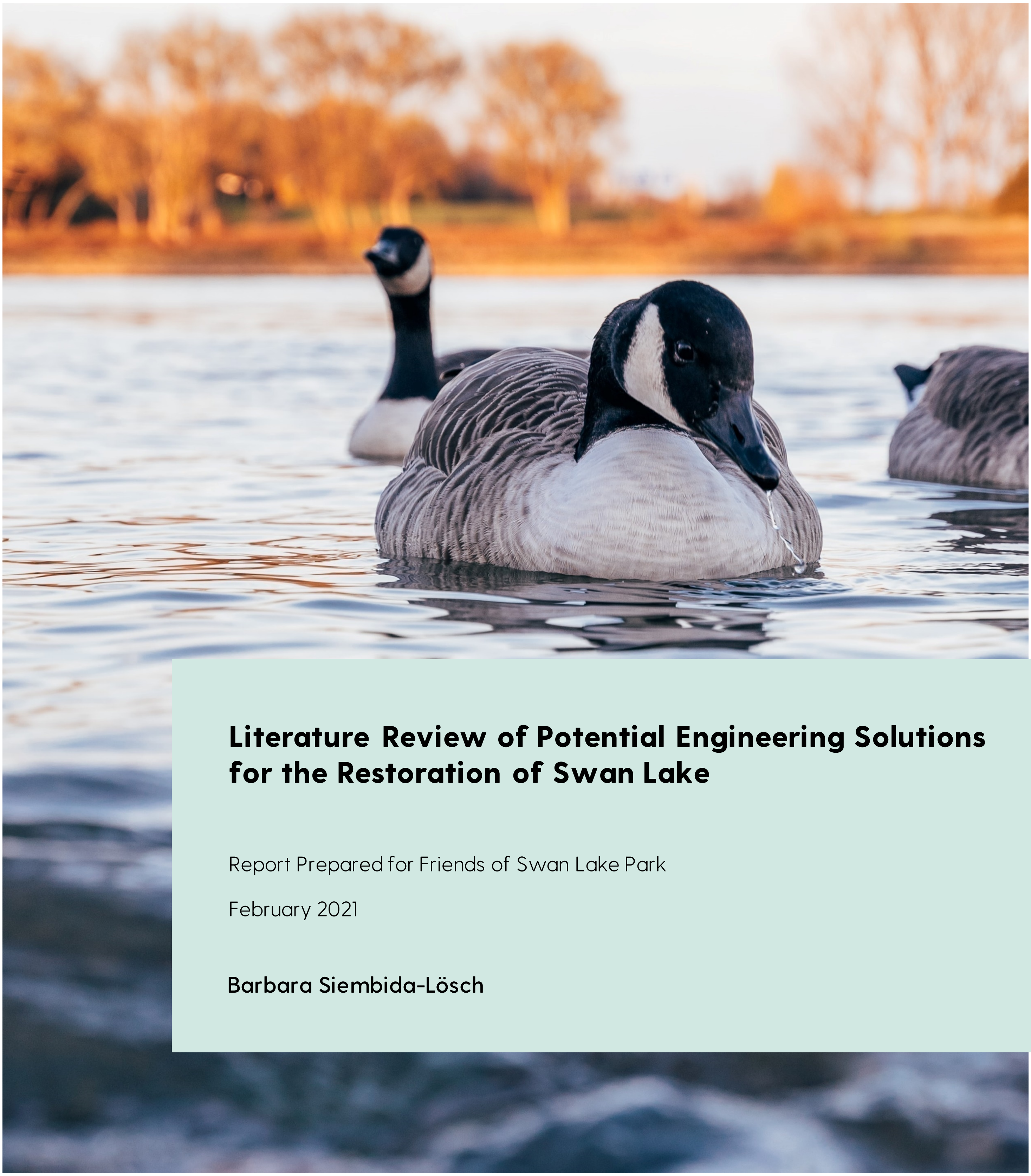

Literature Review of Potential Engineering Solutions for the Restoration of Swan Lake

Report Prepared for Friends of Swan Lake Park

February 2021

Barbara Siembida-Lösch

centre for advancement of water and wastewater technologies

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Barbara Siembida-Lösch, Ph.D., P.Eng.

Fleming College Centre for Advancement of Water and Wastewater Technologies; Lindsay, Ontario.

For more information, please contact:

Centre for Advancement of Water and Wastewater Technologies

200 Albert St. S

Lindsay, ON K9V 5E6

cawt.ca

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Executive Summary

Swan Lake, a man-made lake located in Markham, Ontario, has long suffered the effects of eutrophication, an over enrichment of minerals and nutrients. A surplus of external nutrient inputs has resulted in the continued accumulation of nutrients stored within the lake from year to year (referred to as legacy nutrients). The overall nutrient load, accompanied with warm weather conditions, allowed for prolonged cyanobacteria blooms throughout Swan Lake and perpetuating the eutrophication issue even further.

The Friends of Swan Lake Park (FSLP) are citizens of Markham and stewards committed to the health and restoration of Swan Lake and Swan Lake Park. In partnership with Fleming College's Centre for Advancement of Water and Wastewater Technologies (CAWT), the FSLP are interested in improving the water quality of Swan Lake and identifying solutions to do so. Water quality concerns include improving oxygen levels, decreasing phosphorous and nitrogen levels, and reducing chloride concentrations. FSLP's primary objective is to identify a sustainable treatment program that will provide a long term stable aquatic environment in Swan Lake. FSLP's ultimate goal is to establish Swan Lake as mesotrophic: a lake classified as having moderate productivity and nutrient concentrations.

In 2020, the City of Markham initiated a phosphorus management effort that includes an enhanced Canada Geese management program, a shoreline redesign effort, and a periodic Phoslock treatment program to begin in the Spring of 2021.

The results of this comprehensive literature review are meant to help FSLP better understand some of the environmentally sound options available, and to guide them on next steps for the future restoration and improvement of water quality in Swan Lake. These options may serve as complementary approaches to the current phosphorus management plan, contributing to an enhanced and sustainable aquatic environment. Ideally, these additional strategies will also result in savings by reducing the frequency, or eliminating completely, the need for future Phoslock treatments.

This document presents solutions that address the water quality issues faced by Swan Lake and the pros and cons to each approach. While vendors are named and provided, the CAWT does not endorse any one product and is simply providing these systems as a reference.

The solutions presented in this report include: 1) water recirculation through a bioswale and use of floating treatment wetlands for increasing oxygen levels while lowering phosphorus, nitrogen and chloride levels; 2) oxygenation and circulation systems for increasing dissolved oxygen concentration and decreasing phosphorus and nitrogen drawn from the sediments, and 3) sorptive media, biological processes, and solar stills for lowering chloride levels.

Conclusions and Recommendations

Overall, and based in conjunction with existing water quality reports previously done, it is apparent that besides phosphorus, other water quality issues (nitrogen and chloride pollution, and oxygen depletion) need to be addressed for the successful restoration of Swan Lake.

There are several approaches that can be taken to achieve this goal, options range from a large and all-encompassing approach to taking several small steps gradually and making meaningful impacts over time. However, due to a significant initial capital expenditure, the former approach should be investigated and assessed with some preliminary pilot studies to ensure water clarity will not deteriorate due to water movement.

Therefore, we recommend proceeding with a series of incremental targeted efforts in order to validate the impact of each new process introduced. To mitigate the existing water quality issues in Swan Lake, any technique employed should be quick to implement and be sustainable. Additionally, any technique used will also need to be ecologically safe and cost effective.

To complement the current phosphorus management program we recommend consideration be given to three additional initiatives. Following the introduction of each initiative, we recommend an assessment of the impact before introducing an additional technique.

The three programs that may complement the planned periodic Phoslock treatment are:

1. A periodic treatment of granulated calcium peroxide to increase oxygen levels;
2. Adding chloride-tolerant plants to further decrease nutrients and chlorides in conjunction with the shoreline restoration plan and through the installation of floating treatment wetlands in areas near the former dump sites;
3. In parallel, laboratory and/or field tests should be performed to determine if diffused aeration systems (such as “bubblers”) are a feasible long-term solution for maintaining oxygen in the proper range without worsening water clarity.

The CAWT at Fleming College has the required expertise and resources to support and assess this type of investigation.

Although an important and potentially long-term goal, restoring Swan Lake water quality from the current hypereutrophic state to mesotrophic nutrients level may require significant resources. It will be necessary to evaluate what kind of lake management tools are possible, affordable, and preferable for reliable management and restoration of Swan Lake. Before a decision is made or implemented the objectives, patterns, and expectations shaping future water management should be further explored and defined.

1.0 Background

A former quarry, Swan Lake has high levels of naturally occurring phosphorus in addition to a pre-existing external load. External phosphorus inputs of approximately 30 kg per year are generated in equal parts by wild Canada geese and from runoff. To a more minimal extent, stormwater flows from surrounding residential areas also contribute to the phosphorus loads.

Currently, phosphorus levels in Swan Lake are managed using Phoslock, a patented phosphorus locking technology. An initial treatment was applied in 2013 but the benefits lasted only two years. The recommendation by Freshwater Research (2020) to schedule a Phoslock treatment every 5 years, with earlier intervention if required, is currently under review, with an expected decision to be reached in the Fall of 2021. FSLP are encouraging discussions around more frequent treatments (e.g. every 3 years instead of every 5 years) as well as the establishment of long-term water quality goals. The City of Markham has engaged the Toronto and Region Conservation Authority (TRCA) to review opportunities that will enhance the existing goose management program and identify options to reduce stormwater inflows, hence reducing the external nutrient inputs.

Based on a report released by Freshwater Research in 2020, it appears that levels of dissolved oxygen (DO) in Swan Lake consistently fall into the poorest quality rating, with the designation of eutrophic or hypereutrophic, and DO recordings typically below 3 mg/L. Only the hardiest of fish can survive at such low DO levels. The challenge lies in finding a means to improve oxygen levels in Swan Lake in a manner that also supports the nutrient management goals (phosphorus and nitrogen reduction). A successful oxygenation program will improve the aquatic environment and help manage internal phosphorus loading while reducing the amount of Phoslock required in the long run.

Swan Lake contains high concentrations of nitrogen, primarily due to geese migration in the autumn, as well as possible ammonia release from particulate matter accumulated on the lake bottom. High concentrations of ammonia and nitrate in lakes and streams can cause excessive growth of algae and other plants, leading to accelerated eutrophication or “aging” of lakes, and occasional loss of DO.

In addition to the aforementioned issues, Swan Lake contains an excessive amount of chloride, attributed by Freshwater Research to winter de-icing operations. The levels of chloride in Swan Lake exceed the short- and long-term Canadian Water Quality Guidelines for the Protection of Aquatic Life – Chloride (Canadian Council of Ministers of the Environment, 2011) of 640 and 120 mg Cl^-/L, respectively, and are harmful to many forms of aquatic life. Therefore, chloride reduction is essential to the restoration of the lake’s ecology.

2.0 Objectives and Deliverables

The primary objective of this research is to identify and outline potential solutions to address the low levels of oxygen and high concentrations of both chloride and nitrogen in Swan Lake. The focus is on solutions that can be applied in a manner that are either complementary to the current phosphorus management program or that may also reduce phosphorus levels and thus the costs of the long term Phoslock program.

FSLP would like the CAWT's assistance in addressing these water quality issues in Swan Lake by accomplishing the following:

- reviewing the current research reports provided by the FSLP;
- visiting the site to gain a full understanding of the current environment and the issues affecting the lake;
- conducting a thorough literature review to identify potential solutions for mitigating dissolved oxygen, chlorides, and nitrogen levels in Swan Lake, along with the pros and cons of each of those solutions;
- providing scientific background on the existing water quality issues of Swan Lake and highlighting the importance in addressing these issues; and
- offering direction for selecting appropriate techniques to address water quality issues within Swan Lake.

This literature review document summarizes the CAWT's findings and identifies solutions for improving water quality within Swan Lake. The identified solutions within this document may serve as complementary approaches to the current phosphorus management initiatives, contributing to an enhanced and sustainable aquatic environment.

3.0 Potential Engineering Solutions for the Restoration of Swan Lake

There are several options that can be used to reduce nitrogen and chloride levels and improve the oxygen-depleted conditions within Swan Lake. Some methods described below will be multipurpose, addressing multiple water quality issues and not targeting a single contaminant.

3.1 Reduction of Nitrogen Levels

Freshwater Research (2020) reported a consistent hyper-eutrophic state of Swan Lake between 2016 and 2018. Hyper-eutrophic lakes have high levels of biological productivity due to the rich nutrient composition and experience significant algal blooms throughout much of the summer and fall. Further, it was found that ammonia (NH_3), total Kjeldahl nitrogen (TKN), and total nitrogen

(TN) concentrations near the Swan Lake bed were elevated even after the Phoslock treatment in 2013, which indicates that Phoslock does not fully reduce nitrogen compounds.

Of the aforementioned nitrogen compounds, ammonia is the most usable form for cyanobacteria and algae to thrive. Ammonia in sediments is mainly released to the overlaying water by diffusion, sediment resuspension due to hydro-dynamics, and re-working of sediments by animals or bioturbation (Hu et al., 2001). The release of ammonia can lead to water eutrophication, severely depleted oxygen levels (hypoxia), and poisoning of aquatic organisms (Camargo and Alonso, 2006).

Under oxygen depleted conditions, net decomposition of organic nitrogen from detritus (mineralization) and subsequent release of nitrogen and ammonium is greater than under oxygen rich conditions (Force et al., 1971). Since Freshwater Research (2020) observed the pattern of low dissolved oxygen (DO) levels on the lake bottom and in the water column, it is especially important to improve oxygen levels to reduce the amount of nitrogen released into water that overlies sediments. The following sections outline two main strategies: i) water circulation with pre-treatment, and ii) floating treatment wetlands, to decrease nitrogen levels in the lake.

3.1.1 Water Recirculation with Treatment

Review of the provided project documentation and the site visit reveal that Swan Lake is a stagnant 'pond' with summer thermal stratification and some mixing occurring during fall turnover, precipitation, and storm events. Since there are no watercourses flowing into and out of the lake, Swan Lake is a closed system with very long hydraulic detention time (HDT). This means that the water, and other substances or contaminants in the water, remain in the lake for a long time. In order to prevent further contaminant build-up over time and thus water quality deterioration, a lake mixing strategy may need to be developed.

In shallow water bodies, mixing is typically insufficient. Therefore, adjustment of the HDT becomes a feasible tool in the control and prevention of excessive algal growth. As a general rule, an HDT between 20 and 50 days at least 80% of the time is recommended (WSUD Engineering Procedures: Stormwater, 2005). According to Reynolds (2003) the sensitivity of lakes to eutrophication, in relation to changes in phosphorus loads, can be classified according to HDT. Short HDTs dampen the response of lakes to changes in phosphorus loads due to its more frequent flushing. The most sensitive lakes are those with a detention time of greater than 30 days. Wagner-Lotkowska et al (2004) also recommend an HDT of less than 30 days for the control of algal blooms in medium sized reservoirs.

Therefore, a lake management plan may include adjusting HDT down to an upper limit of 30 days. **A recirculating pump** can be installed to increase the turnover of the waterbody so that an acceptable HDT of 30 days is achieved. Based on the Freshwater Research report (2020), the volume of Swan Lake is 102,000 m^3. To be effective, the pump would need to recirculate water at a flow rate of about 3,400 m^3/day (142 m^3/h), which is estimated as the lake volume divided by the required maximum HDT. These numbers will need to be adjusted based on monthly inflows/outflows (precipitation, runoffs from ponds #104 and #105, any uncontrolled runoff, groundwater recharge, evaporation, etc.). The pump operation may just be required during the drier months, but this would need to be determined in a field study. Furthermore, the recirculated lake water will need to be passed through a water treatment system to reduce nutrient level in the water column and hence to limit the growth of planktonic algae. Some of the treatment systems that can accomplish nutrient reduction are **constructed wetlands and bioswales**.

Constructed wetland systems are shallow, extensively vegetated water bodies that are used for removal of course sediments, fine particles and soluble pollutants from stormwater. Although a constructed wetland may provide habitat for wildlife and a space for recreation, such a treatment system requires longer detention periods to ensure adequate nutrient removal. Long detention times translate to a relatively large land area for wetland installation, especially if nitrogen removal is required. For that reason, constructed wetlands may not be a feasible solution and thus are not discussed in this report.

Bioswale is a bioretention system that is located within the base of a swale (a low, a hollow, or a depression). This system provides a water conveyance (transportation) function and removes fine and coarse sediments and soluble or fine particulate contaminants from the polluted water. Bioswales can be designed to either encourage infiltration, which is the downward entrance of water into the soil, or as conveyance and treatment systems that do not allow infiltration by means of an impermeable base, as shown in Figure 1 (WSUD Engineering Procedures: Stormwater, 2005). The latter one may be a good fit for treating, conveying, and recirculating the Swan Lake water. The system presented in Figure 1 includes two layers along with a drainage layer that is required to convey treated water into the perforated underdrains and then back to the lake. Commonly, sandy loam, course sand, and gravel are used. Randall and Bradford (2013) demonstrated that a sandy soil mix can provide 53.4% of Total Nitrogen (TN) reduction. In addition, the incorporation of organic matter into the filter media may enable denitrification under anaerobic conditions (Alcala et al., 2009; Collins et al., 2010). Some studies point to the use of some specialized media, e.g. Bio-sorption Activated Media, that includes three layers of tire crumb, clay, and sand, which are efficient in TN removal (up to 85%) (Chang et al., 2019; Wen et al., 2020). When selecting the proper media, a balance between sufficient hydraulic conductivity, allowing passing water through the filtration media as quickly as possible, and the required detention time for treatment must be considered.

Bioswales are planted with vegetation that grow in the filter media, providing biofilms on plant roots that pollutants can get adsorbed to. The type of vegetation varies depending on landscaping requirements, but typically the denser and higher the vegetation the better the filtration process (WSUD Engineering Procedures: Stormwater, 2005). Nitrogen removal in bioswales primarily occurs through plant uptake, nitrification, and denitrification, but also through adsorption and immobilization (Collins et al., 2010). Aerobic conditions develop as water drains through bioretention areas, enhancing nitrification. However, a longer drainage time, i.e. contact time, is a crucial factor in promoting denitrification (Smith, 2008).

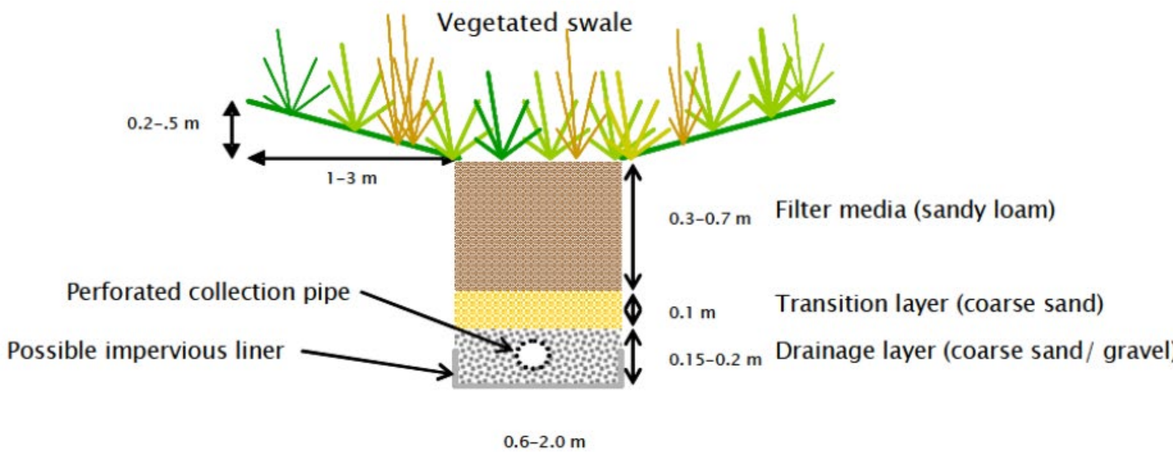

Figure 1. Typical section of a bioretention swale (WSUD Engineering Procedures: Stormwater, 2005)

This long-term solution could be used as an alternative to the planned Phoslock treatment. A benefit of recirculating water and installing a bioswale lies in the nutrient removal (in a bypassed stream), and hence limiting the build-up of nutrients in the lake. The nutrient loaded water from Swan Lake can be recirculated via the North Channel through a bioswale filled with pre-selected media. Several media should be tested and evaluated for the most efficient nutrient removal in a bench-scale beforehand.

This option is more comprehensive, as it will address more issues simultaneously, but it may require greater capital investment to implement. Decreasing HDT in the lake by water recirculation (and thus oxygenating water), removing excess phosphorus, nitrogen and chloride (see 3.3.2) from the waterways will address nutrient and oxygen levels in the lake, and hence prevent future algae blooms.

3.1.2 Floating Treatment Wetlands

Another solution for nutrient management in ponds, lakes and slow-flowing waters are man-made floating treatment wetlands (FTWs) that mimic a natural filtering process. These systems employ aquatic plants growing on a tethered buoyant mat distributed on the lake surface (Figure 2). Plant roots and mats provide a large surface area for growth of naturally occurring bacteria and biofilms that assimilate nutrients. Since FTWs shade the surface and buffer water turbulence, they can also promote settling of suspended algae and solids beneath the mats (Tanner et al., 2011).

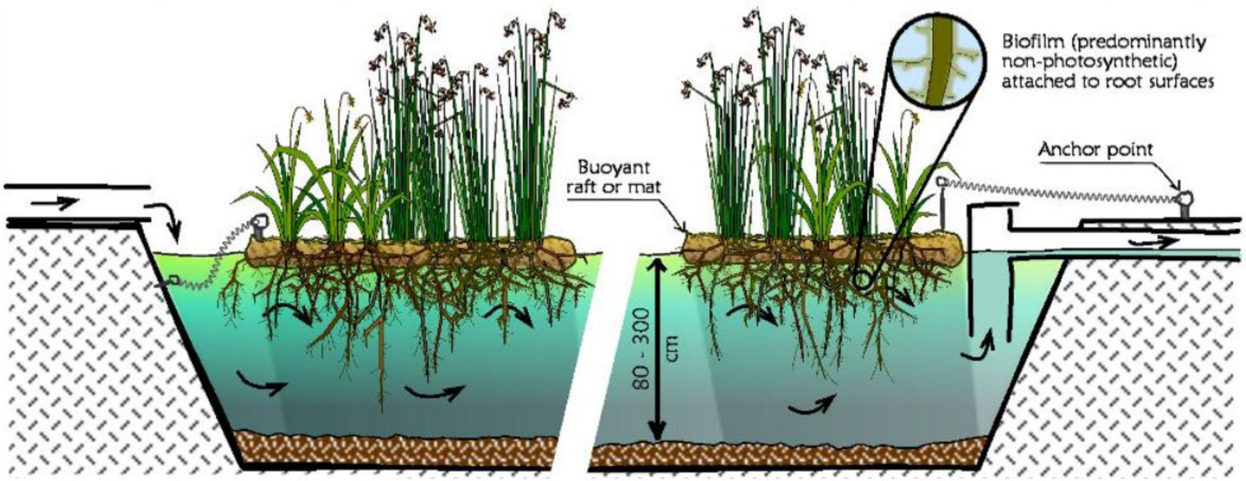

Figure 2: Cross-section of floating treatment wetlands in a treatment pond (Tanner et al., 2011)

The nutrient removal capacity of the FTW is the sum of nutrients accumulated in the plant biomass (stems, leaves, and roots) to support its growth, and nutrient reduction through microbial processes, and sedimentation. Each year, once plants have accumulated nutrients from the water column they should be harvested at the end of the growing season before the start of vegetation decay and nutrient release. Meuleman et al. (2002) suggested that TN removal efficiency could be increased from 9% to 20% by harvesting above-ground tissues in September instead of winter, when most nutrients were translocated to the root system.

FTWs are kept in water year-round, as cold weather freezing and thawing cycles do not seem to harm them, and neither do low oxygen levels. Wang et al. (2015) demonstrated the potential of perennial macrophyte survival and regrowth after ice encasement stress in winter and also showed its adaptation to stresses of the low DO concentrations (minimum: 1.2 mg/L) in summer.

FTWs have been shown effective in substantially reducing nutrient levels. Olguín et al. (2017) assessed efficiency of two FTWs in an urban pond receiving stormwater runoff and concluded that FTWs were very efficient at oxygen release and coliform and nutrient removal (ammonium uptake up to 35% and nitrate up to 80%). In another study performed by Nichols et al. (2016) the TN removal was 17% (N=11) for the influent TN concentration between 0.6 and 3.2 mg/L. They concluded that TN removal performance was found to be affected by low and highly variable TN influent concentrations.

In spite of many positive results, some studies suggest that the benefit to pond performance with the addition of FTWs was modest, most likely due to insufficient FTW surface area coverage (Winston et al., 2013). Schueler (2000) suggested that there may be a background level of TN that cannot be reduced by wetlands beyond the rather low concentration of 1.9 mg/L, no matter how much more surface area or treatment volume is provided.

In addition to potential water quality improvements, FTWs also create thriving surface and aquatic habitats, including beneficial bacteria in the root systems that can improve the water purification. Depending on the vegetation type, root lengths are typically 0.4 - 0.8 m and become home to a variety of fish and wildlife (Headley and Tanner, 2008).

At Swan Lake, use of FTWs may be beneficial in areas near the former dump sites or in Turtle Inlet.

Several manufacturers offer different types and shapes of floating treatment wetlands:

1. Floating Island International (BioHaven® Floating Islands) - USA
2. C + M Aquatic Management Group (PhytoLinks™) - Ontario, Canada
3. Aqua Biofilter Inc. (Aqua Biofilter™) - USA
4. Beemats LLC (Beemats MAPS Floating) - USA
5. Charleston Aquatic Nurseries (Modular Floating Wetlands) - USA
6. Floating Islands Australasia Pty Ltd. (Floating Biospheres™) - Australia
7. BlueWing Environmental Solutions and Technologies (BlueWing Floating Treatment Wetlands) - USA
8. Waterfront Construction, Inc. (Waterfront Construction Floating Wetland Islands) - USA
9. Curry Industries Ltd. - Manitoba, Canada

Disclaimer: Please note the list presented is based on published information and should not be viewed as our vendor recommendations.

3.2 Improvement of Dissolved Oxygen Levels in the Lake

Based on the Freshwater Research (2020) report, it appears that levels of dissolved oxygen (DO) in Swan Lake consistently fall into the poorest quality rating, with the designation of eutrophic or hypereutrophic status, and DO recordings typically below 3 mg/L.

Between May and July 2019, the DO concentrations in the water column dropped to between 0.2 and 0.8 mg/L at the lake depths from 1.5 to 3.5 m (City of Markham Environmental Services, 2020). The low DO levels coincide with an increase in temperature and nutrients (mainly dissolved phosphate and ammonia). Bacterial activity may be most intense near the lake bottom, where bacteria decompose settled organic matter, creating lower and at some point, depleted oxygen levels on the lake bottom. Under such oxygen-depleted conditions, ammonia (NH_3-N) and phosphate (PO_4-P) may get released from the sediment. As the waterbody naturally de-stratifies (distinct thermal layers disappear) during late summer, the nutrient enriched bottom water mixes within the entire water column, resulting in more available nutrients and oxygen depletion that can lead to algae blooms (Austin and Lee, 1973; Nowlin, et al., 2005; Beutel, 2006; Wu et al. 2014; VT DEC, 2019). Oxygenation and circulation are the two primary methods for increasing DO levels, encompassing multiple and often overlapping techniques that are discussed in sections 3.2.1 and 3.2.2 below.

Artificial oxygenation or circulation has been used as an important tool in lake restoration efforts (Beutel, 2006; Wagner, 2015). Most of these systems are able, if designed properly, to prevent oxygen depletion in target areas, which has been shown to minimize the release of nutrients from lake sediments, providing benefits to water quality (VT DEC, 2019). However, it should also be noted that the evidence on the long-term positive effects of aeration as a restoration tool has been questioned (Nygrén, 2017). Some researchers have suggested that nutrient release from the sediment cannot be effectively regulated through oxygen, as eutrophication may not be caused just by high concentration of dissolved nutrients and depleted oxygen levels on lake bottoms, but rather these are parallel symptoms of eutrophication (Gächter and Wehrli, 1998). Also, Moosmann et al. (2006) have stated that nutrient retention may be regulated by the nutrient concentration rather than by the oxygen level in the lower layer of water in a stratified lake.

However, Decker et al. (2004) reported that low DO levels can directly affect zooplankton, causing them to migrate horizontally or vertically in the water column. Dissolved oxygen concentrations and the shifts in position and density of zooplankton may greatly affect predator-prey relationships and hence fish growth and development (Jobling 2008).

3.2.1 Oxygenation

Oxygenation pumps oxygen into the deeper water layers of a thermally stratified waterbody. For shallow water bodies, like Swan Lake, a bottom-based **diffuser system**, also called **laminar flow aeration system**, (e.g. Airmax, AquaAir® Ultra, Clean-Flo, Air Flo 3) can be used for increasing oxygen levels (Figure 3). This aeration system forces compressed air down to the base of the lake, into the water column through a diffuser, enabling it to bubble back up. The diffuser system can be supplied in various shapes (tube, plate, disc) and materials (ceramic, rubber, silicon). The rubber and silicon diffusers may employ a course of fine bubbles resulting in a high oxygen transfer rate, directly translating into higher oxygen levels. Jermalowicz-Jones (2012) presented case studies indicating that fine bubble diffusion can be an effective and affordable approach for reducing the intensity and duration of cyanobacteria blooms.

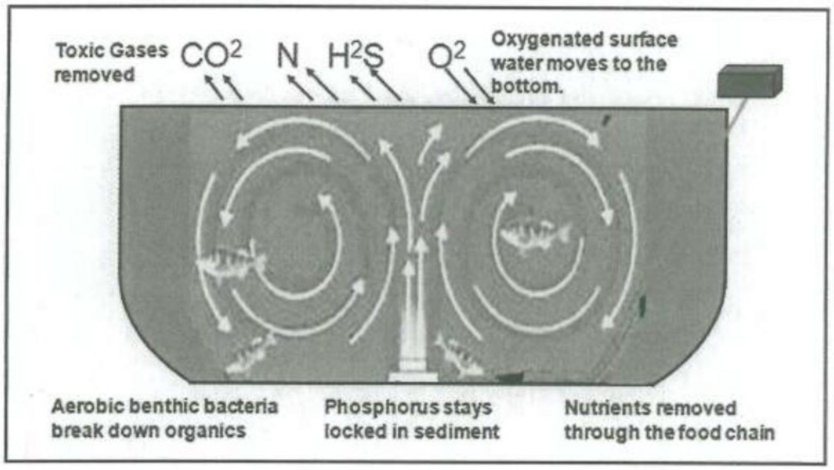

Figure 2: A conceptual diagram of the Laminar Flow Aeration Process (Jermalowicz-Jones, 2012)

A new technology, **Oxygen Nano-Bubble Modified Mineral** (ONBMM), has recently been introduced where nano-bubbles were loaded on the surface of natural minerals to increase DO levels at the sediment-water interface (SWI) (Wang et al., 2020). Researchers reported that ONBMM effectively improved DO levels near the SWI, and the release of Total Phosphorus (TP), Ammonia NH_3-N, and TN loading from sediment was reduced by 96%, 51%, and 25%, respectively. In light of this, ONBMM may have great application potential for internal pollution control in lakes.

Nykänen et al. (2012) have developed a method for increasing oxygen levels using **granulated calcium peroxide (CaO_2)** as a slow oxygen releasing compound. Granulated CaO_2 was spread manually (without any additional mixing) over the whole surface of the test pond. Upon sinking to the lake bottom, this compound released oxygen (O_2) in a reaction with water during 5 to 7 months. To our knowledge, any long-lasting benefits beyond 7 months is not known and would have to be further investigated and evaluated.

In shallower areas of the lake where a bottom-based diffuser system can't be installed, a surface aerator, such as a **pond water wheel**, might be a useful solution. The oxygen-rich top layer of water is extracted from the lake's surface and transferred to the water column by water mixing.

Water fountains that spray water at a distance are not recommended due to potential health risks associated with inhalation of tiny airborne droplets or mist contaminated with harmful algal bloom toxins (Lau and Harte, 2007).

3.2.2 Circulation

Circulation uses air to force the movement of water so that it interacts with the atmosphere, or to move more oxygenated surface layers of water into deeper locations. There are a variety of products and methods developed to meet the purpose of circulation (VT DEC, 2019):

1. **Diffuser Systems** (see 3.2.1) release a diffused bubble plume from the lake bottom to force water to mix.
2. **Circulators** (e.g. SolarBee® and AerationPlus©) use solar power and mixing drive systems to pull in water at the desired depth, providing effective mixing to a predetermined depth.
3. **Updraft Pumps** use wind or solar sources to power low velocity, axial flow pumps to force water upward.
4. **Downdraft Pumps** use wind or solar sources to power low velocity, axial flow pumps to force water downward.

A more turbulent environment created by circulation may lead to an increase in DO levels in Swan Lake. However, circulation may also result in decreased transparency, as continued mixing keeps turbulence-adapted phytoplankton in suspension.

3.3 Reduction of Chloride Concentrations

Swan Lake has been experiencing high levels of chloride with spikes above 1000 mg/L and annual averages of almost 500 mg/L in 2017 and 2018 (Freshwater Research, 2020). This excessive amount of chloride exceeded both the short- and long-term thresholds of the Canadian Water Quality Guidelines for the Protection of Aquatic Life – Chloride (Canadian Council of Ministers of the Environment, 2011), which are 640 and 120 mg Cl^-/L, respectively.

As a classification, Swan Lake's elevated chloride levels puts it on the border between being a freshwater lake (with salinity less than 500 mg/L) and a sub-saline lake (salinity ranges from 500 to 3,000 mg/L). Most freshwater organisms have a narrow range of tolerance to changes in salinity (Canadian Council of Ministers of the Environment, 2011). Moreover, some researchers have shown that freshwater salinization is a critical life altering factor influencing zooplankton survival. It changes the trophic interactions in a lake through altering ecosystem functions, such as decomposition and nutrient cycling, leading to algae blooms (Kim and Koretsky, 2012; Jones et al., 2017; Du Plooy, et al., 2017). Therefore, chloride reduction is essential to the restoration of lake ecology.

High chloride concentrations in Swan Lake seem to be associated with winter de-icing operations. Road salts (in the form of sodium chloride) are commonly used as the preferred de-icing chemical due to their cost, effectiveness, and ease of handling. Another source of road salt entering watersheds is calcium chloride brine solutions that are used for dust suppression on gravel roads and construction sites during dry weather in the summer (TAC, 2013). There are several strategies and methods that can be considered to lower chloride levels in Swan Lake. These strategies can be implemented either outside or inside the lake.

3.3.1 Chloride Management Methods Outside the Lake

It seems that the most economically viable strategy to protect lakes is to prevent large amounts of salt from entering the water system. The **development of salt management plans** and **implementation of best management practices** in the areas of salt application, salt storage, and snow disposal may be the best way to prevent chloride entering the lake.

For municipalities, there are new technologies such as computerized salt spread controllers, temperature sensors, spreader calibration and reinforced plow blades that can reduce salt usage while still not compromising road safety. Some municipalities have been using **beet juice** on roads or a mixture of the juice with salt to make the de-icing processes more effective. The sugar from beet water helps salt stay on the roads, reducing run-off. City of Toronto has been using products like Beet 55, a mixture of saline, sugar and beets, when temperatures drop below -20 °C (Global News, 2017). Some other materials that have been in use (mostly in the USA) are **molasses, ashes, volcanic rock and potato juice, and brine of cheese and pickles** (CLF, 2015).

3.3.2 Chloride Management Methods Inside the Lake

There are limited practical methods to remove dissolved chlorides inside the lake. These methods are discussed below.

1. **Chloride adsorption on media** (e.g. Chlorocel, manufactured by Porocel). This method could be used in sync with nitrogen reduction as described in section 3.1.1. The Porocel media would be incorporated in a bioswale as an additional layer of media.
2. **Biological treatment.** Chloride-tolerant plants that can take up chloride in parallel to nutrients can be integrated in FTWs or possibly be incorporated into the planned redesign of the Swan Lake shoreline. Schück (2019) identified *Phalaris arundinacea* and *Glyceria maxima* as the species with highest chloride removal capacities. The findings of that study indicate that removal of chloride can be achieved by FTWs in cold climates using a combination of native plants.
3. **Solar Still**. A floating solar still is used to desalinate small amounts of water using evaporation and condensation (Kaushal and Varun 2010; Arunkumar et al., 2012; Sengar et al., 2012; Hoque, et al., 2019). Although we are unaware of any studies that use the technology for the purpose of chloride reduction in lakes with lower salinity levels.

4.0 Summary and Recommendations

This document explored the scientific literature documenting some of the feasible strategies that may improve water quality in Swan Lake. In order to offer direction for selecting appropriate techniques for addressing the existing water quality issues, the following activities were accomplished:

- review of the current reports provided by FSLP;
- site visit to Swan Lake to gain a full understanding of the current environment and the issues affecting the lake;
- completion of a thorough literature review to identify and outline the pros and cons of the potential solutions for mitigating dissolved oxygen, chlorides, and nitrogen levels in Swan Lake; and
- provision of scientific background on the existing water quality issues in Swan Lake and the importance for addressing these additional issues.

This document covered the following solutions:

1. Water recirculation through a bioswale or use of floating treatment wetlands (FTWs) for lowering phosphorus, nitrogen and chloride levels and increasing oxygen at the same time.
2. The use of diffuser aerators, Oxygen Nano-Bubble Modified Mineral, granulated calcium peroxide, pond water wheels, circulators, or updraft/downdraft pumps to increase DO levels.
3. Lowering chloride levels through the use of sorptive media, FTWs and their aquatic plants, or solar stills.

The pros and cons of the most feasible techniques within each solution are presented in Table 1 on the next page. As outlined in Table 1, some of the suggested techniques can address most or all water quality issues. For example, water recirculating through a bioswale that included the appropriate chloride-sorptive media, would address the removal of the TN and chloride pollutants, while water recirculation would contribute to water mixing and its oxygenating. The use of FTWs with diverse vegetation, including chloride-tolerant plants, can address issues related to the nitrogen and chloride pollutants.

There are several approaches that can be considered, either by selecting one bigger and more expensive option (such as water recirculation with pre-treatment in a bioswale) that may address all issues at once, or by taking several small steps gradually. However, due to a significant initial capital expenditure, the former approach should be investigated and assessed with some preliminary pilot studies to ensure water clarity will not deteriorate due to water movement.

Table 1. The pros and cons of selected solutions and techniques

Purpose	Solution/Technique	Pros	Cons
Oxygenate water and enhance phosphorus, nitrogen, and chloride removal	1. Water recirculation by using a submersible pump followed by treatment in bioswale	• Potential reduction of the frequency of Phoslock treatment • Decrease of hydraulic detention time • Mixed and oxygenated water • Bind and adsorb soluble nutrients, metals, and hydrocarbons, and filter particulate matter • Ability to incorporate chloride-reducing media such as Chlorocel • Provides a landscape feature in an urban development	• Significant initial capital expenditure • Possible soil erosion and media washout when too high flow rates are applied • Larger area requirements to maintain the proper contact time for denitrifiers • Bioswale performance may be lower prior to vegetation establishment and maturity • Chloride-sorptive media need to be replaced, raising associated costs • Potential decrease in water clarity due to water movement • Power source required (pump operation) • Pump maintenance required
	2. Floating treatment wetlands (FTWs)	• No chemicals involved • Bind and adsorb soluble nutrients, metals, and hydrocarbons, and filter particulate matter • Chloride-absorbing plants can be incorporated • Provides a landscape feature in an urban development • Minimal operational requirements	• Establishment of the plants may require 6-12 months • Performance may be lower prior to vegetation establishment and maturity • Low nutrient levels may affect development of plants • Annual plant harvesting required • Lower performance outside plant growing season • Capacity may be too modest for a waterbody as large as Swan Lake
To increase oxygen level	1. Oxygen Nano-Bubble Modified Mineral	• No maintenance • Quick effect	• A new technology in the development phase • Needs to be repeated
	2. Granulated calcium peroxide		• Chemical treatment • Newer application/usage with few studies • Needs to be repeated
To mix water and increase oxygen level	1. Diffuser systems 2. Circulator	• Proven technology • Mixed and oxygenated water • Low maintenance	• Power source required • Compressed air required • Potential to decrease water clarity

Therefore, we recommend taking the latter approach, by taking small steps and implementing a single solution followed by assessment of its performance. It is often considered that a combination of different restoration measures is most effective, but the outcomes of several simultaneously applied restoration procedures are difficult to discern. To mitigate the existing water quality issues in Swan Lake, any technique employed should be quick and sustainable. Additionally, any successful technique used will need to be thorough, ecologically safe, cost effective and multifunctional.

We recommend that consideration be given to the following three treatments that should be complementary to the planned periodic Phoslock program:

1. **To increase the oxygen levels and avoid any potential disturbance of the lake sediment, granulated calcium peroxide can be used.** This method may provide quick results and does not require any equipment installation. Since this treatment will inhibit the release of phosphorus and nitrogen from sediment, and will increase the oxygen level, this treatment may be applied prior to Phoslock. However, some preliminary laboratory studies are required to determine the most optimal dose of calcium peroxide. In addition, it will need to be determined if there are any potential interferences between the calcium peroxide and Phoslock treatment. We would recommend identifying a small area on the lake for this treatment where Phoslock will not be applied (e.g. Turtle Inlet) and perform a monitoring study to assess the quality of water and any long-lasting benefit of the granulated calcium peroxide treatment. In addition, a laboratory-scale experiment should be carried out in parallel to field operations to rule out any potential interferences between the Phoslock and granulated calcium peroxide treatment. The use of granulated calcium peroxide could be beneficial between the Phoslock cycles and possibly reduce the Phoslock frequency (e.g. from 3 to 5 years).

2. Depending on the calcium peroxide performance, further treatment of nutrients may be required. **For that purpose, FTWs with chloride-tolerant plants can be installed to further decrease nutrients and chlorides.** FTWs are promising restoration tools, mimicking the processes that naturally occur in wetlands and nearshore environments while being cost and space effective. **We would recommend starting to install FTWs above the area of the former dumpsites, as these locations may be contributing to nutrient leaching. The application of granulated calcium peroxide may also focus on those locations first.**

3. In parallel, some additional laboratory and/or field tests can be performed to determine if diffuser aeration systems are a feasible long-term solution for maintaining oxygen in the proper range without worsening water clarity. Increasing DO concentrations in lakes has been shown to improve water quality parameters and aquatic organism habitats, and thus may be used to support active lake restoration.

Although an important and potentially long-term goal, restoring the Swan Lake water quality from the current hypereutrophic state in the lake to mesotrophic nutrients level may require significant resources. It will be necessary to evaluate what kind of lake management tools are possible, affordable, and preferable for reliable management and restoration of Swan Lake. Before a decision is made or implemented, the objectives, patterns, and expectations shaping future water management should be further explored.

It is recommended that this literature review is followed by some experimental work, as outlined above. The CAWT has the required expertise and resources to assist with the next steps in restoring Swan Lake water quality.

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About the CAWT

Fleming College's Centre for Advancement of Water and Wastewater Technologies (formerly the Centre for Alternative Wastewater Treatment) is a research centre located at the college's Lindsay, Ontario, Canada campus. When its doors opened in 2004, the CAWT was primarily focused on researching treatment wetland systems and phytoremediation technologies for cold climates.

No longer focusing on just alternative technologies, in the last decade the CAWT has gained an international reputation for engaging in innovative water and wastewater applied research and offering technology development services to the private sector, governments, non-governmental agencies, and to universities.

Designed for customizable operations and project implementation, the CAWT is a unique centre with advanced infrastructure and on-site facilities.

The CAWT is ISO/IEC 17025 certified by the Canadian Association for Laboratory Accreditation (CALA), participates in the CALA Proficiency Testing Program, and has passed the VerifiGlobal Peer Assessment (ISO/IEC 17020:2012 Conformity Assessment in the scope of ISO 14034:2016 Environmental Management – ETV).

Contact Information

Brett Goodwin, Ph.D.
Vice President, Applied Research & Innovation
Fleming College
t: 705 324-9144 x3093
e: brett.goodwin@flemingcollege.ca

Mary Lou McLean
Manager, Office of Applied Research & Innovation
Fleming College
t: 705 324-9144 x3080
e: mary_lou.mclean@flemingcollege.ca

Jennifer Andersen, M.Sc.
Manager
CAWT
t: 705 324-9144 x3068
e: jennifer.andersen@flemingcollege.ca

Fleming College
200 Albert St. S.
Lindsay, ON K9V 5E6

cawt.ca

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