing floating islands. Similarly, Turtle Inlet, the small inlet of water near the foot bridge on the north-west portion of the lake could be converted to a bioswale or as an area to host floating islands.

Floating islands are designed to absorb phosphorus and nitrogen by encouraging plant growth above and below the waterline and are designed to mimic how natural wetlands purify water. Features can be added to improve the efficiency for water purification by creating a rich habitat in the root systems for billions of beneficial bacteria.

Two manufacturers of floating islands, Currie Industries and Biomatrix, were identified.



On a floating island, the roots extend into the water and absorb nutrients (phosphorus and nitrogen) from the water. The plants are then harvested in late summer. The roots remain intact on the platform and are left to regrow the next spring, repeating the process.

A case study on the Biomatrix website, cites the success of the floating islands on Hicklin Lake, in Washington State. What’s interesting is that the local residents encouraged the adoption of the floating islands as an alternative to a third aluminum treatment. The initial results showed improvement but not as significant as that provided by the aluminum treatment.

The plants on the island (or in a bioswale) can be harvested near the end of the growing season to minimize the return of the nutrients back into the ecosystem. Perhaps an annual harvest of the phragmites and bulrushes surrounding the Lake shoreline would also contribute to increased absorption by the existing shoreline plants.

C) Purification by Extraction and Recycling via the Aquifer (Drawdown)

Swan Lake has two natural sources of fresh water – precipitation and underground sources from the local aquifer. The aquifer is the source that filled the original quarry. We cannot influence precipitation but it is possible to draw periodically from the aquifer.

Periodically extracting water from the lake would reduce the amount of phosphorus, nitrogen and chloride in the lake water. Fresh water would then gradually enter the lake from the aquifer, improving the fresh water mix within the lake. Lake water could be removed in three possible ways:

1) Withdrawn in the summer months for irrigation. Nutrient rich water from the lake could be used to refill city of Markham water trucks, used to irrigate the new park area along Williamson Road or used by neighbouring Swan Lake Village for lawn irrigation.
2) Water could be pumped into the adjacent stormwater ponds, with possible chemical treatment before entering the pond.
3) Alternatively or in addition, water could be pumped into the 16th Avenue stormwater system through existing connections.

Average precipitation data for the Greensborough area show low precipitation rates for the months from November through March and consequently this period would represent a period of low volume demands on Markham's stormwater sewer system and therefore a period during which the stormwater sewer system would have the capacity to handle these small volumes of water.

Consideration would have to be given as to whether the lower lake volumes during the winter months would be detrimental to the welfare of the aquatic life in the lake.

The removal option is a relatively low cost option – the infrastructure is in place, all that is required is the temporary deployment of water pumps. Extraction would effectively remove some of the excess nutrients and chlorides in the lake but it would likely not improve oxygen levels.

Several concerns about these "drawdown" approaches have been raised:

i) Freshwater Research notes that the lake mixes during the summer, so there will not be a reliable access to phosphorus laden water from the deeper areas of the lake.
ii) The report also concludes that directing lake water into the stormwater ponds would not be beneficial since the water is not rich in settling sedimentary particles. However, this fails to recognize that the basic objective of removal of the contaminants is itself beneficial.
iii) Markham staff suggested that the downstream stormwater system has limited capacity to accept additional water from Swan Lake. As noted above, the downstream system should have capacity during the winter months.
iv) The adjacent stormwater ponds also have limited capacity to take on extra water so it may be necessary to deepen the ponds to manage any extra flows.

6) A PLAN FOR ATTAINING IMPROVED WATER QUALITY GOALS

It is important that the City of Markham commit to defining what they think success looks like in the context of both the aquatic environment and in terms of community objectives.

Scientists have developed a rating system for lakes that can be used to set out measurable goals. These ratings were designed to help categorize the aquatic environment but there is also a direct correlation to the options available for community use as summarized in the chart below.

Lake Conditions and Community Options Associated With Trophic States

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.**

Swan Lake is categorized as a hypereutrophic lake. 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.

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

Interim and Long-term Goals

Freshwater Research notes that it would be “nice” to keep Swan Lake in the eutrophic category briefly realized following the 2013 treatment (phosphorus levels below 100 µg/L and water clarity greater than 1 metre) and recommended this as a “long-term” goal.

As an “interim” goal Freshwater Research recommends staying within the hypereutrophic level (150 µg/L and water clarity of 0.45 meters) followed by Phoslock treatments every five years with an earlier treatment should phosphorus levels exceed 150 µg/L.

Friends of Swan Lake Park have encouraged Markham to adopt a 3-year Phoslock treatment plan that potentially should make Freshwater Research's proposed "long-term" goal immediately feasible by keeping phosphorus levels below 100 µg/L throughout the 3-year period and hopefully provide greater environmental stability for the aquatic life within the lake. If it is feasible to add additional quantities of Phoslock, that would help keep phosphorus in check through the three year period.

The Phoslock treatment was successful in achieving or exceeding the mid-point Eutrophic state goals in 2014 for the key measures of algae (chlorophyll and clarity) and for phosphorus. We recommend that we strive to restore water quality to 2014 levels and establish trigger points to maintain the mid-point eutrophic level during the initial three year period.

Eutrophic Classification Measures

	Algae Measures (1)		**Nutrient Measures (1)**		**Dissolved**
	Chlorophyll (µg/L)	**Clarity (3)** (meters)	**Phosphorus** (µg/L)	**Nitrogen** (µg/L)	**Oxygen (2)** (mg/L)
Eutrophic Range	9.1 - 25	1 - 2	31 - 100	0.65 - 1.2	5 - 11
Remediation Trigger	25	1	100	1.2	5
Midpoint Goal	17	1.5	65	0.93	8
2014 Actual (Post Phoslock)	**12.6**	**1.4**	**60**	**1.1**	**<2.5**
Note: 1) Freshwater Research 2) Fondriest Environmental 3) Water clarity as indicated by Seechi Depth					

Nitrogen levels improved to the eutrophic category following the 2013 Phoslock treatment however there was no measurable improvement in oxygen levels. In parallel with the Phoslock treatment, additional actions are required during the initial three years to reduce nitrogen levels, improve oxygen levels and reduce chloride levels within the context of the existing Federal guidelines.

The ideal sustainable solution is to reach the point where Swan Lake can be categorized as a mesotrophic lake but that objective is likely only feasible if efforts are successful in lowering nutrient sources such as phosphorus and nitrogen and establishing a healthy aquatic environment by improving oxygen levels and reducing chloride levels.

Proposed Six Year Action Plan

The lesson from the initial Phoslock treatment was that maintaining that success depends on prompt follow-up treatment with Phoslock at least every 3 years combined with the implementation of effective programs to reduce the inflow of phosphorus from stormwater and geese.

We believe the following comprehensive six year program could stabilize Swan Lake as a eutrophic lake and provide a basis of assessing whether attaining mesotrophic status is feasible.

The proposed program is based upon a 3-year Phoslock treatment protocol enhanced by active programs to address phosphorus, nitrogen, chloride and low oxygen levels. Major efforts are currently underway to reduce the phosphorus sources through geese management, which should aid in reducing nitrogen but other actions may be required to reduce nitrogen levels. Additional efforts are definitely required to address excessive chloride levels and for improving low oxygen levels.

A) Reparation Phase - Years 1-3 (2021 – 2023)

During the reparation phase, efforts should be undertaken to manage the four key issues identified: excessive phosphorus, excessive nitrogen, excessive chloride and low oxygen levels.

2021: Phoslock Treatment and Investigation of Other Treatment Options

1) Implement initial Phoslock treatment in spring. Add additional quantities if feasible
2) Complete the TRCA shoreline redesign to mitigate geese impact and support community use (currently planned)
3) Investigate options for addressing excessive nitrogen levels, excessive chloride levels, and oxygenation options
4) Implement spring geese relocation program and repeat hazing program for fall geese migration (currently planned)
5) Define long term community role for Swan Lake

2022 – 2023: Implementation

1) Implement the shoreline redesign and removal of phragmites
2) Implement selected oxygenation option
3) Implement program to reduce nitrogen levels (beyond geese management)
4) Implement program to reduce chloride levels
5) Restock with supportive fish
6) Plant supportive aquatic plants
7) Ongoing water quality monitoring

B) Monitoring Phase - Years 4-6 (2024 – 2026)

1) In 2024 undertake the follow up Phoslock treatment including adding additional quantities if feasible
2) Continue ongoing monitoring of water quality and where required alter or rebalance programs initiated during the Reparation Phase
3) If there is a measurable improvement, community level activities such as paddling sports and sport fishing may become feasible

C) Reassess and Rebalance in 2026

In 2026, reassess the success of the programs with the following success criteria in mind:

a) Were these programs sufficient to sustain water quality at the eutrophic level or better?
b) Is it feasible to take the lake to a sustainable mesotrophic level? Is so, what additional actions would be required?
c) If the other measures have been effective, is it feasible to adopt a 5-year program for the Phoslock or is it necessary to stay with a 3 year program?
d) What additional community activities can be implemented?

Appendix A: Questions Arising From the Water Quality Reports

1) Phosphorus and Phoslock

a) The Freshwater Research Report eliminated several other treatment options, concluding that Phoslock was the best option to address the immediate issues in Swan Lake. How sensitive is this recommendation to the estimates of external load? Would it be altered if:
   i. If geese contribution were known to be higher?
   ii. If stormwater runoff was known to be lower?

b) If Markham adopts an ongoing periodic treatment process of Phoslock (every 3 – 5 years),
   i. Which of the alternate treatments have merit as complementary approaches for the management of phosphorus and can help reduce the ongoing dependency on Phoslock?
   ii. Which of the alternate treatments have merit as complementary approaches for managing the other three challenges facing Swan Lake? (nitrogen, chloride, low oxygen)

c) How many years can we expect the planned 2021 dosage of Phoslock to keep phosphorus levels below 100 µg/L? Below 150 µg/L?

d) Beyond the assessed immediate need, is it technically feasible to add additional quantities of Phoslock to address future incoming external loads?
   i. If so, would it be possible to add sufficient quantities to extend the benefit by 1-2 years?

e) Do the benefits of a long term Phoslock program (over 20 years) outweigh the extra financial cost compared to other chemical options, such as aluminum?

f) Are multiple applications of Phoslock over a 20 year period environmentally safe?

2) Improving Nitrogen Levels

a) What triggered the decline in nitrogen levels following the Phoslock treatment in 2013?
b) Why would nitrogen levels rebound more quickly than phosphorus levels?
c) Can we expect an ongoing repetitive Phoslock program to also reduce nitrogen levels?
d) If an aggressive Phoslock program were employed to reduce phosphorus, say with annual treatments, at what point would nitrogen become the dominant nutrient?
e) Could we achieve mesotrophic levels of water quality without dealing with nitrogen?
f) What options are available for reducing nitrogen levels in Swan Lake?

3) Improving Chloride Levels

a) Have there been any efforts made to measure the health of zooplankton in the lake?
b) What amount of chloride entering Swan Lake each year can be attributed to each possible source (from each of the paved street areas, from each of the stormwater ponds, other?
c) What can be done to reduce the inflow of chloride each year?
d) What type of road salt would cause less environmental damage?
e) What can be done to treat the chloride amounts already in Swan Lake?

4) Improving Oxygen Levels

a) Assuming an ongoing Phoslock treatment program, is it better to maintain stratification of the lake water or to encourage mixing?
b) Which methods of direct oxygenation could effectively be deployed in Swan Lake?
c) Which methods of indirect oxygenation could effectively be deployed in Swan Lake?
d) Does the Fish Management program include a program for restocking the lake? What types?
e) Is the concept of overstocking with algae eating fish a feasible approach?

5) Management of Stormwater Inflows

a) How recent have the three oil/grit separators connecting to Swan Lake been cleaned?
b) How recent were the two stormwater ponds cleaned?
c) What is the basis for concluding that the two stormwater ponds are not material contributors to the issues within Swan Lake?
d) Freshwater Research suggests that monitoring of the water quality in the stormwater ponds could be undertaken. Have there been any recent tests of the stormwater ponds? If not,
   i. Are there any plans to test and monitor the water within the stormwater ponds to confirm that they are not major contributors to issues within Swan Lake?
   ii. Are there any plans to test and monitor the overflow water that bypasses the stormwater ponds during high flow periods?
   iii. Are there any plans to test and monitor the flows into Swan Lake from the three oil/grit separators?
e) Markham has adopted an enhanced Geese Management program to reduce the external phosphorus load attributed to Canada Geese. What additional actions, if any, are planned to reduce the external phosphorus load attributed to stormwater management sources?

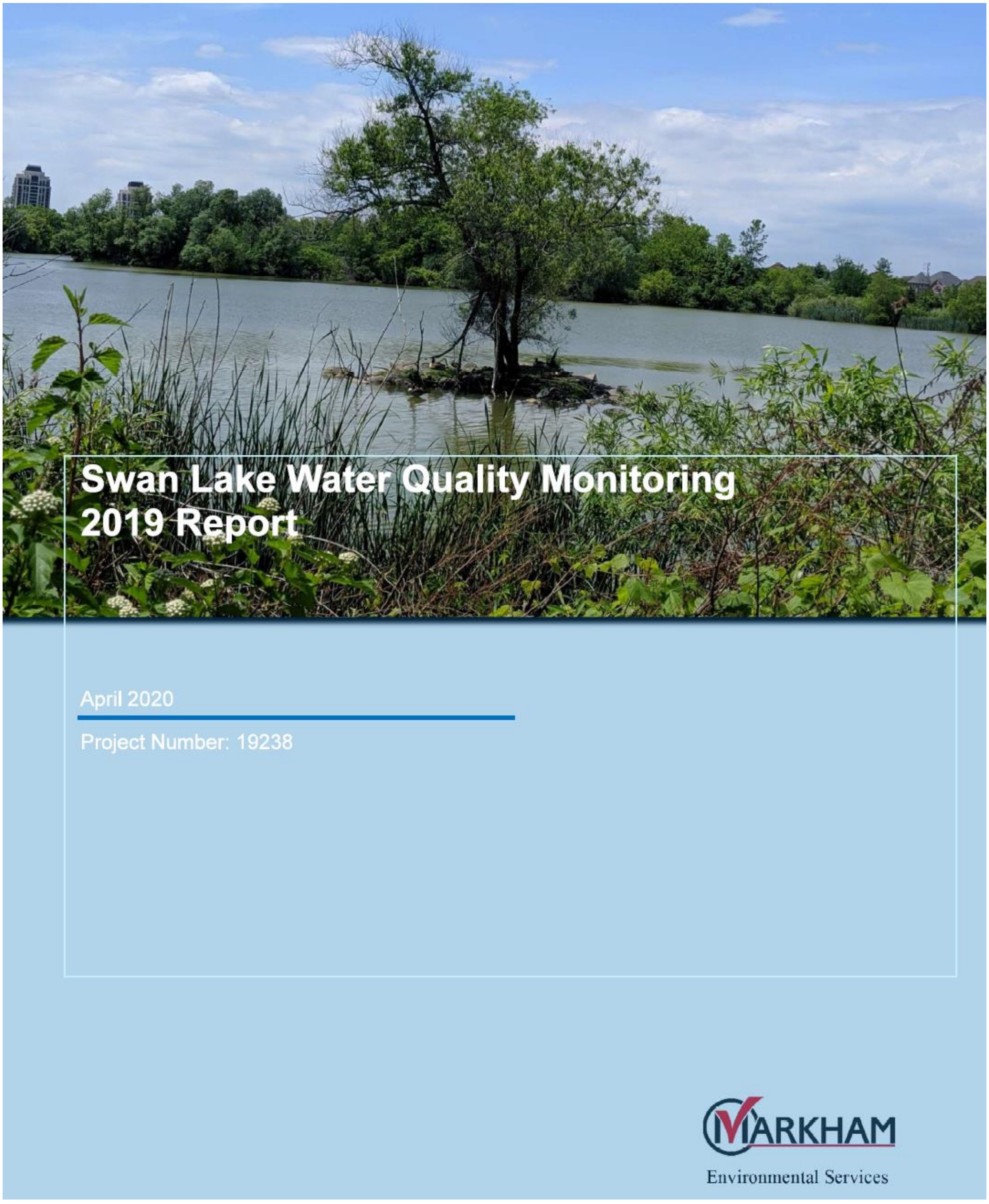
6) Water Budget Model

Swan Lake has no natural surface level inflows or outflows. The analysis assumes active inflows/outflows from the aquifer, precipitation and periodic stormwater inflows during times of heavy rains. There is an overflow outlet to the stormwater sewer system on 16th Avenue.

A number of questions arise related to the hydrology of the lake:

1) What is the assumed daily rate of inflow from the aquifer?
2) What is the water renewal time? i.e.: the time required for an amount of water equivalent to the total amount to enter the lake.
3) In the phosphorus estimating model, an export factor of 15% is assumed. Is this to be interpreted to be associated with the combined loss through the aquifer and/or sewer drainage?
4) What is the estimated annual inflow of fresh water from the aquifer? Presumably it is less than the 15% export values since the export value reflects some loss through the stormwater sewer system.

Appendix B: Markham Swan Lake Water Quality Monitoring 2019 Report



Swan Lake Water Quality Monitoring 2019 Report

April 2020

Project Number: 19238

MARKHAM
Environmental Services

Executive Summary

Background

Swan Lake is situated in the City of Markham at the intersection of Sixteenth Avenue and Williamson Road. Swan Lake has an approximate area of 5.5 ha and a maximum water depth of 4.5 m. 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. Water quality monitoring of Swan Lake has been conducted annually since treatment in 2013 in order to track water quality and the continued effectiveness of the Phoslock. 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 help establish a long-term plan for the treatment of Swan Lake.

Results

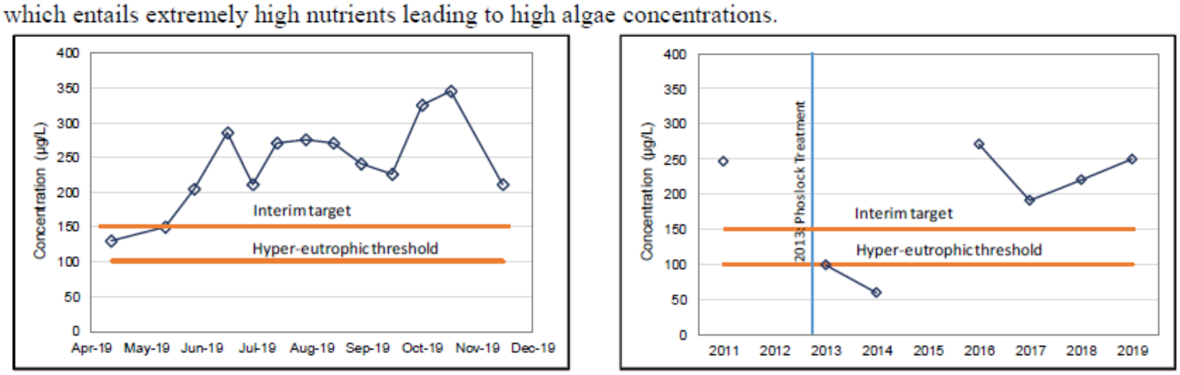
Water quality is currently monitored at two shoreline sites; the Dock, and the Bridge. Water quality is monitored bi-weekly throughout the summer (May-September) and monthly in the spring (April) and fall (October-November). Samples and measurements are taken at 0.5 m increments for the depth of the lake. A level logger is used to record the water level in the Lake.

Figure ES-1 provides the monitoring results for the 2019 monitoring period, as well as annual summaries of available data from 2011 to 2019. The figure includes plots of measured phosphorus concentration, dissolved oxygen, water clarity, chloride concentration, geese count, and water level.

Figure ES-1: 2019 Monitoring Results and 2011-2019 Annual Results

a) Phosphorus Concentration

Phosphorus concentration is the most important indicator of 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 entails extremely high nutrients leading to high algae concentrations.

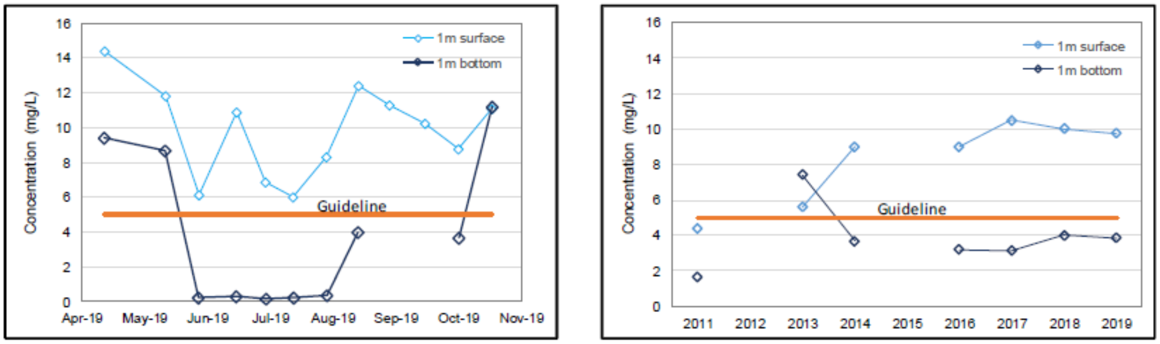


Note 1: The 2019 values are averages of samples collected at 0.5 and 1.5 m from surface.
Note 2: Annual concentrations are summaries of the growing period.
Note 3: The interim target shown is based on the draft water quality improvement strategy report (January 2020), and applies to the average over two consecutive years.

Figure ES-1: 2019 Monitoring Results and 2011-2019 Annual Results, Cont'd

b) Dissolved Oxygen (DO)

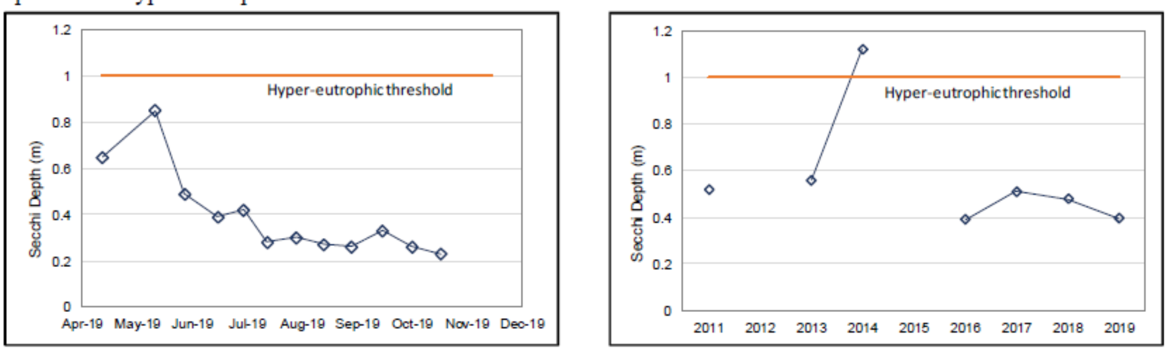
Reduced oxygen levels will cause lethal and sub-lethal (physiological and behavioral) effects in aquatic organisms, especially fish. The minimum dissolved oxygen concentration required for the protection of warm water fish is 5 mg/L. DO concentrations are shown at 1 m from the surface and 1 m from bottom, to visualize stratification and habitat suitability for fish, which may be able to survive in different parts of the lake and not others due to the stratification.



Note : In 2019, the Lake was stratified throughout the summer, but in the fall, the layers were mixed and similar concentrations were observed over depth.

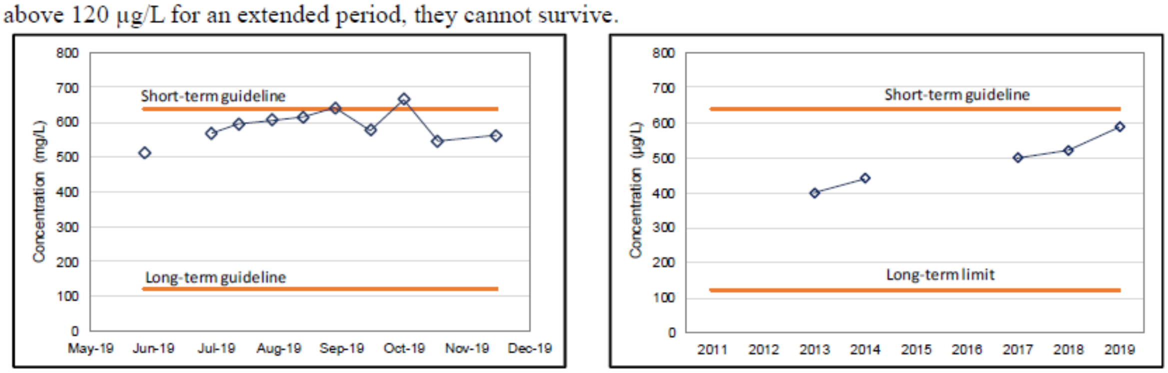
c) Water Clarity (Secchi Depth)

Secchi depth represents water clarity, which declines when algae level increases. Water clarity of **<u>under</u>** 1 m represents a hyper-eutrophic condition.



d) Chloride Concentration

Chloride concentration has been increasing in urban lakes as a result of de-icer application for winter maintenance. Fish can survive a short time period if the concentration is above 640 µg/L; however, if the concentration stays above 120 µg/L for an extended period, they cannot survive.



Note: Meeting the long-term guideline provides protection against negative effects on aquatic ecosystem structure and function during indefinite exposure. The short-term guideline is intended for the protection of most species against lethality during severe but transient events.

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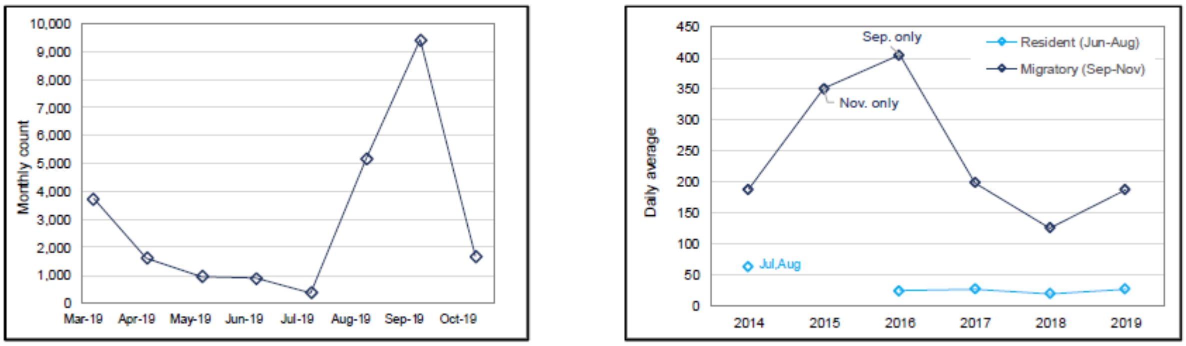
April 2020

Figure ES-1: 2019 Monitoring Results and 2011-2019 Annual Results, Cont'd

e) 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. While the waterfowl number in Ontario has been reported to have doubled over the last ten years[1], the Swan Lake geese population has decreased since the inception of the geese control program, indicating the efficacy of the program.



Note 1: 2019 data are the sum of counts in each month.
Note 2: Annual data are daily averages of counts over June-August and September to November, representing resident and migratory geese, respectively.

Table ES-1 provides a summary of the observed blue-green algae blooms (a.k.a. cyanobacteria) 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 ES-1: Records of Blue-Green Algae Blooms and Toxicity

Year/Period	Blue-green 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

Results Summary and Recommendations

Based on the measured Secchi desk transparency, and nutrient concentrations, Swan Lake was classified as hyper-eutrophic in 2019. Given that the three year average of 2017-2019 is above the 150 µg/L

[1] https://www.simcoe.com/opinion-story/8074290-goose-population-on-the-rise

threshold, the City should look into the next steps associated with treating the nutrient levels in the Lake to reduce algae growth. This work was initiated in the middle of 2019.

Other observations and decisions made in 2019 are as follows:

- In 2019, Environmental Services staff advised the Park Operations staff not to re-install the decorative fountain until after a treatment has been completed to avoid the spray of 'dirty' water on bystanders.
- Some of the warning signage that was previously in the park may have been removed or damaged. A review of the need for additional signage is to be performed in 2020.

Appendix C: Swan Lake Water Quality Management – Freshwater Research

MARKHAM

Freshwater Research

SWAN LAKE WATER QUALITY MANAGEMENT

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Date July 17, 2020

Respectfully submitted: 17, July, 2020

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Disclaimer

While reasonable efforts have been made to ensure that the contents of this document are factually correct, the authors and Freshwater Research do not accept any responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this report.

Acknowledgement

Zahra Parhizgari and Kate Rothwell, Environmental Engineers, and Rob Muir and Rob Grech, Managers of the Environmental Services Department, City of Markham, provided steady support during the preparation of this report and their enthusiasm is gratefully acknowledged. Many previous staff of the City of Markham provided insights, knowledge, and skills to the long-term monitoring effort in Swan Lake.

Title photo: Apr 10, 2017 (Photo, Gertrud Nürnberg)

Executive Summary

Swan Lake in the City of Markham is a highly eutrophic (hyper-eutrophic) lake with cyanobacterial blooms ("bluegreen blooms"). These blooms can contain species that produce toxins with health effects on pets, livestock or humans. A detailed monitoring study in 2011-2012 and historic data (1993-2008) revealed that most of the water quality problems originated primarily from internal phosphorus (P) sources, such as the bottom sediments. After the determination of available treatment methods, a chemical treatment with Phoslock was conducted in the spring of 2013. Several post-treatment monitoring studies evaluated the effects and efficiency of the treatment in several reports and published peer-reviewed papers.

Although the Phoslock treatment improved water quality from hyper-eutrophy to eutrophy for two years after application, by 2016 water quality was as low as or lower than in the pre-treatment year 2011, and trophic state variables indicated hyper-eutrophic conditions again (Summary-Table 1). Phytoplankton biomass (as determined by chlorophyll concentration and Secchi disk transparency) were above pre-treatment measurements. Occasional cyanobacteria surface blooms were observed at specific sites of at least 7 genera of potentially toxic cyanobacteria. Microcystins were measured well above (3.7 times, 73 µg/L) the provisional federal guideline for recreational activities (20 µg/L).

Summary-Table 1. Trophic state of Swan Lake based on water quality of the monitored pre- (2011) and post-treatment growing periods (2013-2018) at Deep Site 3 or Dock Site 1.

	Swan Lake						Definition	
	2011	2013	2014	2016	2017	2018	Eutrophic	Hyper-eutrophic
Secchi Disk Transparency (m)	0.47	0.43	1.4	0.29	0.40	0.53	1 – 2.1	< 1
Total phosphorus (mg/L)	0.247	0.099	0.060	0.272	0.191	0.221	0.031 – 0.100	> 0.100
Total nitrogen (mg/L)	2.71	1.64	1.14	4.50	2.26	2.55	0.65 – 1.20	> 1.20
Chlorophyll *a* (µg/L)	32	52	12.6	111	61**	41**	9.1 – 25	> 25
Anoxia in polymictic lakes	---- severe ----		some	--------- severe ------------			occasional during summer stratification	
Anoxia (AF, d/summer)***	50	31	33	48	40	51	40 – 60	> 60
Modeled anoxia (AA, d/summer)****	90	70	59	92	84	87	Not applicable	

* For total nitrogen the sum of total Kjeldahl-N and nitrate concentration (mostly below the detection limit) was used when available, otherwise, just total Kjeldahl-N.
**Predicted from Secchi average according to a significant regression model (Appendix B).
***AF values are computed from dissolved oxygen profiles (Appendix A). They present the number of days an area equal to the total surface area of Swan Lake is overlain by anoxic water per growing period. In shallow, wind-mixed lakes, such as Swan Lake, the (observed) AF presents an underestimate with respect to the trophic state classification that is based on thermally stratified, deeper lakes.
****AA values are based on morphometry and long-term TP concentrations according to a significant regression model (Appendix A). AA values more likely present the anoxic sediment area involved in sediment release than AF values, which describe anoxia throughout the lake water.

Because of the deteriorated conditions closer to shore, 2017 monitoring added two shore line sites (Site 1 and 2), in addition to (2017) or instead of (2018) the previously monitored open water site (Site 3) accessible by boat only. 2017 water quality characteristics of the three monitoring sites were quite similar and we concluded that Site 1 (main dock) water was representative of the nutrient and trophic state of Swan Lake and could be used in comparison with previous lake data.

A total phosphorus (TP) mass balance analysis using hydrological budgets provided by City of Markham staff was conducted for 10 years, 2009-2018, to determine the TP contributions from specific sources and to estimate internal load. The TP inputs from external sources were estimated on an annual basis, using monitored data for phosphorus and water volumes provided by the City. Waterfowl contributed about 55% and the immediate lake shore contributed 38% to the external load long-term average of 29 kg/yr (range: 20-50 kg/yr). The remaining 7% of external load was contributed by the stormwater management ponds and precipitation unto the lake.

In comparison, internal load averaged 41 kg/yr (range 0-60 kg/yr). Internal load was a low 25 kg in 2013 when treatment was applied in early May and assumed to be 0 kg in 2014 (because of low water TP concentrations). The mass balance model estimated internal load to be above 35 kg in all other years including pre- and post-treatment periods indicating a diminishing treatment benefit. A mass balance model converted the loads to water TP concentrations (by considering P settling according to annual hydrological conditions), so that the contribution of individual sources to the lake concentration could be assessed (Summary-Table 2).

Summary-Table 2. Modelled TP contribution from external and internal P sources (presented as concentration and percent of total TP input).

P Source	2009-18		2016-18	
	mg/L	%	mg/L	%
Atmospheric deposition	0.003	1%	0.003	1%
SWM ponds	0.003	1%	0.003	1%
Immediate lake shore	0.036	16%	0.033	13%
Geese	0.054	24%	0.078	31%
Internal (sediment)	0.132	58%	0.136	54%
Total input	0.228	100%	0.254	100%

Internal P loading usually stems from former external inputs which are stored in bottom sediments, and it may originate in nutrient-rich previous land fill and recent inputs from water fowl feces in Swan Lake. P released from the bottom sediments has a high biological availability, and its release during elevated water temperature in the summer increases its effect on summer-fall lake water quality. For these reasons, the management of internal load is more promising for immediate results than that of external load, although long-term management must also attempt to reduce external sources to prevent further increase in legacy sediment P.

Even by just considering the relative contribution from the different TP sources (Summary-Table 2) without acknowledging the different bioavailability, the importance of various treatments can be assessed. For example, with a treatment that intercepts P release as in 2014 (after the 2013 Phoslock application), the resulting TP concentration would be below 0.100 mg/L, indicating eutrophic, rather than hyper-eutrophic conditions (Summary-Table 1). Consequently, phytoplankton would be diminished and Secchi disk transparency improved, possibly to the 2014 growing period of 1.4 m also indicative of eutrophy. In contrast, a 50% success in geese and runoff management that decreases TP from these main external sources by half would only decrease TP concentration by 0.056 mg/L (half of the concentration attributed to geese and shoreline in 2016-18) yielding still a TP concentration of almost 0.200 mg/L.

Based on this understanding, long-term management goals are proposed as a growing period TP average of below 0.100 mg/L and an average Secchi transparency of above 1.0 m. In the short-term, we determined a more appropriate (interim) goal from the relationship between TP and Secchi observed in Swan Lake. These include the growing period average of 0.150 mg/L or less of TP and a Secchi depth of 0.45 m or better.

We suggest a series of triggers that would lead to an initiation of appropriate management actions. Our proposed triggers are:

1. The surface bloom of a potentially or proven toxic strain of cyanobacteria, confirmed by a licenced or Provincial (MECP) lab or by Abraxis strips to trigger direct attention.
2. The occurrence of two blooms within a period of four years that cover at least 25% of Swan lake area.
3. Water quality not compliant with the interim goal of growing period average 0.15 mg/L total phosphorus concentration in the surface mixed layer.
4. Water quality not compliant with the interim goal of growing period average 0.45 m Secchi disk transparency.

While a single occurrence of cyanotoxin requires action (posting signage), only the average conditions concerning water quality measured as nutrients and Secchi disk transparency over a growing period (May/Jun - Sep) should trigger more comprehensive actions. The proposed goals are based on monitored data, consequently we present a detailed monitoring plan.

The proposed triggers 3 and 4 were tripped every year since 2016, and we present a review of applicable management approaches to deal with (a) external and internal TP loading, which can be judged the cause for the water quality deterioration, and (b) the overabundance of phytoplankton and the potential toxicity of cyanobacteria, which likely are the symptoms and consequences of the high TP levels. Triggers 1 and 2 cannot be evaluated for lack of information on the spread of cyanobacteria.

Detailed recommendations include (Summary-Table 3):

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

Two treatments are the most important and promise to be most effective: continued water fowl management and repeat internal load abatement (Summary-Table 3).

As preferred treatment to abate the internal P loading, we chose another Phoslock application. This treatment provided at least two growing periods of improved water quality and successfully treated sediment P release according to the mass balance analysis. There was no obvious negative effect from the previous treatment. Estimated cost for such a treatment is a total of $171,000. Treatment may need to be repeated in several years, depending on the successful management of the external P sources. A five-year repetition is suggested, with adjusted frequency according to the occurrence of the triggers.

An alternate treatment that includes aluminum compounds (poly aluminum chloride) may also help to reduce internal loading in the short run. Concerns of public perception and non-committal statements by Ontario Ministry of the Environment, Conservation and Parks (MECP) render it less recommendable, despite possibly lower costs.

To ensure effectiveness, we suggest that the dosage be based on the mobile P sediment fractions that can be determined by a specialized commercial laboratory (at a cost of about $20,000). Fish management involves a fish survey and fish salvage at a cost of $5,000 and $20,000. The annual costs for the long-term continuous waterfowl management and water quality monitoring are $13,500 and $12,000. Treatment costs of shoreline runoff through naturalization are estimated at $100,000. Costs of investigation of phosphorus load from the historic dumpsite are around $20,000. Detailed costs for 2021, including 25% contingency are presented in Summary-Table 4.

Following the initial treatment and other short-term measures, a long-term strategy will need to be developed to maintain and enhance Swan Lake's water quality in a sustainable manner. This strategy may include repeat treatments, continuous management of geese and fish, as well as additional measures.

Summary-Table 3. Evaluation, implementation, and estimated cost of recommended actions

Recommended Tasks	Importance*	Comment	Approximate Cost
Internal Load treatment	1	One application Incl. monitoring, evaluation	$171,000 (Table 27)
Fish management	1	Once (but $5,000 annually)	$25,000 (Section 6.3)
Sediment quality determination	2	Once	$20,000 (Table 26)
Water fowl management	1	Continuous	$13,500 (Table 28)
Water quality monitoring	2	Growing season	$12,000 (Section 6.6)
Shoreline BMPs	3	Naturalization	$100,000 (Table 28)
Historic dumpsites investigation	3	Five boreholes, testing for phosphorus	$20,000 (Table 28)

*Valued 1-3 with "1" most important

Summary-Table 4. Costs of short-term strategy for 2021 *(long-term management not included)*

Item	Total Cost
Implementation Plan	$10,000
Material (Phoslock)	$105,000
Application	$31,000
Enhanced Monitoring and Evaluation	$25,000
Fish Management	$25,000
Contingency (25%)	$49,000
Total cost	**$245,000**