Technical Report II

Review of Beaver Lake Ecology and the Need for Aeration as an Immediate Priority

CRD, Parks and Environmental Services

Contents

1.0 Introduction

A Technical Report written in 2017, *Investigation of In-Lake Remediation Options,* describes the science of Elk and Beaver Lakes ecology, and provides evidence of the benefits expected from implementing oxygenation technologies and focuses on the remediation options for Elk Lake.

This Report presents lake ecology and oxygenation options specific to Beaver Lake.

2.0 Recommended Change of Focus of Remediation from Elk Lake to Beaver Lake

The Elk/Beaver Lake Initiative (EBLI) was created by the Capital Regional District (CRD) in 2016 to implement one or more actions that will lead to a reduction in the frequency and toxicity of cyanobacteria (a.k.a. blue-green algae, 'BGA') blooms in Elk and Beaver Lakes. Additional objectives are to improve fish habitat, manage weed growth, and ensure continued recreational use. The EBLI was established in response to public demand for focus on the struggling Elk and Beaver Lakes' ecosystem. In addition to annual *winter* toxic cyanobacteria blooms in Elk Lake, there was concern over the sustainability of a healthy fishery under low oxygen (anoxic) conditions, the proliferation of nuisance aquatic weeds, the presence of invasive aquatic and terrestrial species, and public health and safety during water contact recreation. Remediation of Elk Lake was the primary focus at the onset of the EBLI. Beaver Lake had not been monitored consistently for water quality concerns, and was not considered a priority.

Unexpectedly, the risks to the public and loss of recreational values caused by toxic cyanobacteria blooms have now become more severe in Beaver Lake than Elk Lake. This is mainly because cyanobacteria are extremely prolific in the summer at Beaver Lake. During the summer of 2016 toxic cyanobacteria surface scum resulted in strong advisories against water contact in Beaver Lake from August to December 2016. As a result of this extended toxic bloom, more frequent monitoring of Beaver Lake water quality was conducted between August 2016 and July 2017. Water contact advisories were again issued for Beaver Lake beginning in July 2017 due to the visual identification of surface scum. Subsequent water quality testing resulted in undetectable (< 5 ppb) concentrations of cyanotoxins, but the phytoplankton community demonstrated 100% abundance of potentially toxin-producing cyanobacteria which could have become toxic at any time. Due to the high risk of cyanotoxin production, the public was advised to avoid contact with Beaver Lake water for the duration of the summer.

Elk Lake has not had a cyanobacteria bloom with toxins exceeding 5 ppb since February 2015. The focus on Elk Lake stemmed from the cancellation of the New Year's Eve Polar Bear Swim several years in a row, and concerns over winter cyanobacteria scum in the shallow edges of the lake which persisted from December to February in previous years. The winter of 2016/2017 was unusually cold with air temperatures near 0°C from December to February. There is no doubt that the cold weather prevented any severe cyanobacteria blooms from occurring. Even if subsequent winters are warmer, and cyanotoxins are detected above recreational guidelines in Elk Lake, it has become evident that cyanobacteria blooms in Beaver Lake are much more problematic than those in Elk Lake.

Aside from the necessary relocation of the Polar Bear Swim, toxic wintertime blooms in Elk Lake result in minimal disruption to water contact activities in Elk Lake compared to summertime lake closures for Beaver Lake. Cyanotoxins have not been severe enough to result in fish-kills as have occurred at other lakes world-wide. Boaters and rowers are at low-risk for exposure to cyanotoxins in the winter if they avoid the lake edges where surface scum is evident, do not let dogs enter or drink water in "scummy" coves, and if they abide by simple safety strategies such as wearing waterproof gloves (a necessity for comfort in the winter months) and washing wet clothes and hands with soap and water following surface water activities. Therefore, it may be of greater benefit to the Capital Region to re-focus, prioritize, and allocate resources to improving the summer water quality of Beaver Lake in order to maintain summertime recreation values and public safety.

In addition to preserving Beaver Lake as a summertime recreational site, aeration may reduce the aquatic invasive weeds that currently cover nearly 100% of the channel and Beaver Lake. The weeds are a nuisance and potential hazard to boaters, rowers, and swimmers throughout the summer months. CRD Regional Parks devotes significant resources to manage weed growth in Beaver Lake and the connecting channel by running a weed harvester 3-5 days per week throughout the summer. The 2016 aquatic weed survey showed that the invasive weeds grow in areas < 3 m deep, and are thus a minor problem in Elk Lake.

Finally, it should be noted that based on new research on Beaver Lake cyanobacteria and lake ecology, insufficient or no aeration in Beaver Lake will likely result in increased summer advisories warning users against swimming and dog exposure to water from June-September every summer from now on. This would result in the complete loss of Beaver Lake as a swimming lake immediately. Any business case for Elk Lake must be based on the "replacement value" of the lake if it were to become unusable in the future. We are not currently at risk of losing Elk Lake as a venue for rowers, boaters, fishermen, and swimmers, but are at immediate risk of losing Beaver Lake for summer-long recreational use.

The content of this submittal is intended to support the development of a Request for Proposals (RFP) for a Beaver Lake water quality improvement system.

3.0 Benefits of Upflow Bubble Aeration

The following section summarizes the likely benefits to Beaver Lake from an appropriately sized aeration system in accordance with the goals of the EBLI. Additional scientific information and a review of potential aeration options for Beaver Lake follows. Additional reports are currently pending, and include the results of the 2017 fish inventory and a student project that evaluated the lake-bottom substrate.

The installation and proper maintenance of an upflow bubble aeration system will improve the ecosystems of Beaver Lake and the connecting channel. Successful case studies for this type of system are abundant for North American lakes. According to case studies and the supporting lake science, an upflow bubble aeration would:

1) **Greatly reduce and/or eliminate summer blooms of potentially toxic cyanobacteria.**
2) **Greatly reduce the growth and coverage of water milfoil in Beaver Lake and the connecting channel.**
3) **Greatly reduce the mucky layer above the Beaver Lake sediment.**

4.0 Beaver Lake Background

Beaver Lake has a maximum depth of 8 m, and an average depth of about 4 m. Temperature data showed that Beaver Lake does not exhibit strong thermal stratification in the summer, but dissolved oxygen levels are very high at the surface, and decline to near zero below 4 m.

Beaver Lake experienced toxic cyanobacteria blooms in August, September, and October-November 2016, which persisted until air temperatures were near 0°C in December 2016. A phytoplankton bloom was observed in Beaver Lake in June 2017. The bloom was a normal seasonal phenomenon in which the lake became productive due to the onset of summer warm water temperatures.

On July 9 2017, surface scum was observed near Beaver Beach on the morning of a Saanich Strawberry festival. Water samples were taken the next day, and cyanotoxins were below detection limits; however, potentially toxic cyanobacteria were 100% dominant in the sample, and the risk of cyanotoxin production and subsequent toxin release was very high. An advisory warning lake users of the high risk of toxins was posted on the CRD website, and advisory signs remained in place for the remainder of the summer because potentially toxic cyanobacteria continued to dominate the phytoplankton community.

5.0 Differences in Elk and Beaver Lake Ecology

As demonstrated by **Figures 5.1 and 5.2**, the bathymetry of the two lakes is very different. As a result of the differing bathymetry, the ecology of each lake is very different and water quality is driven by very different processes.

Elk Lake Ecology

As shown in **Figure 5.1**, the Elk Lake basin is an average of 13 m deep, with several deep zones extending to 18 m. During the summer, surface water temperatures reach 20°C or higher, while the deep water is much cooler at 10°C or less. This significant difference in temperature is naturally occurring in many lakes and is referred to as “stratification”, resulting in the formation of a “thermocline”. The thermocline acts as a barrier between the cooler deep water and the warmer surface water, which persists throughout the summer until the surface water cools in the fall and the lake is able to mix.

In Elk Lake, this summer thermocline is typically at 9-10 m depth. Due to the thermocline barrier, atmospheric oxygen dissolved in the surface waters cannot mix with the deeper lake waters and as a result, dissolved oxygen (DO) concentrations below 9 m are very low (< 1 mg/L). Low dissolved oxygen (DO) concentrations in deep waters can be problematic because it does not support deep water aquatic life and can cause the release of phosphorus from the lake sediments. Low DO also impacts rates of decomposition in materials at the lack bottom that could further compound the issue of nutrient loading.

The recommended remedial action for Elk Lake differs significantly from the approach recommended for Beaver Lake. At Elk Lake, the recommended remediation is a high efficiency hypolimnetic oxygenation system. This system would maintain adequate deep-water dissolved oxygen levels important for aquatic life and necessary for reducing release of phosphorus from sediments that contribute to internal nutrient loading. This system also ensures that the thermal stratification is not disrupted, in order to conserve cooler deep water temperatures to support fish and other aquatic life.

Beaver Lake Ecology

As shown in **Figure 5.2**, the Beaver Lake basin is an average of 4 m deep, with a mid-lake maximum of 8 m deep. Summer water temperatures in Beaver Lake range from warm (at least 20°C) at the surface at to cool (12°C) in the deeper zones (7-8 m). The temperature between surface waters and deep waters are very gradual and therefore the lake is weakly stratified. As a result, in Beaver Lake there is not a strong thermocline that would isolate the surface waters from the deeper waters, as there is in Elk Lake. Despite very minimal thermal stratification, there are significant differences in dissolved oxygen levels in the different depth zones of Beaver Lake. During the summer, DO concentrations have varied from high (14 mg/L) at the surface to very low (2.5 mg/L) in the deep waters. These low deep water DO levels during the summer is likely driven by the consumption of oxygen from biological processes, such as decomposition in the lake sediment, rather than thermal stratification.

Prior to the construction of the Beaver Lake dam in 1873, Beaver Lake was a marsh. As a result, Beaver Lake has developed a thick layer of "mucky" material on the lake bottom that undergoes a continual process of decomposition. Oxygen and nitrogen are required for the decomposition of this mucky layer which consists of partially decomposed plant and animal (e.g., zooplankton and fish) material. With sufficient oxygen and nitrogen, bacteria actively decompose plant and animal material year-round, as long as temperatures remain relatively warm (above 5°C). In Beaver Lake, these temperatures have been historically maintained year round.

Through the process of decomposition, important for cycling nutrients and breaking down organic matter, the sediment bacteria consume oxygen year round, causing DO concentrations to remain very low (< 3 mg/L). During warmer summer months, the sediment bacteria decompose materials at higher rates, therefore consuming more oxygen, and decreasing DO. Therefore, high decomposition rates paired with weak thermal stratification, result in very low DO levels in deep-waters of Beaver Lake. These anaerobic conditions in deep waters contribute to the release of Phosphorus from lake sediments, and increase internal nutrient loading.

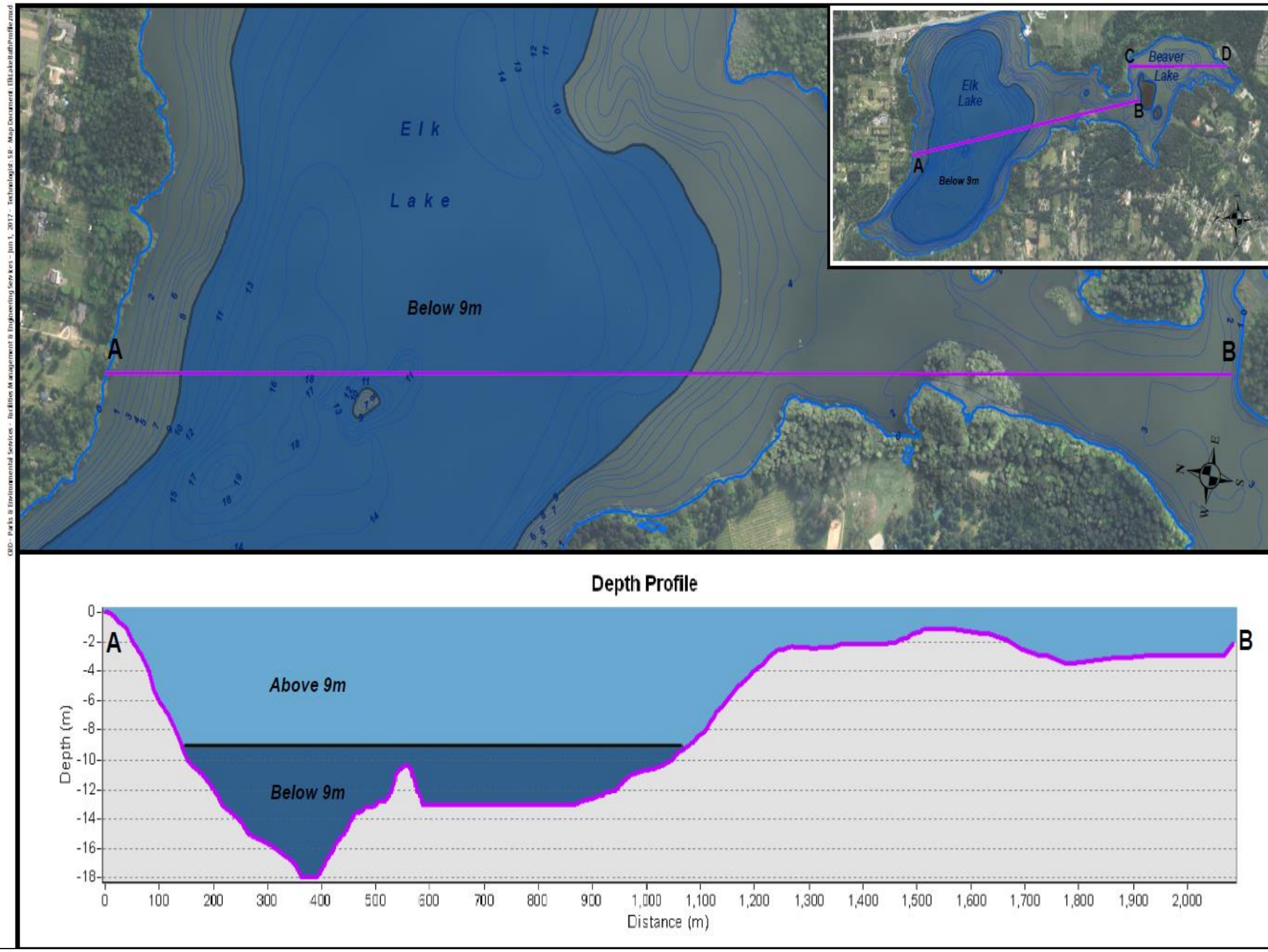

Figure 5.1 Elk Lake Depth Profile

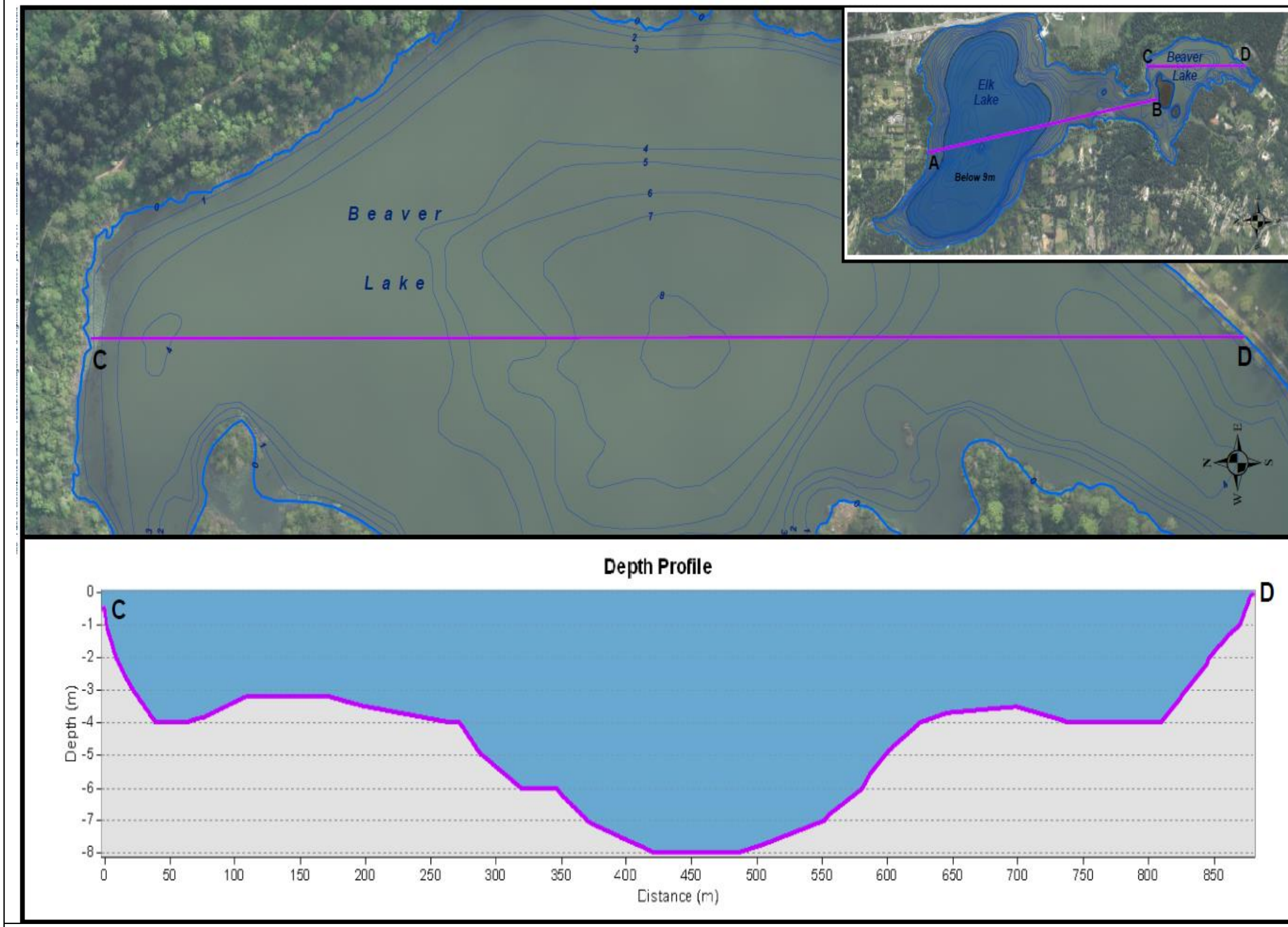

Figure 5.2 Beaver Lake Depth Profile

6.0 Cyanobacteria in Beaver Lake

External inputs of phosphorus in Elk and Beaver Lakes contribute an estimated ~12% of phosphorus to the lake system. The remaining ~88% of phosphorus is recycled within the lake between biota. The growth of plants and other photosynthetic aquatic life, such as cyanobacteria depends on having adequate light, temperature and nutrients such as phosphorus and nitrogen. For optimum growth, most plants need nitrogen and phosphorus in a ratio of approximately 15 parts nitrogen to one part phosphorus (15N:1P). Both Elk and Beaver Lakes have an abundance of phosphorus, but the concentration of nitrogen is limiting for much of the year. As a result, cyanobacteria dominate the phytoplankton community because they can fix nitrogen from the atmosphere into a more useable form (ammonia). Other plants require direct nitrogen inputs from other external sources to support their growth. One strategy to reduce cyanobacteria abundance is to reduce biologically available phosphorus in the water column.

Upflow bubble aeration would reduce biologically available phosphorus in two ways:

- Increase DO at the sediment-water interface to promote chemical and biological sequestration of phosphorus
- promote an early season (March/April) release of phosphorus to surface waters to be flushed out of the system by storm water overflows

7.0 Weed Growth in Beaver Lake

Beaver Lake and the channel connecting Elk Lake has experienced extensive aquatic weed growth for at least 30 years. Weed harvesting is conducted throughout the summer to ensure that weed mats are maintained at such a depth below the water surface that boating and rowing activities are not disrupted. The majority of aquatic weeds are invasive water milfoil (*Myriophyllum spicatum*), likely a local variety that has hybridized with European water milfoil. Like other plants, water milfoil grows rapidly from June-August, and dies back and decomposes over the winter. Regular cutting of milfoil weed beds causes the plants to develop stronger and more extensive root systems such that the channel and Beaver Lake now exhibit nearly 100% cover by water milfoil in the summer. The harvested weeds are removed from the lake and composted elsewhere. However, in the fall and winter, the remaining milfoil below the water surface dies back and decomposes over the winter. The decomposition of this unharvested milfoil contributes to the oxygen deficit in Beaver Lake. This large mat of decomposing milfoil also contributed to increasing depth a muck layer in Beaver Lake.

8.0 Remediation Options and Lake Mixing

At Elk Lake, maintaining the thermocline is important to ensuring cooler deep water temperatures for fish and other aquatic life. Remediation actions for Elk Lake, therefore cannot involve significant mixing of water that would disrupt the thermocline. However, in Beaver Lake, the result of mixing would have a less of an impact because the difference between deep and surface water temperatures is less significant. As a result, we would expect that mixing would have less of an effect on the fish and other aquatic life in Beaver Lake. However, any remediation option involving significant mixing should monitor impacts to benthic and fish communities.

9.0 Upflow Bubble Aeration

Upflow bubble aeration systems are designed to mix lake water in order to enhance the distribution of oxygen throughout the lake water column. These systems work by diffusing tiny bubbles from the lake bottom upward in order to promote atmospheric oxygen exchange. Air consists of 20% oxygen, 78% nitrogen, and small percentages of water vapor and other gasses. An added benefit of upflow bubble systems is that nitrogen also becomes more biologically available to increase the rate of decomposition. Providing oxygen to Beaver Lake will:

- Reduce cyanobacteria abundance by aiding in sediment phosphorus sequestration;
- Enhance the decomposition of muck and dead aquatic weeds by providing oxygen to bacterial decomposers.

Review of Upflow Bubble Aeration Options

In determining the best remediation system to address water quality issues at Beaver Lake, a number of factors must be considered. Firstly, any remediation system should be designed to reduce of frequency and toxicity of cyanobacteria blooms, reduce invasive weed growth, support fish habitat and ensure ongoing recreational use of the lake. Other considerations include an evaluation of capital costs, long-term operations and maintenance costs, system resilience or warranty, and scientifically supported track-records. Operation and maintenance of any system in Beaver Lake should be operated and maintained 9-12 months of the year until the target reductions of cyanobacteria, phosphorus, aquatic weeds, and muck are achieved, following which the duration of operation can be re-assessed.

The following provides leading examples of systems that are likely to achieve the ecological and operational objectives of Beaver Lake and the connecting channel for the greatest long-term value. Estimated capital cost of purchasing an upflow bubble system sized appropriately for Beaver Lake varies from about $80,000 up to $300,000, plus annual maintenance and electricity. The recommended system is expected to reduce the need for aquatic weed harvesting within 1-3 years, and this will offset a portion of the costs over 10 years.

Oxygen Concentration System by Gaia Water

The oxygen concentration system by Gaia Water takes in air, separates out the oxygen, and pumps concentrated oxygen as very tiny bubbles throughout the entire water column (Gaia Water 2016). The Gaia Water system was tested against fountains and surface bubblers in Lake Ida Anne (Langford, BC), a very small lake that acts as a secondary stormwater catchment for the Bear Mountain development. Prior to the installation of the oxygen concentrator in 2015, the lake suffered from severe cyanobacteria blooms. Between 2 July and 13 August 2015, the oxygen concentration system increased DO in the epilimnion by about 1mg/L per week, and as a result eliminated the cyanobacteria on the lake surface.

The Gaia Water system consists of a hospital-grade oxygen concentrator, and a proprietary “land shark” pump (**Figure 9.1**). The exact oxygen diffusion mechanism is not yet known.

Risks and Considerations:

- Uses pure oxygen instead of air;
- Gaia Water is a relatively new company with a short track-record;
- The system has not been used in a lake the size and depth of Beaver Lake;

- The number of systems and diffusers may be extensive, on a similar scale as the Vertex System described below.

A B

Figure 9.1 Gaia Water oxygen concentration system. (A) Oxygen concentrator (B) Land Shark pump

Vertex Aeration System

Vertex Water Features manufactures lake aeration systems that can be designed to meet the objectives of Beaver Lake water quality improvements. In addition to a long-track record of proven success, the company has recently developed a system for large lake aeration. Their website highlights the successful reduction of mucky material in a 65 hectare lake. Vertex Water previously recommended their AIR5 XL2 system for larger lakes which would be configured with shoreline compressors and in-lake diffusers similar to what is shown in **Figure 9.2** (left). The recently developed HE33 system has more powerful compressors and higher efficiency.

Risks and Considerations:

- Requires numerous diffusers and power access points;
- Excellent warranty for equipment;
- Scientifically documented track-record with numerous third-party case studies;
- Includes tamper-proof housing;
- Compressors can be located away from the lake edge.

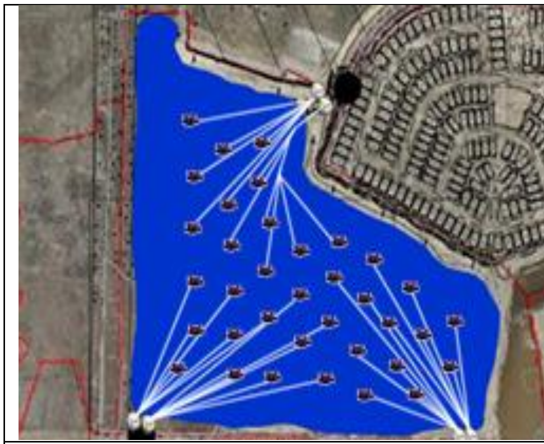 

Figure 9.2 Vertex AIR5 XL2

Laminar-flow Aeration

Laminar-flow aeration systems (**Figure 9.3**) have successfully reduced aquatic plant cover and phosphorus loading in numerous lakes, including lakes over 500 acres (202 hectares). Laminar-flow technology consists of a small (quiet) compressor on the lake shore, and self-sinking air lines that connect from the compressor to diffusers on the lake bottom (**Figure 9.4**).

Laminar flow aeration systems work by drawing oxygen from a lake shore compressor and diffusing it outward into the lake sediments and upward toward the lake surface. Lake Savers™, a distributor of Clean-Flo™ aeration systems, claims that their patent-pending diffusers evenly distribute dissolved oxygen through the sediments, purge H_2S and CO_2, and are non-turbulent (i.e., will not stir up the sediments). Success stories include Toa Vaca Reservoir (Puerto Rico), Indian Lake (Dowagiac, MI), and numerous others (Lake Savers 2016).

Toa Vaca Reservoir is an 800 acre (324 hectare) lake with a maximum depth of 147 feet (45m). Prior to aeration, there was no oxygen below 35 feet (10.6 m). The aeration system was installed to reduce internal phosphorus loading, including the associated release of iron and manganese. After four months, DO had increased from 0.55 to 4.8 mg/L at 21m and from 0.58 to 3.9 mg/L at 45m. Total phosphorus was reduced by 80% at 21m and 88% at 45m (Lake Savers 2016).

Risks and Considerations:

- Likely the most expensive system;
- Sized for large lakes;
- Scientifically-documented track-record with numerous third-party case studies;
- Includes tamper-proof housing;
- Compressors can be located away from the lake edge.

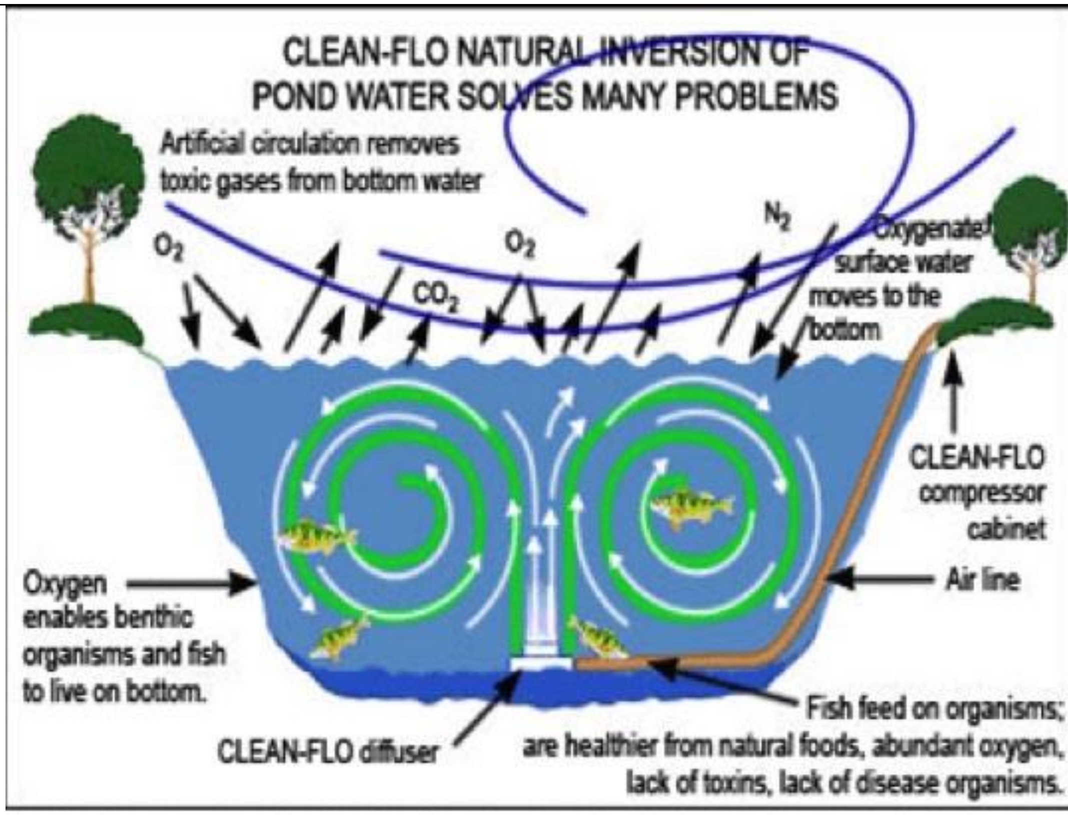

Figure 9.3 Clean-Flo laminar flow aeration system

- **Large Lake System at Indian Lake, Dowagiac, MI.**
- **This Single Compressor is treating over 200 acres**
- **It is located 300' from the Lake!** ***(Lake Savers is the only company with the technology to locate compressors off the lake)***

Figure 9.4 Clean-Flo™/Lake Savers™ laminar flow aeration systems

10.0 Conclusion

The scientific information and examples of available technologies presented in this document should guide the evaluation metrics of a RFP. Costs should be evaluated on the basis of overall value to the Beaver Lake ecosystem, operations, and recreational activities over the next 10 years. The scientific analyses in this document should over-ride any previous assumptions about the ecology, and risks to public health and enjoyment of Beaver Lake. Immediate action is needed in order to prevent summer-long health and safety advisories for Beaver Lake in the future.