Hawrelak Lake Water Quality Feasibility Study

Prepared by

APPLIED ECOLOGICAL SERVICES

Prepared for

City of Edmonton, Alberta, Canada

and

the marc boutin architectural collaborative inc.

16 December 2020

Acknowledgements

Applied Ecological Services, Inc. (AES) gratefully acknowledges the following people, who contributed to the *Hawrelak Lake Water Quality Feasibility Study*:

Mike Jenkins	City of Edmonton, Biological Sciences Technician
Bill Barr	City of Edmonton, Biological Sciences Technologist
Brittany Hogaboam	City of Edmonton, Biological Sciences Technologist
Rachel Dumont	City of Edmonton, Program Manager
Junho Kim	City of Edmonton, Engineering Technologist
Tim Smith, AAA, MRAIC	the marc boutin architectural collaborative inc., Intern Architect
Maureen Hetzler, BES MLA BCSLA	PFS STUDIO, Associate
Don Laycraft	ion irrigation inc., Certified Irrigation Designer/ Auditor/ Landscape Water Manager

We also thank City staff and other individuals on the Technical Advisory Committee for the William Hawrelak Park Rehabilitation Project. They provided valuable input at key stages in the development of the water quality feasibility study.

This report was prepared for:
City of Edmonton and **the marc boutin architectural collaborative inc.**

This report was prepared by:
Applied Ecological Services, Inc.
Kim Alan Chapman, PhD
Steven I. Apfelbaum, MS
Joseph Miller, BS, PE
Doug Mensing, MS
Lauren Jennison, BS, LEED
Eoghan O'Neill, MS

Citation: Applied Ecological Services, Inc. 2020. Hawrelak Lake Water Quality Feasibility Study. Report for the City of Edmonton and the marc boutin architectural collaborative inc. Alberta, Canada.

Table of Contents

TABLES

FIGURES

APPENDICES

Purpose of This Study

This report summarizes existing conditions in Hawrelak Lake and its watershed for the purpose of assessing the feasibility of best management practices (BMPs) to improve water quality in the lake. Applied Ecological Services, Inc. (AES) reviewed existing information sources (Appendix 1) including data from the City and other organizations. AES also obtained recent and new digital and field data for ground elevations, infrastructure, land cover, water quality, lake sediment depth, and soils. Using this baseline information, AES worked with City staff, the Park Rehabilitation Advisory Committee and the marc boutin architectural collaborative inc. (MBAC) team to identify and evaluate approaches for improving lake water quality in the park.

The information in this water quality feasibility study will allow readers to understand how the lake ecosystem is structured and functions, and the reasons for the choice of BMPs that comprise the preferred alternative.

The City expressed a desire for three outcomes of this study and the implementation of its recommended BMPs.

- Improve water quality and create a more pleasant lake environment for visitors. City Council has inquired multiple times on how to make the lake swimmable, but several constraints exist to achieving that outcome.
- Prevent cyanobacterial blooms and, to a lesser extent, other algal blooms for International Triathlon Union (ITU) events.
- Reduce *E. coli/Enterococcus* levels in the lake. Testing has demonstrated the bacteria have a bird origin. The City is shifting its monitoring standard from *E. coli* to *Enterococcus*.

Inventory of Data Sources

A variety of water quality and climate-related studies have been conducted since the 1980s for Hawrelak Lake and the associated North Saskatchewan River. Studies of other lakes provided additional insights into how best to manage Hawrelak Lake and address its history of algae blooms, elevated bacteria levels, and other issues that degrade the aesthetics and harm the recreational value of this popular Edmonton destination. Appendix 1 describes the data sources that were used in the development of this feasibility study.

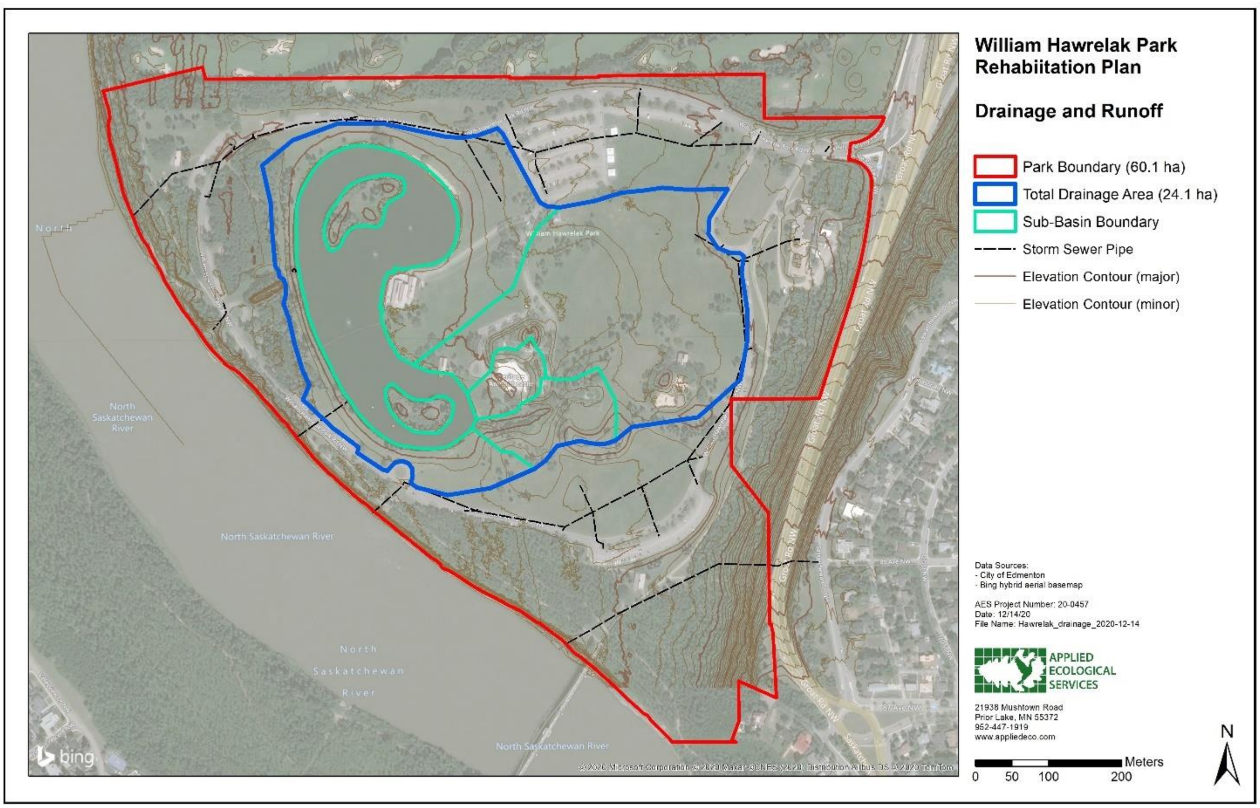
Summary of Existing Conditions

This summary is drawn from the existing data sources (Appendix 1) and new data collected to fill gaps in the understanding of the sources of lake pollution and causes of algae blooms, which are driven primarily by phosphorus. City staff were interviewed by AES and the MBAC team on May 26, 2020.

Lake Setting

- The park was a gravel pit from 1950-1967. It was graded and filled to create a “stormwater management basin” and park in the late 1960s.
- Surface soil is clay fill (20 cm to 3 m depth) over alluvial sands, gravels, and clays. Bedrock is close to the land surface in the south part of the park and 10 m below the surface in the north. A water table was detected at 1.5m below the surface in geotechnical borings near the pond-stream area southeast of the lake.
- The lake is susceptible to eutrophication due to physical factors (Figure 1).
    - It has a small drainage area (24.1 ha) primarily comprised of managed turf.
    - It is a shallow lake, 1.5m in the deepest parts. Because wind mixes the water of shallow lakes, there is no summer lake stratification—the formation of a deep cold layer of water and a shallow warm layer. Deep and shallow water are completely warmed and fully sunlit during the summer, which creates ideal conditions for algae blooms.

Figure 1. Hawrelak Park drainage area (blue) and local sub-basins (green) that drain to the lake; storm sewer pipes are shown draining to the river

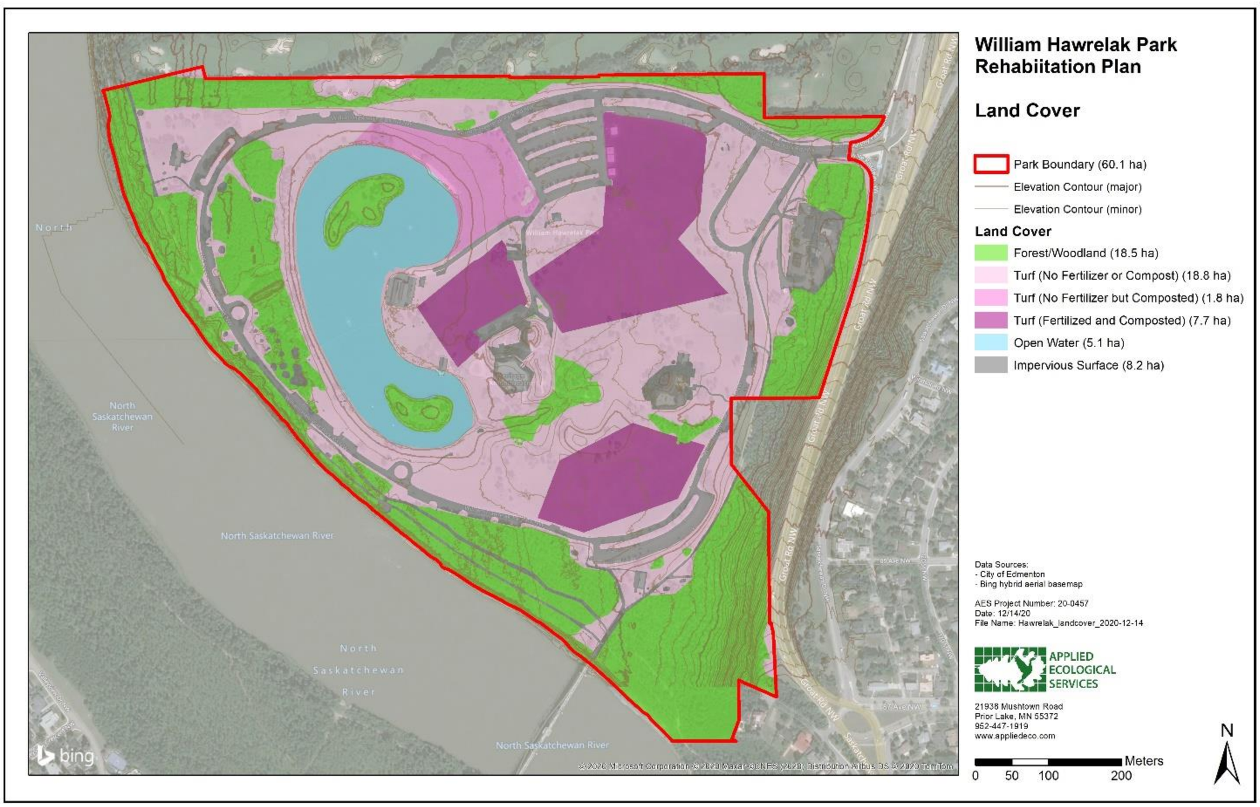


  - There is little connection to groundwater due to the clay liner and depth of the aquifer. The clay liner was repaired in 1999 and 2013 when it was discovered to be leaking. Leakage indicates that the lake loses water, rather than gains it from groundwater.
  - The average 1.5m lake bottom may be near the 1.5m groundwater level detected in the boring near the southeast pond-stream area, but no evidence of a connection exists.
- Nearly the entire park slopes towards the lake, but all runoff from streets, parking lots, and turf outside the ring road enters storm drains which discharge to the North Saskatchewan River. No runoff from impervious surfaces enters Hawrelak Lake, which is good for water quality.
- The park is approximately 60 ha in size. Turf comprises most of the park's land cover, with roughly equal amounts of impervious surface (pavement, buildings) and woodland (Table 1, Figure 2).

Table 1. Land Cover in Hawrelak Park

Land Cover	Area (ha)	Percent of Park
Forest/Woodland	18.5	30.8
Turf	28.3	47.1
Lake (Open Water)	5.1	8.4
Impervious Surface	8.2	13.6
Total	**60.1**	**100**

Figure 2. Hawrelak Park land cover



- There is a narrow, vegetated buffer along much of the lake edge, but little emergent vegetation. Photos taken on July 31, 2020, illustrate conditions at the lakeshore (Figures 3-8).
- The small pond and stream that drain to the lake are filled with lake water from a pump near the pavilion; the pump is managed by the City of Edmonton. The pond and stream are used as interpretive features by a volunteer organization.

Figure 3. Hawrelak Lake east shore, with riprap and a narrow, unmowed strip of vegetation

Figure 4. Hawrelak Lake north shore, west of beach, with turf mowed to water

Figure 5. Hawrelak Lake north shore, with turf mowed to water's edge

Figure 6. Hawrelak Lake west shore at river water outfall, with narrow, unmowed strip of vegetation

Figure 7. Hawrelak Lake west shore, with small patch of native bulrushes, a marsh plant

Figure 8. Hawrelak Lake south shore, with turf mowed to water's edge

Water Quality in the Lake

City staff reported that, for many years, filamentous and colonial green algae are commonly present in Hawrelak in the summer. Green algae do not pose a health risk but can make beaches and lakes unattractive. When the algae die they fall to the lake bottom and decompose, lowering oxygen levels. In 2015, blooms of blue-green algae (cyanobacteria) began. Cyanobacteria are a health risk to humans, pets, and wildlife due to the toxins they excrete.

E. coli and *Enterococcus* bacteria levels are sometimes higher than allowed for full body contact in the lake. In the 2003-2016 period, fecal coliform counts averaged 152.7 cfu/100 mL. Fortunately, genetic testing established that birds are the source of this bacteria, indicating that waterfowl are the source of bacteria in the lake.

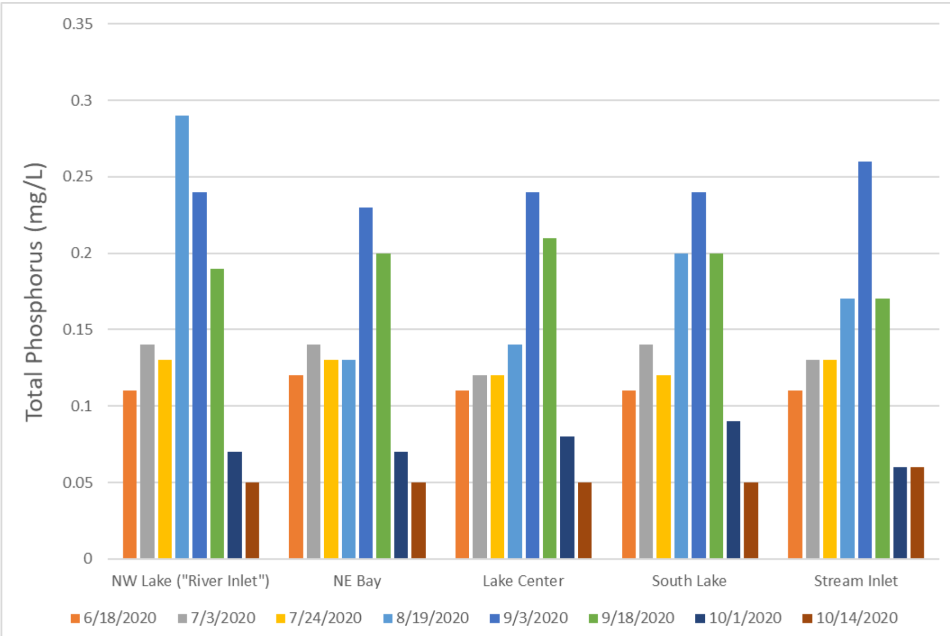
City staff began sampling water quality in the lake shortly after the master planning process began in spring 2020. Five sampling locations were chosen to represent different sections of the lake (Figure 9). Two samples were taken each month, beginning June 18 and ending October 14, 2020, after which ice formed, preventing water quality sampling. (Water quality sampling will begin again at ice-out in March or April and continue through June 2021 to complete a year's sampling.)

Figure 9. Hawrelak Lake water quality sampling locations, 2020

Water samples were collected using standard techniques and sent to a laboratory for analysis. Samples were tested for major factors related to lake eutrophication, algae blooms and water pollution: dissolved phosphorus, total phosphorus, nitrate-nitrogen, total suspended solids, *E. coli* bacteria, and fecal *Streptococci/Enterococci*.

Water quality sampling in summer 2020 detected an average of 0.14 mg/L of total phosphorus, increasing from spring into summer and decreasing in the fall (Figure 10). The five sampling locations in the lake were similar in their phosphorus concentrations, indicating that one sampling location could be used to represent the phosphorus concentration for the entire lake.

Figure 10. Phosphorus concentrations in Hawrelak Lake, June-October, 2020

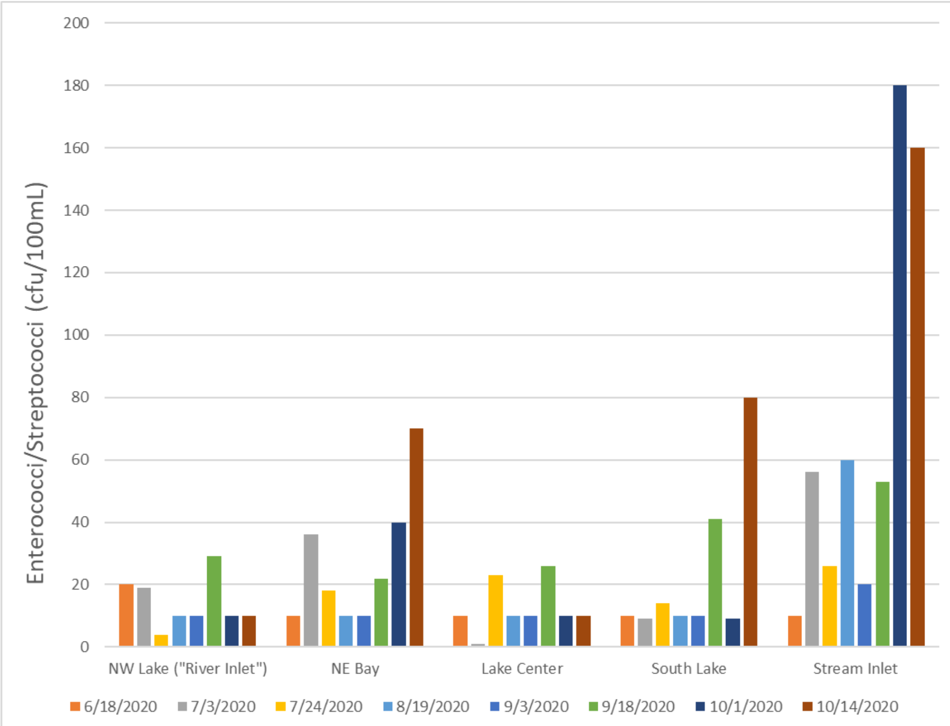


Studies suggest (Appendix 1) that, given favorable conditions, total phosphorus levels above 0.025 mg/L are associated with a greater probability of algae blooms. The average total phosphorus level in Hawrelak Lake in 2020 was an order of magnitude higher than this target concentration.

Enterococci bacteria counts in Hawrelak Lake from June-October 2020 were generally 10-20 cfu/100 mL or less, well below Canada Health's 2012 standard and the US Environmental Protection Agency's standard of <61-151 cfu/100mL for a single sample (Figure 11). This suggests swimmers could have swum in Hawrelak Lake in 2020 under conditions that met the guidance for full body immersion. In future years, however, bacteria counts could exceed the standard given the right conditions.

Enterococci counts increased in the fall, perhaps due to an increase in geese numbers as they congregated before the fall migration. Counts were especially high in the southeast lake near the pond-stream outlet. This finding is discussed in more detail below.

Figure 11. Enterococci/Streptococci concentrations in Hawrelak Lake, June-October 2020



Potential Phosphorus Inputs to the Lake

Waterfowl Feces. Geese dropping add phosphorus and nitrogen to land around lakes and deposit nutrients directly into lakes; perhaps half the droppings enter lakes while geese are floating on or flying over lakes, and half fall on the ground around the lake where geese graze and loaf (Figure 12). In 2020 City staff counted nine goose nests (Figure 13), fewer than in previous years, perhaps due to oiling of eggs as a population control measure.

For modeling phosphorus loading (see below), duck body mass was converted to goose units. Literature and AES's own data were used to estimate the quantity of droppings and phosphorus per goose. The model used counts by City staff to arrive at an estimate of 75 geese being present in all months except July, when 115 geese were counted, including young. In late October 2020, 140-150 geese were observed in the southeast park, presumably representing local geese and others that were congregating prior to migration.

Figure 12. Hawrelak Lake south shore, with evident high density of goose droppings

Figure 13. Goose nesting locations on Hawrelak Lake, 2020

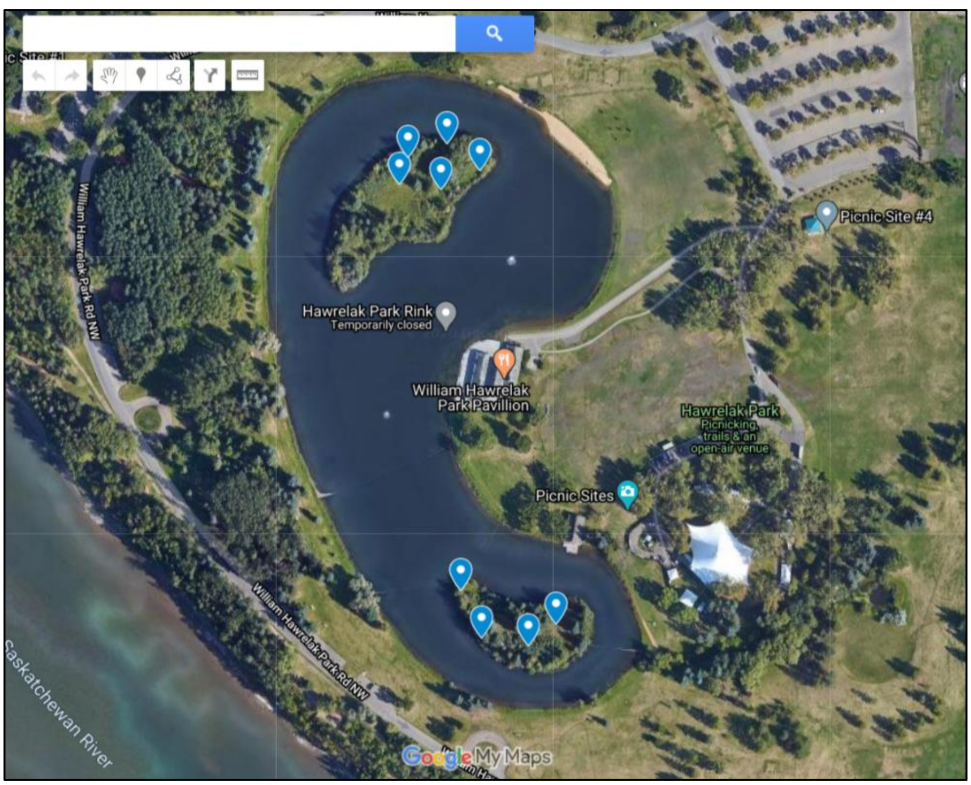


Figure 14. Geese (150-200) on Hawrelak Lake ice, October 5, 2020

Lake Sediment. Lake sediment accumulates on lake bottoms, especially in eutrophic lakes like Hawrelak. (Organic-rich lake sediment is called *gyttja*.) Contributors to sediment in Hawrelak Lake are waterfowl droppings and feathers, algae that died and fell to the lake bottom, and sediment pumped into the lake from the river. The life cycle of cyanobacteria includes a dormant form (spores or akinetes) that overwinters in bottom sediment.

Removal of bottom sediment occurred in 1999 and 2013 to achieve the acceptable depth of 1.5m for the triathlon course. Sampling by City staff in 2020 established there is on average 3.5 cm of loose sediment across the lake bottom, but as much as 8 cm in some locations. If sediment was removed in 2013, roughly 0.6 cm of sediment has accumulated each year since.

In 2020, City staff also collected data on the phosphorus concentration of the sediment, using the same locations as for water quality sampling, plus four locations on the lake's west and east sides (Table 2). The average total phosphorus concentration in lake sediment was 12.4 mg/L, ranging from 3.0 in the northwest lake corner to 21.8-23.2 near the west shore of the lake.

When phosphorus containing sediment exists in a lake that freezes in winter, the lower oxygen levels in the sediment lead to the production of soluble (or dissolved) phosphorus. When ice-out occurs, the soluble phosphorus is mixed by wind and currents with the rest of the lake water, resulting in lake wide high total phosphorus concentrations until the phosphorus is consumed by plants and algae or becomes attached (adsorbed) to bottom sediment. Spring water quality sampling at ice-out in 2021 will establish whether an ice-out pulse of phosphorus occurs in Hawrelak Lake.

Table 2. Hawrelak Lake phosphorus concentrations in bottom sediment

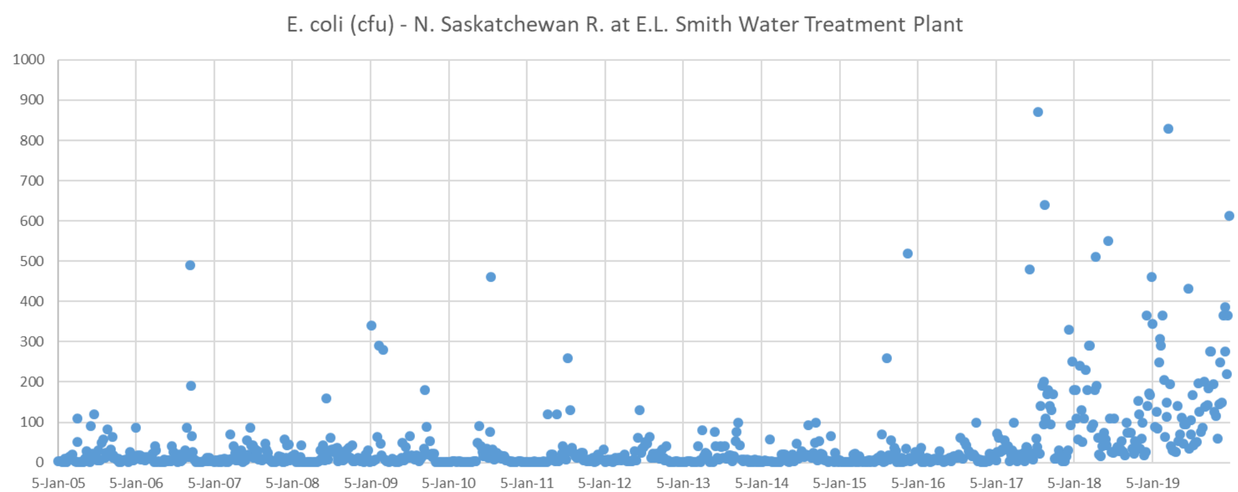
Sediment Sample	**Sed 1**	**Sed 2**	**Sed 3**	**Sed 4**	**Sed 5**
Sediment Location Name	NW Lake ("River Inlet")	NE Bay	Lake Centre	South Lake	Stream Inlet
Total Phosphorus (ml/L)	3.04	14.4	9.44	4.52	16.8
Sediment Sample	**Sed 6**	**Sed 7**	**Sed 8**	**Sed 9**	**Average**
Sediment Location Name	East Shore - North	East Shore - South	West Shore - North	West Shore - South	**Entire Lake**
Total Phosphorus (ml/L)	6.24	12.2	23.2	21.8	**12.4**

River Water. Often in June and before triathlons in summer, water with potentially high phosphorus concentrations (>0.03 mg/L) is pumped from the North Saskatchewan River to fill the lake. The pump is west of the lake near the river and the outfall into the lake is near the center of the lake's west shore.

There is also a standpipe in the lake's southwest corner which can be used, with pumping, to lower the water level in the lake.

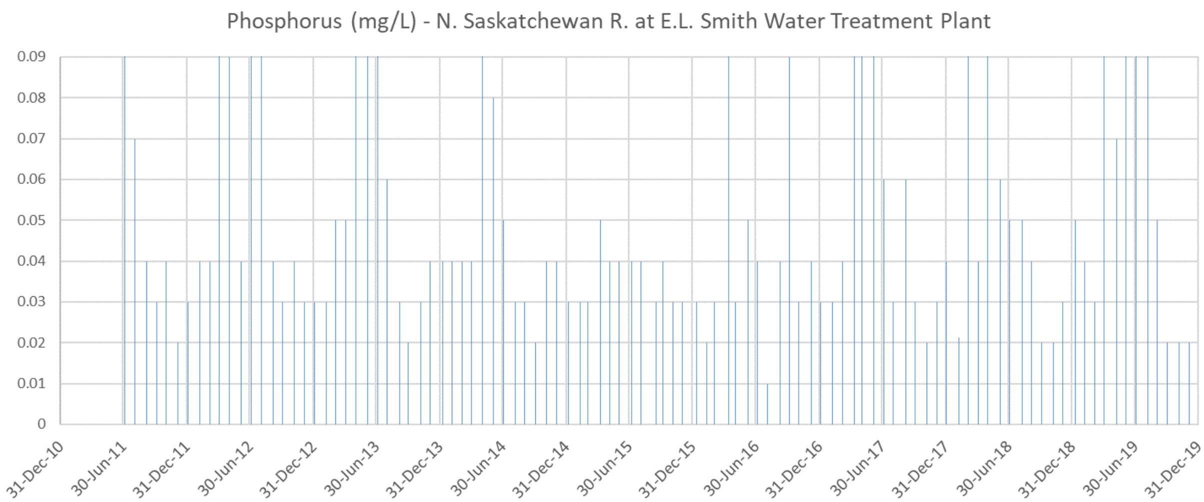
The quality of river water to fill the lake is changing and will continue to change. Climate studies detect and predict an increase in winter and spring precipitation in the region, which will increase the amount of runoff entering the river from its tributaries. *E. coli* bacteria levels in the river have noticeably increased since 2016, as detected in water quality testing at the intake of the E.L. Smith Water Treatment Facility (Figure 15).

Figure 15. E. coli bacteria levels in the N. Saskatchewan River upstream of Hawrelak Park, 2005-2019



Phosphorus levels in the river are usually higher than that at which algae blooms are likely to occur (0.02-0.03 mg/L), given warm water temperature (e.g., see Walker & Havens 1995, Carvalho et al. 2013). Only 10 percent of samples (11 of 111, 2010-2019) were below 0.03 mg/L (Figure 16). Dates and periods of high phosphorus in river samples correspond to dates and periods of elevated sediment and turbidity.

Figure 16. Phosphorus concentrations in the N. Saskatchewan River above Hawrelak Park (2010-2019) (concentrations above 0.09mg/L were truncated for graph readability)



Land Surface Runoff, including Lawn Fertilizer. Fertilizer is applied in three general locations in spring and usually fall (see Figure 2), using 40-3-3 (N-P-K) and sometimes 24-6-12 fertilizer. Near the east lakeshore, 8 bags of fertilizer and 100 cu yds of compost are applied. On lawns away from the lake, 56 bags of fertilizer and 280 cu yds of compost are applied most years. An area east of the beach receives only compost.

Soils were tested to determine character and bulk density, which can influence water quality. Appendix 2 presents the Soil Analysis Summary for the project. Nine soil testing areas of similar vegetation cover were sampled in July 2020 for chemical constituents and bulk density (Figure 17).

In each testing area, two soil samples from the top 10 cm of the soil profile were taken and mixed and one bulk density sample was obtained. Samples were sent to a laboratory that analyzed total phosphorus, total Kjeldahl nitrogen, percent sand-silt-clay and bulk density.

The total phosphorus and Kjehldahl nitrogen levels in all areas greatly exceeded typical levels in soils (Table 3, Appendix 2). This suggests the soil is a potential source of soluble phosphorus and nitrogen, which could be borne to the lake in shallow groundwater, assuming the lake's clay liner is breached or that groundwater movement is lateral rather than vertical. Sand-clay percentages indicate the soils are clay loams to loams. The dry bulk density (0.65 to 0.95), however, was consistent with loam soils.

Figure 17. Hawrelak Lake Park soil sampling areas (1-9)

Table 3. Soil character in the watershed of Hawrelak Lake

Soil Constituent	Unit	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
Texture		Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
Sand	50 µm - 2 mm % by wt.	33	28	30	28	25
Silt	2 µm - 50 µm % by wt.	36	39	37	40	46
Clay	<2 µm % by wt.	31	33	33	32	29
Phosphorus	mg/kg	1340	1010	1470	1520	1050
Total Kjeldahl Nitrogen	mg/kg	7510	5700	8280	8380	7850

Soil Constituent	Unit	Soil 6	Soil 7	Soil 8	Soil 9	Average
Texture		Clay loam	Clay loam	Loam	Loam	
Sand	50 µm - 2 mm % by wt.	33	28	32	34	**30**
Silt	2 µm - 50 µm % by wt.	40	41	44	40	**40**
Clay	<2 µm % by wt.	27	31	24	26	**30**
Phosphorus	mg/kg	1060	1380	860	850	**1171**
Total Kjeldahl Nitrogen	mg/kg	6210	10000	5200	5420	**7172**

Minor Potential Sources of Phosphorus

- **Sodium Hypochlorite.** In preparation for ITU events, City staff apply on average 15,000 L (12 percent solution) of sodium hypochlorite to the lake. The actual amount ranges from several thousand to 50,000+ L, depending on the year. The effect of chlorinating the lake has been to reduce macroinvertebrate and algae-eating zooplankton populations and eliminate limneids (snails and other gastropods) from the lake ecosystem. Most formulations of sodium hypochlorite contain phosphorus, but the brand used by the City does not contain phosphorus.

- **Bare Soil**. Steep, bare banks around lakes are a source of phosphorus as the unstable slope angle allows soil to erode into the lake. Soil is a source of phosphorus. Photographs taken around the lakeshore on July 30, 2020 did not indicate extensive or significant bank erosion, but the high lake level may have concealed locations where banks were eroding.
- **Irrigation Water**. City staff are discussing the pros and cons of using potable City water rather than lake water for irrigating turf. At issue is the use of irrigation water from a "stormwater basin", which is the regulatory designation of Hawrelak Lake since it receives runoff from its surroundings. Irrigation water from stormwater basins must be managed to meet City and Alberta Health standards related to bacteria. Pros of irrigating with lake water are:
    - Lake water is more environmentally benign than using potable City water.
    - Lake water level can be easily and quickly lowered by irrigating turf, rather than seeking a permit to discharge to the river. High water levels can flood the Pavilion, risking damage to the heated floor, so time is of the essence when water levels must be lowered.
    - In future years, EPCOR Utilities will be required by Alberta Health to add 1 mg/mL of orthophosphate to potable water as a lead abatement strategy. This has the potential to add phosphorus to soils already rich in phosphorus.

  Pros of irrigating with potable City water are:

    - Reduced cost due to the avoided need to replace or maintain the existing irrigation pump or install an ultraviolet filtration system, which may be deemed necessary to comply with City and Alberta Health standards.
    - Public health concerns would be eliminated; management strategies, however, may also reduce public health concerns without the use of a UV filter.
- **Winter Road Safety Materials.** Because storm sewers draining impervious surfaces discharge to the river, no materials applied to roads reach the lake. Roads in the park, however, only receive sand that is swept up in spring. Small amounts of salt are applied to the ice castle's walkways but swept up after the ice melts.
- **Pet Wastes.** No pets are allowed in the park and those that bring pets in generally pick up after their pets.
- **Sanitary Sewer Leakage.** There is no sanitary sewer line running beneath or near the lake.
- **Lawn Clippings and Leaves.** Organic debris is a source of phosphorus. City turf management practices, however, generally keep lawn clippings and leaves out of the lake.

City Management of Water Quality in the Lake

The City's approach to managing water quality in Hawrelak Lake has evolved over time. Several studies have been completed to understand how best to manage water quality, in particular to prepare the lake for ITU events. A review of past City plans suggests that solutions have been directed at symptoms of poor water quality—algae blooms, high bacteria counts—rather than the root causes. The City wisely embarked on this water quality feasibility study in order to identify and address the root causes of poor water quality in Hawrelak Lake, which the City believes will lead to a holistic, ecologically based solution.

Past City solutions and practices to addressing poor water quality in the lake are:

- **Geese and Other Bird Control.** The City tested various techniques to control geese and gulls in the park and learned that hazing with dogs was most effective, but the public raised objections around concerns for animal welfare. Fencing at the lakeshore worked well because geese did not move from the lake to adjacent turf when there was this barrier. Obviously, fencing also limited people's access to and interrupted their visual enjoyment of the lake. Moving nests and geese away from the lake failed: geese simply returned to their previous haunts. Oiling eggs as a birth control measure appears to be reducing goose numbers in the nesting season.
- **Lake Sediment Removal.** Dredging the sediment in 1999 and 2013 was done for ITU events and is planned for future events to meet ITU lake depth standards. This would temporarily have reduced the amount of dissolved phosphorus released into the water at spring ice-out.
- **Reduced River Water Pumping**. The City repaired breaks in the clay liner in 1999 and perhaps 2013, which slowed leakage losses from the lake and reduced the need to pump lake water to top off the lake for ITU events.
- **Annual Application of Sodium Hypochlorite.** Since 2015, cyanobacteria blooms and elevated *E. coli/Enterococcus* bacteria levels have been observed. To manage this, each year the City now applies sodium hypochlorite—a form of chlorine—to reduce *E. coli/Enterococci* bacteria and cyanobacteria before to ITU events. Silt curtains and baffles are installed to separate the southern quarter of the lake from the northern part, where the swimmers are. The northern part is then treated. The baffles also confine paddle boats to the southern lake. After three applications over a few days, bacteria and cyanobacteria levels meet ITU event standards.
- **Invasive Aquatic Species Control.** As in many North American lakes, the invasive Eurasian water milfoil (*Myriophyllum spicatum*) is a problem at Hawrelak Lake. This species produces large amounts of vegetation in eutrophic lakes, such as Hawrelak. The vegetation prevents boaters and swimmers from moving freely. When it dies, it falls to the lake bottom and decomposes, consuming oxygen and adding to the accumulation of lake bottom sediment. The aquatic herbicide, Diquot, has been applied in mid-June to reduce Eurasian water milfoil abundance.
- **Fountains.** The three fountains on Hawrelak Lake are placed for aesthetics purposes. Fountains and other mechanical water quality improvement devices are discussed below.

Modeling of Water Quality Issues

A review of data to identify the likely sources of phosphorus loading to Hawrelak Lake identified five major sources. These sources were incorporated into a GIS- and spreadsheet-based model used to estimate the amount of phosphorus entering the lake from each source. The major sources were:

1. Waterfowl feces directly into the lake and on the ice
2. Lake sediment phosphorus release during spring ice-out
3. River water pumping to top-off the lake before the ITU
4. Land surface runoff
5. Fertilizer runoff

The following summarizes the methods used to estimate end-of-month concentrations of total phosphorus (TP) in Hawrelak Lake. The model estimates the volume of water and TP contributions from the various sources to the lake and calculates a volume-weighted average for each month starting in April 2020. The model is primarily spreadsheet based.

1. **Waterfowl Feces.** Hawrelak Lake is a natural habitat for waterfowl (primarily geese). The TP contributions from goose feces was estimated based on bird counts from the City of Edmonton, estimates of individual bird feces TP loadings, and the lake volume. Per-bird feces loadings and phosphorus content were estimated using values from an algal control study for a similar lake in Everett, Washington (Snohomish County, Washington 2020). Considering those data, it was assumed that Hawrelak Park geese weighed 4.8 kg, 2.28 percent of their body weight was deposited as feces each day, and the TP content of the feces was 1.5 percent. It was also assumed that 50 percent of all feces produced is deposited directly into the lake and the other 50 percent does not reach the lake, and that waterfowl were present from April through November.
2. **Lake Sediment Phosphorus Release.** The modeled timeframe begins in April, the typical month when ice-out occurs and soluble phosphorus is released into the water column available for algae and plant growth. Release rates were estimated from the study "Prediction of Phosphorus Release Rates from Total and Reductant-Soluble Phosphorus in Anoxic Lake Sediments" (Nurnberg 1988). Release rates for Hawrelak Lake were estimated by averaging the six highest release rates from the eight lakes in the study, or 4.6 TP/m^2/day. The model assumes that sediment TP is released only during ice-out in April and no other month.
3. **River Water Pumping.** The North Saskatchewan River, with variable TP concentrations, is used to top off the lake and meet the ITU dept requirement. This occurs around June of each year. The volume of river water pumped into the lake was estimated from data provided by the City. The summer background TP concentration of the River was averaged based on measurements taken between 2009 and 2019 at the E.L. Smith Water Treatment Plant (EPCOR 2020), approximately 12 km upstream of Hawrelak Park.
4. **Land Surface Runoff.** Runoff flows into Hawrelak Lake during medium to large storm events, with its sediment and adsorbed phosphorus, are carried downslope to the lake where mixing occurs. Historic rainfall data (Government of Canada 2020) and land use characteristics were used to estimate runoff contributions to the lake using the SCS Runoff Curve Number Method (SCS 1997 Update). Runoff-producing rainfall events occur during the months of May through September, with a July peak. The WinSLAMM model (Voorhees and Pitt 1997) was used to estimate concentrations of TP in runoff. WinSLAMM is used primarily in the Upper Midwest United States to identify and quantify sources of pollutants in urban stormwater runoff and to evaluate management alternatives for reducing pollutants.
5. **Fertilizer Runoff.** Fertilizer is applied to portions of the Hawrelak Park lawn every spring and fall (assumed to be in April and September). According to the City of Edmonton, forty-eight (48) 25 kg bags of 3 percent phosphorus fertilizer are applied for each fertilization. Based on Kussow (2004), 1 percent of the applied fertilizer is estimated to be lost to runoff. Runoff volumes

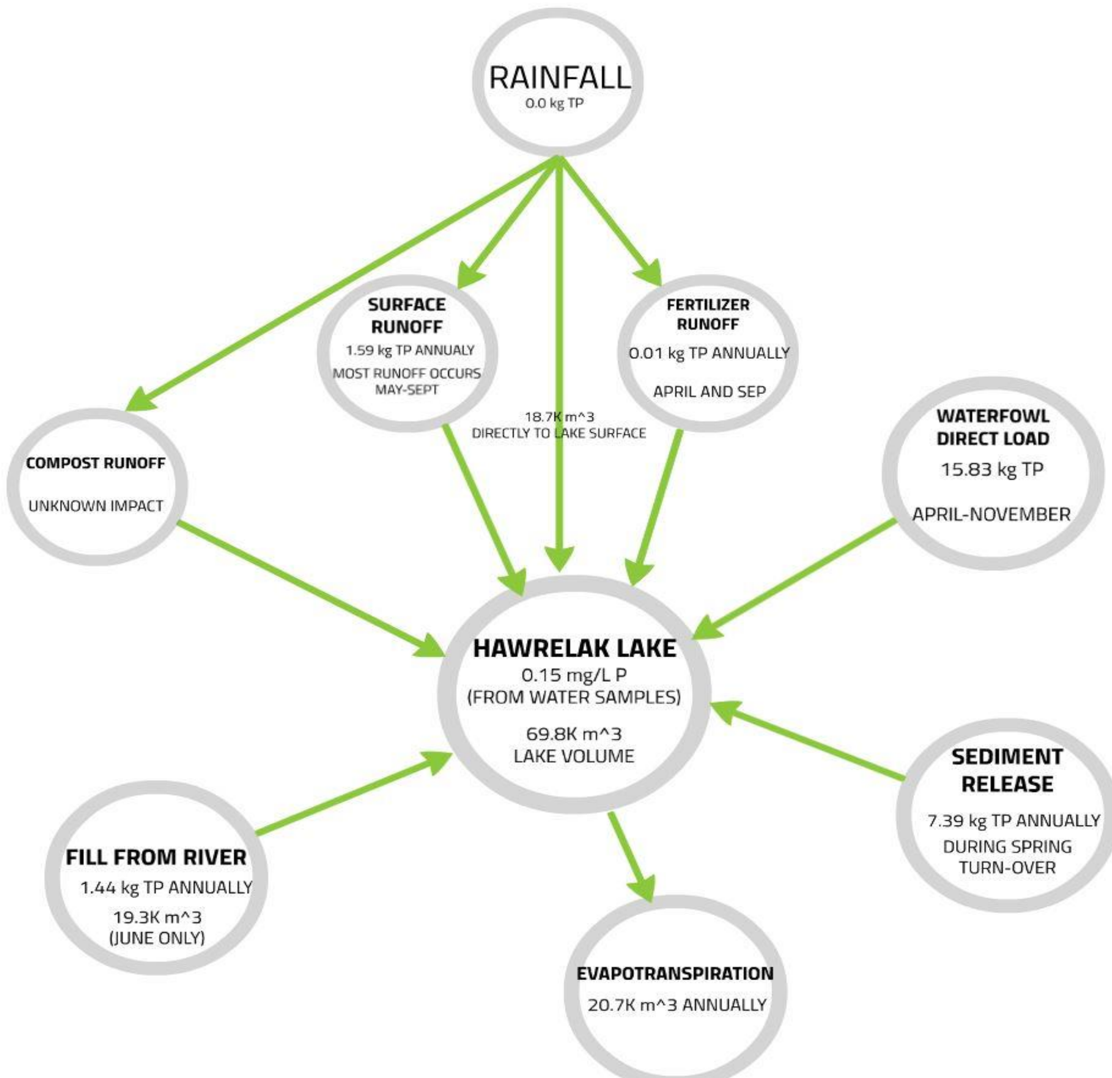
described in the previous section and TP losses in mass units were used to determine TP concentrations of fertilizer runoff to the lake.

Rainfall to Lake Surface

The model assumes the rainfall phosphorus concentration is 0.00 mg/L (Root et al. 2004) and thus makes no contribution of TP to Hawrelak Lake. Historical rainfall data (Government of Canada 2020) was used in the model to calculate the volume of rain falling directly onto the lake surface each month, diluting the TP concentration to some degree. Conversely, evapotranspiration (ET) accounts for water loss from the lake; ET was estimated from values taken from Alberta Environment and Sustainable Resource Development (2013).

The sources and amounts of phosphorus and other factors in the model are summarized in Figure 18.

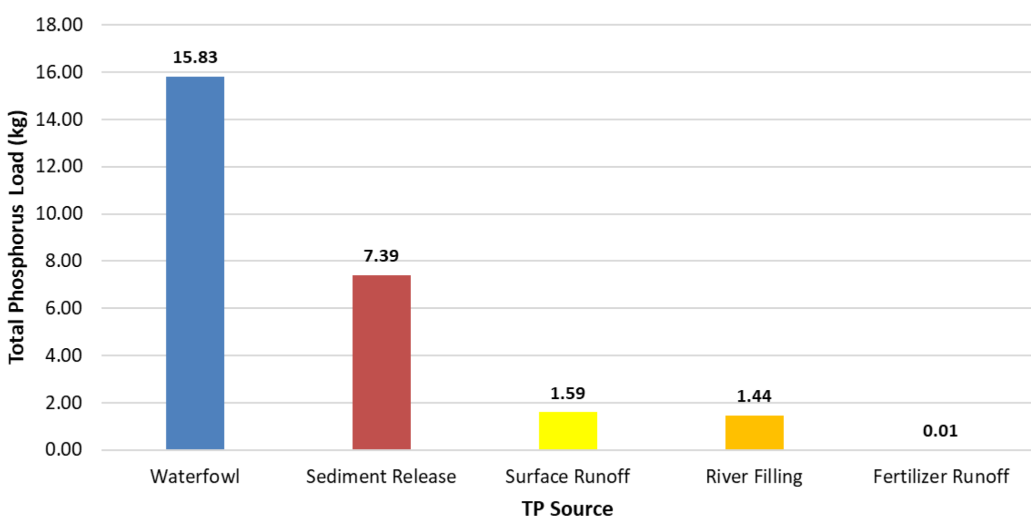
Figure 18. Hawrelak Lake phosphorus loading model



The model indicated that waterfowl droppings directly into the lake are the largest source of phosphorus to the lake (Figure 19). The release of phosphorus from the 3.5 cm of bottom sediment at spring ice-out is another large source. Together these sources contribute 23.2 kg of phosphorus, or 88.4 percent of the annual phosphorus load to the lake. For comparison, an instantaneous loading 1.74 kg of phosphorus to the lake would produce a phosphorus concentration of 0.025 mg/L, the target concentration to ensure a low chance of an algae bloom. Waterfowl and sediment loading exceed this by an order of magnitude.

Surface land runoff, filling the lake with river water, and fertilizer runoff were minor contributors overall. Pumping river water into the lake, however, has the potential to temporarily increase phosphorus concentrations in June when water temperature is rising and river flows and phosphorus concentration levels are high. In June water levels in the river tend to be higher than later in the summer due to snowmelt in the Rocky Mountains and spring/early summer rains. High phosphorus and sediment concentrations are associated with higher river levels.

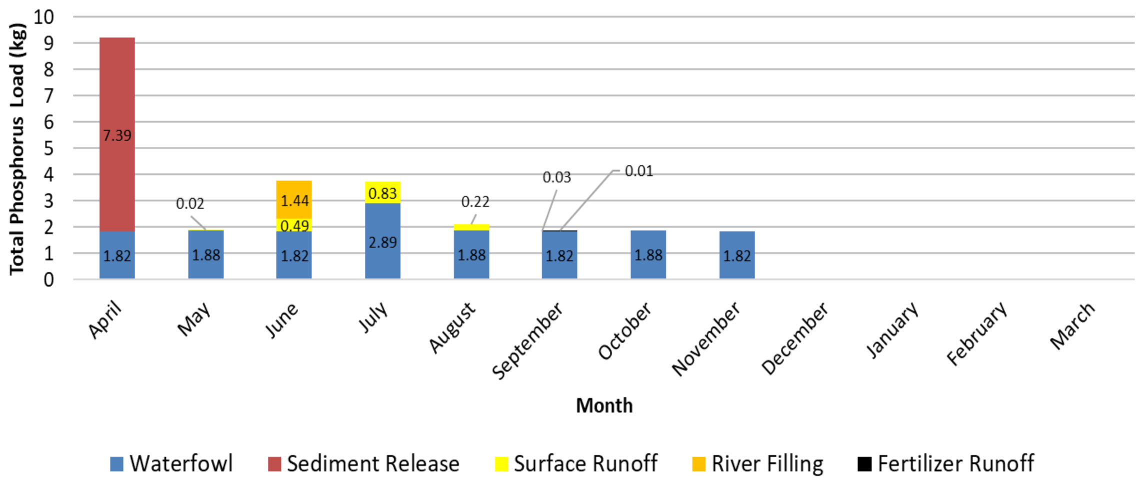
Figure 19. Total annual phosphorus loading to Hawrelak Lake from different sources



The concentration of phosphorus in the lake changes over the course of a year due to the timing of the source's effects (Figure 20). The year begins at ice-out when bottom sediment releases a pulse of phosphorus after a winter of anaerobic bacterial activity in the bottom sediment. Because water quality sampling began in June, empirical evidence of the ice-out phosphorus pulse is lacking, but is a common phenomenon in temperature zone lakes. (The City will begin sampling again at ice-out in March or April to detect this pulse.) In theory, phosphorus concentrations should be high in April after ice-out, but cold water temperatures reduce the chance of algae blooms. Unless all the phosphorus is taken up by plants, algae, and sediment, the high phosphorus concentration may carry over into later months.

Waterfowl—primarily geese, but also ducks in smaller number and size—arrive while ice is still on the lake to set up nesting territories, build nests, and court. At ice-out their droppings fall into the lake. For the remainder of the year and into the fall, even after ice forms, waterfowl drop feces over the lake.

Figure 20. Monthly phosphorus loading to Hawrelak Lake from different sources



The loading amount from waterfowl varies slightly month to month, with more waterfowl present in early summer after nesting, and again in fall as waterfowl congregate and stage in the park before migrating south. Regardless, each month the phosphorus load from waterfowl exceeds the loading of 1.74 kg that produces the target concentration of 0.025 mg/L of phosphorus in the lake.

The continuous waterfowl phosphorus inputs combined with warm lake water in August and September can stimulate blooms of microscopic colonial algae (*Scenedesmus, Desmodesmus*, etc.), which tints the water green. Filamentous green algae (*Spirogyra, Cladophora,* etc.) may form on rocks or accumulate on the surface of the lake, often driven by waves into the lake's shallows. Colonial and filamentous green algae do not pose health risks to humans or wildlife but can create unattractive conditions for swimmers. More concerning is blue-green algae, or cyanobacteria, which does pose a health risk due to excreted toxins and for which Alberta Health and Health Canada have established a swimming standard. The chance for a cyanobacteria bloom is reduced when phosphorus concentrations are below 0.025 mg/L.

Rainfall patterns affect the timing of river filling, which usually occurs in June or July. Phosphorus inputs from surface runoff and fertilized turf are affected by rainfall—summer thunderstorms having the potential to send runoff to the lake. In general, though, surface runoff and fertilizer pollution are minor sources of TP. River pumping is more influential as it can rapidly tip the balance from below 0.025 mg/L concentration to above.

Alternative BMPs to Address Water Quality Issues

In order to arrive at a preferred suite of best management practices (BMPs) to address the poor water quality in Hawrelak Lake, AES compiled all BMPs that could be applied or had been tried by the City. Aes Focused on BMPs that address sources of phosphorus in a shallow lake, rather than treating symptoms as has been recommended in past reports (e.g., continue to chlorinate the lake and install a piped velocity mixer system, as recommended by Associated Engineering (2017)). The list is organized by the categories in the model, in the order of the significance of their phosphorus loading. Goose management and lake sediment, contributing the most phosphorus, are at the top of the list (Table 4).

Table 4. Potential BMPs to improve water quality at Hawerelak Lake

BMP/Model Category	BMP Technique	TP Reduction Effect[1]	Est. Cost[2]	Comments
Goose Management	Goose hunt/other fatal actions	3	3	Potential public opposition
	Active chase by dogs, raptors	3	3	potential public opposition
	Densely plant shrubs on islands	2/3	3	Reduce area of nesting habitat
	Sound or other deterrent	?	2/3?	Unknown effectiveness of sound; birds habituate
Lake Sediment Management	Remove sediment by dredging to clay liner	3	1	City has budgeted for this
	Alum treatment	3	2	Repeat every 8-15 years
	Sediment vacuum to prairie biofilter	2	1	High labor costs
	Beneficial bacteria/enzyme application	2	1	Typically involves frequent repeat applications
Land Runoff Management	Plant shoreline buffer on land	1/2	3	Native seeding 25ft wide; aids goose management
	Plant emergent vegetation in water at lake edge	1/2	2	Live plants at water's edge; aids goose management
	Bioinfiltration/Raingarden/Bioswale	1	2	Only around buldings & plazas next to lake
	Soil Quality Restoration (SQR)	1/2	3	Apply lime, iron, organic matter, etc. Plant & harvest deep-rooted herbaceous plants
	Treat irrigation water to remove P (bioswale, etc.)	1	2	City water treated with orthophosphate for lead
Manage River Water to Fill Lake	Pump during low-turbidity/phosphorus periods	2	3	Monitor turbidity, change operations
	Level-spread water with sheetflow to lake	3	2	Use ravine; swale/berm at shoreline
	Iron-enhanced sand filter (IESF)	3	1	Use ravine & water flow paths
Fertilizer Runoff Management	Use no-phosphorus fertilizer	1	3	Soil phosphorus and nitrogen levels already are very high
Lake Water Treatment (Not in Model)	Treat pond/stream water (IESF in stream is best)	2	1	Adapt pumped lake-pond-stream system
	Diffusers/aeration	1	2	Low effectiveness in shallow lake
	Additional fountains	1	2	Do not recommend

[1] 1=low, 2=medium, 3=high
[2] 3=low, 2=medium, 1=high

The AES and the MBAC team met with City staff and the Technical Advisory Committee (TAC) for the Hawrelak Park Rehabilitation Project to evaluate potential BMPs. The TAC provided feedback (Appendix 3). AES then met with the MBAC team and the Park Rehabilitation project manager, Rachel Dumont, to follow up on the TAC discussion and define a short list of BMPs that would provide a holistic solution to the root causes of poor water quality in Hawrelak Lake.

Goose Management. Hunting, other fatal actions, and active chasing by dogs and raptors were rejected due to potential public opposition on an animal welfare basis, based on the City's past experimentation with these techniques. Sound and other sensory deterrents were rejected due to their unknown effectiveness.

Lake Sediment Management. The City previously rejected alum treatment due to high cost, temporary effects, and questions around the long-term effect of adding aluminum to the lake. The City previously rejected the application of beneficial bacterial and enzyme applications as not appropriate for Hawrelak Lake. Considerations included cost, its temporary nature, and the regulatory requirements of Health

Canada for adding bacteria to public waters. Vacuum removal of sediment was rejected due to logistical challenges and novelty of the approach; while it is being tried elsewhere, more needs to be learned about its cost, level of effort, and effects.

Land Runoff Management. While not rejected as a BMP for the park, biofinfiltration methods—raingardens, infiltration basins, bioswales—are best used in this project to reduce phosphorus and other pollutants that originate at the Pavilion and boat rental area. The MBAC team will develop this BMP as it refines landscaping plans for these locations.

Soil Quality Restoration (SQR) improves turf quality and reduces the need for fertilization and irrigation, but because runoff contributes little to the lake phosphorus loading and can be addressed by other BMPs that provide multiple benefits (see shoreline buffer/emergent planting below), it is not a recommended BMP to address poor water quality. On the other hand, improving the quality of soil in Hawrelak Park may be good in its own right and reduce the need for fertilization and irrigation of turf. (For methods to improve turf, see Appendix 2.) Irrigation water from the lake, which is high in phosphorus, has the potential to return to the lake in overland and subsurface lateral flow. However, the distance between most irrigated areas and the lake, the judicious use of irrigated water, the high potential cost of removing phosphorus before irrigation, and other reasons discussed, removes this BMP from further consideration.

Manage River Water to Fill Lake. Picking the right time to pump low-phosphorus river water into the lake requires planning and daily monitoring. City staff initially balked at this challenge, given existing responsibilities. The alternative to timing river water pumping during ongoing park operations is to construct a surface phosphorus management structure for river water. AES proposed moving the outfall of the pumped river water to the head of a small ravine on the west side of the lake, and constructing a series of water quality treatment cells in the ravine with a level spreader along the lakeshore that would further treat river water and allow diffuse infiltration and overflow along the lake's west side (see Appendix 3 for details). As a further measure, an iron-enhanced sand filter that removes phosphorus would be installed. The costs and ongoing maintenance of this set-up were rejected as more onerous than asking City staff to develop a plan to monitor river water and time its pumping to both meet the lake level requirements for ITU events and the need to pump only low-phosphorus river water.

Fertilizer Management. The City already uses a low phosphorus fertilizer. Given the high phosphorus content of the soil, a lower phosphorus fertilizer may still be appropriate. In combination with SQR, the need for fertilizer on an annual basis may be reduced. It is not the charge of this water quality feasibility study to evaluate the need for SQR or advance methods to achieve it.

Lake Water Treatment. Initially City staff and the Advisory Committee proposed using the pond-stream system to recirculate and clean lake water. On further consideration, it was understood that this would treat a small volume of water at high cost. While evaluating this BMP, however, it was discovered that *Enterococci/Streptococci* bacteria levels in the southeast corner of the lake near the pond-stream outlet rose significantly in late summer and fall of 2020, greatly exceeding the regulatory standard. For this reason, the focus on the pond-stream system changed from phosphorus removal to reducing bacteria. Details are discussed elsewhere. Other in-lake water treatment options, including those not listed, were rejected. For instance, an algicide addresses the symptoms, not the cause, of poor water quality and introduces a chemical to the lake that is not necessary if other BMPs are employed.

Diffusers, Aeration Devices, and Fountains. Aeration and mixing of lake water by mechanical devices has been offered as a way to reduce phosphorus concentration in surface waters and increase rates of sediment decomposition and phosphorus consumption by lake biota. However, Hawrelak Lake's shallow depth enables wind to mix the water, resulting in a relatively homogeneous waterbody, as seen in the similar TP levels across the lake throughout the growing season. Because the water is uniform in phosphorus concentrations and likely temperature and oxygen levels, the reason to install these devices is eliminated.

Details on the effectiveness of these devices is provided despite their lack of utility at Hawrelak Lake. Manufacturers of fountains and diffusers state that these systems improve water quality, empirical studies supporting such statements are sparse. AES conducted a literature review of mechanical water quality devices and concluded they have limited to no value for water quality improvement in most applications. A large amount of equipment is required to treat a large volume of water and achieve the minimal benefits these devices purport to deliver.

Fountains primarily function as a water feature that some find appealing. Fountains typically recirculate water, drawing water from near the surface and spraying it into the air. This provides some aeration of local surface water but does little to aerate most of a basin's water volume, including deeper levels where aeration would be most beneficial. Fountains and diffusers can agitate the water surface and push algae or vegetation away from the spray/bubble zone. Fountains may limit the breeding of some mosquito species and reduce potentially toxic bloom of blue-green algae (cyanobacteria) in small ponds, but it is not clear if such benefits would be realized in Hawrelak Lake.

Diffusers are more efficient than fountains in reducing thermal and chemical stratification and improving dissolved oxygen levels. Higher dissolved oxygen levels in lakes can reduce winter fish kill, increase aerobic microbial decomposition, and increase fish biomass in a pond. Increasing dissolved oxygen throughout a pond can also increase aerobic microbial activity, which reduces the production of hydrogen sulfide by bacteria that do well in low-oxygen environments (anaerobic bacteria). If diffusers are used, fine-bubbled diffusers are more economically efficient than coarse-bubbled diffusers. They have limitations, however, as filters of fine-bubbled diffusers need periodic cleaning and are slower at improving dissolved oxygen levels. If used, diffusers should be elevated above the bottom of the basin in order to limit basin bottom erosion and disturbance of bottom sediments.

In summary, fountains are not a method to achieve water quality improvement. Diffusers may be most useful in deep basins that experience stratification, winter fish kills, lack aquatic species diversity, or emit offensive odors, but are most effective in ponds not lakes. The shallowness of Hawrelak Lake suggests that diffusers would provide little benefit and, moreover, would treat a symptom, not the cause of poor water quality.

Preferred Alternative

On September 17, 2002, the TAC met with the consultant team to discuss irrigation, review the results of the phosphorus loading model, and discuss proposed best management practices (BMPs) for improving water quality in Hawrelak Lake (Appendix 3). On 30 October, 2020, AES and MBAC team met with the City's project manager Rachel Dumont, to refine the conclusions of the TAC so that a cost estimate could be prepared for BMPs that are most likely to be implemented, given park user preferences, the ease of implementation, and the operations and maintenance burden placed on City staff (Table 5).

Table 5. BMPs in Preferred Alternative with Estimated Phosphorus Reduction and Cost

BMP/Model Category	BMP Technique	TP Load Reduction Potential[1]	Likely Install'n. Cost[2]	Likely O&M Effort[3]	Notes
Goose Management	Monitor & remove nests	3	3	2/3	Potential public opposition
	Densely plant shrubs on islands	2/3	3	3	Reduce area of nesting habitat
Lake Sediment Management	Remove sediment by dredging to clay liner	3	1	3	City has budgeted for this; repeat every 5-10 years
	Deepen lake to 2m by excavating below clay liner	2	1	3	Dredge from 1.55m average to 2m average (ITU dive entry depth)
Manage River Water to Fill Lake	Fill lake when turbidity & phosphorus levels are low	2	3	1/2	Monitor in real time E.L. Smith Water Treatment Plant data
Land Runoff Management	Plant shoreline buffer on land	1/2	3	3	Native seeding; 25 ft width; aids goose management
	Plant emergent vegetation in water at lake edge	1/2	2	3	Live plants at water's edge; aids goose management
	Bioinfiltration/Raingarden/Bioswale	1	2	2/3	Only around buildings & plazas next to lake
Fertilizer Runoff Management	Use no-phosphorus fertilizer	1	3	3	Soil phosphorus and nitrogen levels are already very high
Bacteria Management (Not In Model)	Re-landscape & dredge pond & stream area	2/3	2	2/3	Sunlight (UV) reaching pond & stream bottom kills bacteria
	Landscape taller plants/shrubs in staging area near pond	2/3	3	3	100-200 geese stage here in fall; aids goose management

[1] Load Reduction Potential. 3=high, 2=medium, 1=low
[2] Likely Installation Cost. 3=low, 2=medium, 1=high
[3] Likely O&M Effort. 3=low, 2=medium, 1=high

Goose and Lake Sediment Management. The largest sources of phosphorus to the lake are geese and the release of phosphorus at ice-out, accounting for nearly 90 percent of the annual load. While phosphorus release occurs in the spring, it sets the lake up for high phosphorus levels all summer long because geese contribute enough each month to exceed the 0.025mg/L target, below which chances for an algae bloom are greatly reduced. Managing the goose population and removing the average 3.5cm of sediment from the lake bottom are the top priorities to improve water quality in the lake.

Steps to achieve this are summarized below.

- **Monitor and remove nests.** It is relatively easy to monitor and remove nests at the lake edge by foot or canoe. Monitoring must begin while ice is still on the lake in March and early April.
- **Densely plant shrubs on islands.** This will make the island nesting habitat a poor nesting habitat option for most geese, though they may attempt to nest at the edges of islands or along the

mainland shore. (Shoreline plantings discussed below will further discourage geese nesting.) Shrubs will also discourage people from visiting the islands.

- **Remove sediment by dredging to clay liner**. The City is planning and budgeting, to accommodate ITU events, the removal of the sediment from the lake bottom. Controlling geese, preventing algae blooms, and adding river water with no sediment (see below) will lengthen the time between dredging events. Rather than dredge every 5-10 years, perhaps that would occur once every 20-30 years.
- **Deepen lake to 2m.** In discussions with City staff, it was proposed that deepening the lake to 2m—i.e., about 0.5m deeper than the current 1.5m average—would a) increase lake volume, which would reduce phosphorus concentrations given current loading, b) establish the 2m required depth for a triathlon dive entry, and c) lower the lake level, which would help reduce flooding of the pavilion (assuming no groundwater enters the lake due to its clay liner and groundwater depth). This water quality study was not scoped with evaluating the feasibility of this proposal. However, a cost estimate to deepen the lake is provided, assuming 0.5m of material are removed, the clay liner is removed and stockpiled, and the liner replaced with clay added to account for loss and the increased lake bottom surface area. There are several unknowns in this proposal. What material lies below the current lake bottom? Can a 2m lake water depth be maintained while simultaneously protecting the pavilion from flooding? Other unknowns exist, such as groundwater level relative to the potential 2m lake bottom depth.

River Water Management

Phosphorus in river water is a lesser source of phosphorus to the lake than geese and bottom sediment, but when it is pumped to top off the lake for ITU events, it can increase the phosphorus level above the 0.025 mg/L target, raising the chance that an algae bloom will occur afterwards. Pumping river water when phosphorus and sediment levels are low requires monitoring levels in the river daily and anticipating when the lake will need to be topped off to accommodate an ITU event. Daily phosphorus and sediment river data are available from the E.L. Smith Water Treatment Facility just upstream of Hawrelak Park. A City employee would need to be assigned to monitor river conditions and lake water levels and decide when to pump river water into the lake. A water level monitoring device can be installed in the lake which the employee could monitor, along with rainfall, temperature and humidity, to decide generally the week when pumping should occur. The actual date of pumping within that week can be decided based on river conditions. Generally, in April-June river sediment is high and phosphorus is well above the 0.025mg/mL target. The July-August period has lower phosphorus levels, usually 0.02-0.04 mg/L, but some days have higher levels than others. Pumping would occur on a day when the phosphorus concentration is closer to the 0.025 mg/mL target.

Land Runoff Management

Phosphorus loading from surface runoff is the next largest contributor, but not much more than pumped river water. BMPs for runoff are relatively low cost to implement and have a low ongoing maintenance cost compared to more engineered water quality improvement solutions.

- **Plant shoreline buffer on land.** In this BMP a diverse mix of perennial, deep-rooted plants are seeded in a strip from the water's edge and inland 25 feet (Figure 21). Plowing the lake for winter skating and piling and moving snow on the shoreline buffer will not affect the vegetation. The buffer will make the shoreline less attractive to geese, reduce goose droppings around the lakeshore, and filter runoff from nearby mowed turf. This BMP will serve a dual purpose: filtering overland runoff and making the shoreline less attractive to geese, which would reduce the amount of goose droppings near the lake. The public reaction to taller vegetation around the lakeshore will dictate feasibility.

- **Plant emergent vegetation in water.** In this BMP, a mix of native aquatic species is installed as live plants, from the water's edge generally out to 3 feet. Chlorination for ITU events will not affect the vegetation if plant species are chosen for chlorine tolerance. A dense emergent planting will discourage goose nesting at the shoreline. The public reaction to taller vegetation around the lakeshore will dictate feasibility.

Figure 21. Potential island plantings and 25-ft buffer (emergent plants are lakeward of the buffer)

- **Bioinfiltration practices**. No storm sewers from pavement and parking areas discharge to the lake, eliminating that source of phosphorus and other pollutants. The pavilion and boat rental area, however, have rooftop and paving that discharges untreated to the lake. This is a minor source of phosphorus loading, less than any of the sources discussed. On the other hand, installing bioinfiltration practices would model good runoff management. During park renovation, bioinfiltration practices, such as raingardens and bioswales, could be incorporated into the landscaping around the pavilion and boat rental area to remove phosphorus from local runoff before it reaches the lake.

Fertilizer Runoff Management

Fertilizer is widely applied in judicious fashion to discrete turf areas in the park, mostly distant from the lakeshore. As soils in the park already have excessive amounts of phosphorus, switching to a lower phosphorus fertilizer may be appropriate.

In some settings over winter, dissolved phosphorus in soil pore water generated under winter anaerobic conditions may move laterally in shallow groundwater into lakes and streams. If this were occurring at Hawrelak Park, the clay liner around the lake would be a barrier to shallow groundwater moved to the lake from the surrounding landscape.

If desired, the high phosphorus levels in the soil can be reduced by the addition of lime and iron. Under the higher alkaline conditions created by the lime addition, phosphorus binds more readily to iron and soil, which reduces the rate of dissolved phosphorus formation. It may be worthwhile to consider an overall program of soil health improvement that benefits turf growth, rather than focusing on the contribution of phosphorus in subsurface runoff from turf areas to the lake.

Bacteria Management

In general *Enterococci/Streptococci* bacteria counts in Hawrelak Lake water samples in summer, 2020 did not exceed USEPA water quality standard of 61 cfu/100 mL in any one sample (Figure X). (Canadian standards could not be applied as the lab samples were reported in units that do not coincide with the Canadian standard.) Water quality sampling in October, however, detected high counts of *Enterococci/Streptococci* bacteria in the southeast corner of the lake, near the outlet of the stream draining the artificially maintained pond. In addition, bacteria levels were consistently higher here than elsewhere for all water quality samples.

The source of the bacteria is unknown but may be related to the large number of geese that appear to be staging nearby before migrating south. A bacteria source in the pond or stream sediment also could explain the higher bacteria counts here. The stream corridor is shaded. Bacteria are known to persist, once established, in the bottom sediment of shaded streams and be moved downstream in flowing water, especially after storms. Whatever the source, water pumped from the lake through the pond-stream system may be associated with the spike in bacteria counts near the stream outlet to the lake. For that reason, measures that address these two potential sources of bacteria are proposed.

- **Re-landscape and dredge the pond and stream area.** If the pond-stream system harbors bacteria, and if the bacteria are not killed in winter when water is no longer pumped from the lake to the pond, exposing the pond bottom and streambed to ultraviolet radiation in sunlight could kill bacteria in the sediment. The stream, however, is shaded, reducing the amount of sunlight reaching it (Figure 22). Measures to expose the stream to sunlight would include selectively thinning the tree canopy and understory and planting trees away from the stream to compensate for canopy loss. Dredging the pond and stream of sediment could remove that potential source of bacteria. This work could be incorporated into landscaping plans for the Pavilion and vicinity. Before proceeding, the presence and abundance of bacteria in the pond bottom and streambed sediments should be evaluated.

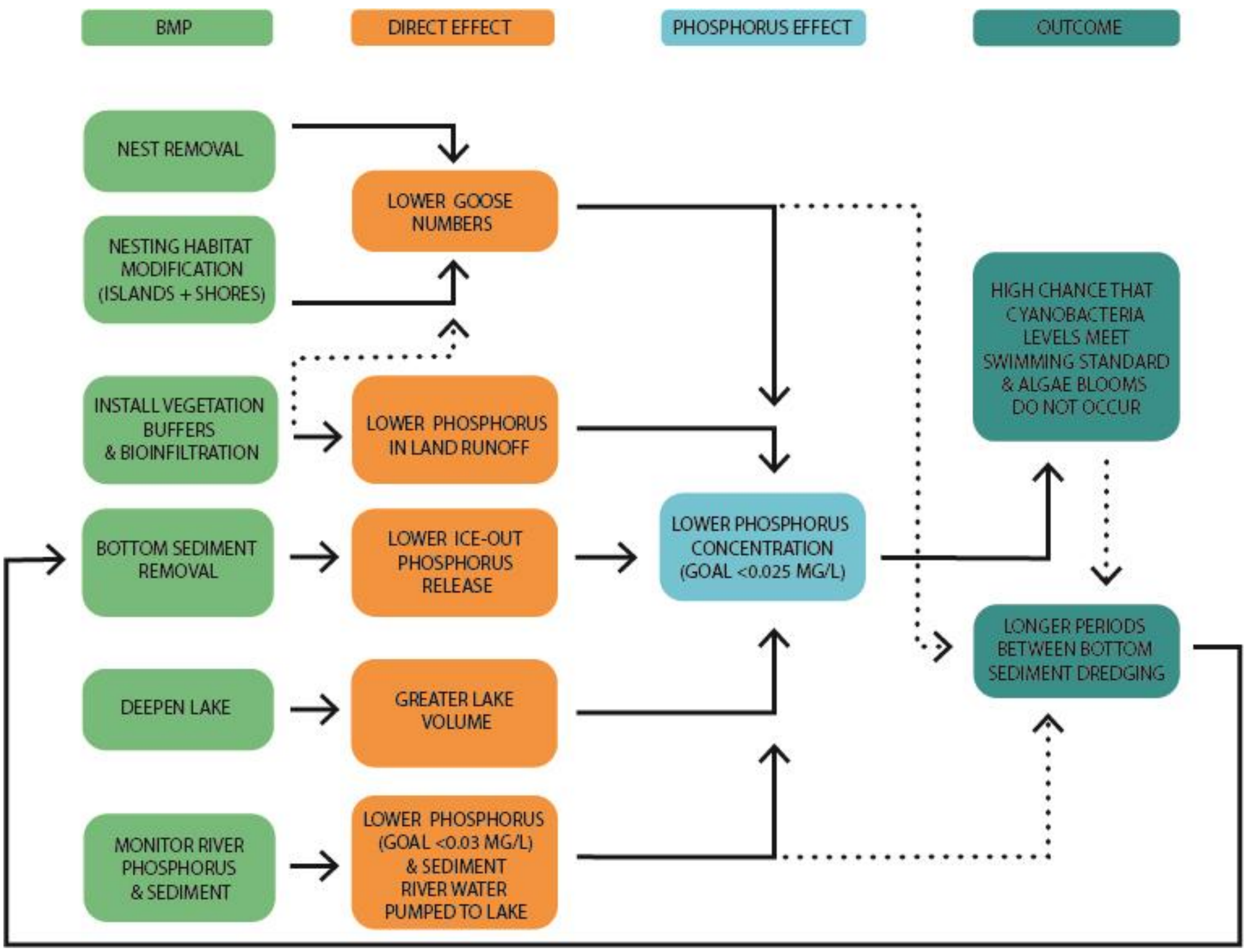
Figure 22. Shaded stream corridor near the southeast corner of the lake

- **Landscape with taller plants and shrubs in staging area near pond.** Before migrating south, large numbers of geese apparently stage in the park, including near the pond, grazing on turf grass and roosting and loafing on the lake and lake ice. While geese graze in different areas of the park, grazing near the pond-stream location may contribute to high bacterial counts in the lake. Increasing the height of vegetation and planting shrubs will create habitat that is not useful or attractive to geese. The boundaries of the taller vegetation area would be integrated with overall landscaping and programming plans for the park.

Summary of Preferred Alternative

The preferred alternative addresses the two largest sources of phosphorus—geese and sediment (Figure 23). It also addresses a large summer contributor of phosphorus—river water pumping. Sediment dredging is an expensive initiative that the City intends to execute for other reasons. The recommended nest removal and vegetation planting to deter geese from nesting on the islands and lakeshores are low-cost practices that should be used in combination to ensure maximum effectiveness. This approach also requires a consistent and creative program of public education and stakeholder mobilization in order to overcome some public preference to not manage the goose population. Operations and maintenance would largely consist of vegetation management and the annual sweep to remove nests.

Figure 23. Schematic summary of preferred alternative



Pumping low-phosphorus river water has great potential to reduce phosphorus loading to the lake at low cost. This necessitates that a City employee be designated who will establish a protocol, monitor river and lake conditions, and make the decision to pump during low-phosphorus periods in the river and in time to fill the lake for ITU events.

Installing a vegetation buffer and emergent planting at the shoreline will treat runoff from adjacent turf and discourage the use of the shoreline and its vicinity by geese. (The City's fencing experiment showed the benefit of barrier between the lake and turf, which a vegetated buffer would also achieve.) This is a low-cost practice with the benefit of largely eliminating phosphorus from goose droppings near the lake. Once established, operations and maintenance of the vegetated buffer would consist of annual inspection and control of invasive and noxious weeds. Improving soil health may be more beneficial for turf management than to reduce the amount of phosphorus reaching the lake in shallow groundwater, given the lake's clay liner.

Water quality sampling revealed that the southeast lake corner experiences high bacteria counts, possibly connected to the artificially maintained pond-stream system and associated with use of the area by geese. The overall landscaping plans for the park could incorporate tree canopy and understory management to increase sunlight reaching the sediment of the pond bottom and streambed, and planting of taller vegetation to discourage geese from staging near this area.

Appendix 1. Inventory of Data Sources

Citation	Source	Description
AECOM. 2014. Tier 2 Risk Assessment: Hawrelak Park- Final. Project # 60330705 (401)	Report	This is a Tier 2 risk assessment for a proposed water park. The gravel pit operated 1950-1967. The park was created by grading and filling with clay soil. Soil tests indicated that Alberta's Tier 1 guidelines for soil remediation would be met. Bedrock is near the surface in the south park--sandstone, mudstone, shale, with scattered bentonite and coal beds. Alluvial sands and gravels are present. The fill is primarily clay and varies from 20cm to 3m. A water table was detected at 1.5m depth near the stream-pond area and in the bedrock, and at 10m depth in the north; discharge of groundwater to the river is expected, rather than to the lake which higher than the groundwater table.
Alberta Environment and Sustainable Resource Development. 2013. Evaporation and Evapotranspiration in Alberta. Alberta, Canada.	Report	Provides data regarding evaporation and evapotranspiration rates for Alberta, including a volume specific to the Edmonton region.
Applied Ecological Services, Inc. 2020. Wm Hawrelak Park Lake: Water Quality in Aerial Photos 2004-2017.	Powerpoint	Series of aerial photographs of Hawrelak Lake from Google Earth illustrating change in lake water color from nearly black to light green, depending on the amount of algae growth in the lake.
Associated Engineering. 2017. Hawrelak Lake Algae Remediation Phase 2 - Concept Development. Project # 2016-3835.	Report	Focused on reducing fecal bacteria and cyanobacteria by physical, biological and chemical means. After evaluating all treatment options, recommended actions were to use multiple controls to control cyanobacteria in lake sediment and use sodium hypochlorite to control blooms. To control bacteria, control wildlife inputs, remove or degrade organic matter with dredging and aerators/mixers, and apply disinfectants. In the long term, the study recommended dredging, lining with a synthetic material, and installation of a piped velocity mixer system on the lake bottom.
Carvalho, L., McDonald, C., de Hoyos, C., et al. 2013. Sustaining recreational quality of European lakes: minimizing the health risks from algal blooms through phosphorus control. Journal of Applied Ecology 50:315–323.	Journal	Studying 800+ European lakes, the researchers suggested that concentrations of total phosphorus above 0.02 mg/L (20 µg/L) were associated with cyanobacteria blooms exceeding the WHO’s low and medium risk thresholds in medium and high-alkalinity lakes. Other factors influence cyanobacteria blooms, such as nitrogen level.
City of Edmonton. 2020. Water Quality Sampling of Hawrelak Lake. Edmonton, Canada.	Excel Sheets & Lab Reports	Two grab samples taken twice each month (June through October 2020) from five sampling locations in the lake. Water samples analyzed for major factors related to lake eutrophication, algae blooms and water pollution: dissolved phosphorus, total phosphorus, nitrate-nitrogen, total suspended solids, E. coli bacteria, and fecal *Streptococci/Enterococci.*

Citation	Source	Description
City of Edmonton. 2020. Soil and Sediment Chemistry & Bulk Density Sampling of Hawrelak Park. Edmonton, Canada.	Excel Sheets & Lab Reports	Nine upland soil testing areas sampled and analyzed for total phosphorus, total Kjeldahl nitrogen, percent sand-silt-clay and bulk density. In addition, lake bottom sediment was sampled from the same locations used for water quality sampling plus four additional locations on the west and east sides of the lake. Sediment samples were analyzed for phosphorus concentration.
City of Edmonton. 2020. Bacteria Counts at Hawrelak Lake. Edmonton, Canada.	Excel Sheets	"Fecal bacteria" samples from Hawrelak Lake 1999-2019, with a focus on testing along the triathlon route
City of Edmonton. 2020. Lawn maintenance activities. Edmonton, Canada.	Map	Spring and usually fall applications; near east lakeside apply 8 bags fertilizer and 100 cu yds. compost; on lawns away from lake to east apply 56 bags fertilizer and 280 cu yds. compost
City of Edmonton. 2020. LiDAR data for Hawrelak Park. Edmonton, Canada.	Digital Data	Bare-ground LiDAR data from City used to create 6 cm contour intervals in park, establish watershed boundaries, and determine surface flow paths.
City of Edmonton. 2019. William Hawrelak Park Rehabilitation Implementation Plan. No. 930731 RPK No. 1818. Edmonton, Canada.	Report	Primarily focused on upgrading infrastructure and human uses of the park.
City of Edmonton. 2016. Bacteria levels in Hawrelak Lake, 2003-2016. Edmonton, Canada.	Excel Sheet	Without chlorination, bacterial levels (*E. coli?*) ranged from 10 CFUs to 520 CFUs, with an average of 153 CFUs. Chlorination reduced bacterial numbers the next day but caused a dramatic increase on the second and third day after treatment. A second treatment thereafter reduced bacterial levels well below the standard of 200 CFU mean over 30 days, or 400 CFU in any one sample. The low levels persisted. The City has since switched the metric from *E. coli* to *Enterococcus*. The City determined that the source of bacteria is exclusively from birds, mostly likely geese; it is not from mammals or other organisms.
Davidson, D.J. 2010. Climate change projections and implications for Edmonton; Discussion Paper 6, The Edmonton Sustainability Papers. University of Alberta, Saskatchewan AB.	Report	Climate models predict warmer winters and springs in Saskatchewan, and wetter summers. Soil moisture will decrease due to interaction of rising temperature and timing of precipitation. Snowpack feeding surface waters will decrease, resulting in earlier spring runoff and less baseflow during remainder of year, a pattern already seen in 100 years of decreasing annual flows in N. Saskachewan River in Edmonton. Heavy rainfall events have been increasing since the 1960s and will continue to do so. These have the potential to cause flooding. Higher cost of living is expected, increasing downward pressure on taxes and reducing government capacity to pay for non-essential services.
EPCOR. 2020. Water quality data at the E.L. Smith Facility.	Excel Sheet	North Saskatchewan River water samples from the facility inlet upstream of Hawrelak Park, assumed to represent river conditions at Hawrelak Park 12 km downstream. Parameters included alkalinity, *E. coli*, total phosphorus, nitrate nitrogen, total suspended solids, and turbidity.
Google Earth Aerial Image. 2017. Hawrelak Lake	Digital Data	Image 8/25/2017 with park boundary; used for land cover map

Citation	Source	Description
Government of Canada. 2020. Canadian Climate Normals 1981-2010 Station Data, Data for Edmonton City Centre A.	Web Site	Precipitation data for the Edmonton region
Jenkins, Mike - City of Edmonton. 2020. Goose activity at Hawrelak Park	Pers. Comm.	Map of goose nests at Hawrelak Park; information on goose numbers in park
Kussow, W.R. 2004. Phosphorus Runoff Losses from Lawns. Better Crops 88 (3).	Journal	Table 3 shows P additions for various applications and associated losses pe acre. The soluble P losses were much less than 1% (AES model used 1% to be conservative). The document found that 98% -100% of phosphorus lost to runoff was from soluble P, not adsorbed/suspended P.
Nurnberg, G.K. 1988. Prediction of Phosphorus Release Rates from Total and Reductant-Soluble Phosphorus in Anoxic Lake Sediments. Canadian Journal of Fisheries and Aquatic Sciences 45(3):453-462.	Journal	Research quantifying release rates of phosphorus in anoxic lakes.
Root, E., W. Jones, B. Schwarz, and J. Gibbons. 2004. Rainwater Chemistry Across the United States. Bereket Haileab, Advisor.	Report	Used for estimating phosphorus concentration in rainfall
Saunders C. & P. Ruffell. 2006. Hawrelak Lake Depth Study.	Unpublished paper	Investigation of lake condition and triathlon water level needs. Lake appeared to have been dredged and the clay liner repacked in 1999. The lake bottom around the triathlon racecourse varies from 622.4-622.6m, with a depth when the lake is "topped off" of 1.2-1.5m. To raise 5 ha of water surface by 6 cm required the addition of 3,000m3 of river water. Over the 2003-2005 seasons, the average added potable water was 12,300m3.
SCS. (1954, 1956, 1964, 1965, 1971, 1972, 1985, 1986, 1993, 1997). 'Hydrology', National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C.	Report	Presents the Runoff Curve Number Method.
Shawn, R.D., P.A. Mitchell and A.M. Anderson. 1994. Water quality of the North Saskatchewan River in Alberta. Alberta Environmental Protection, Edmonton AB.	Report	Water quality study 1985-1989 documenting seasonal change, influences on water quality, and macroinvertebrate community. Above Edmonton water quality is good, deteriorating below due to wastewater discharge. Agricultural inputs above Edmonton were not quantified. Overall, the river met water quality standards and the macroinvertebrate community was not impaired, but productivity increased below Edmonton due to nutrient inputs.

Citation	Source	Description
Snohomish County, Washington. 2020. Sunday Lake Algae Control Plan. Surface Water Management Division, Public Works Department, with technical analysis assistance by TetraTech. Everett, WA.	Report	Plan to address algae blooms in a 49-acre recreational lake.
Summit Environmental Consultants, Inc. 2013. Hawrelak Lake Rehabilitation Environmental Screening Report. Project # 2013-3864.	Report	To prepare for the ITU Grand Final Triathlon, the lake conditions and race standards were evaluated. The lake is a high alkalinity, eutrophic, shallow lake excavated in the mid-1960s in a gravel pit as a "stormwater management basin" but subsequently used as a park feature. Phosphorus concentrations, linked to algae blooms, were over 0.05 mg/L, which is high. Water is pumped from the North Saskatchewan River to "top off" the lake in preparation for annual triathlon events. The two islands are used for nesting by waterfowl. Turf is mowed to within 0.25-2m of the lake water. Design of the deeper channel for triathletes was presented.
Voorhees, J. and B. Pitt. 1997. WinSLAMM (Source Loading And Management Model): An urban area nonpoint source water-quality model for Wisconsin.	Report	Model used for estimating pollutant concentrations in surface runoff.
Walker, W. W. and K. E. Havens. 1995. Relating algal bloom frequencies to phosphorus concentrations in Lake Okeechobee. Lake and Reservoir Mgt. 11:77-83.	Journal	Concentrations of phosphorus below 0.03 mg/L (30 µg/L) were not associated with algae blooms in the littoral zone of Lake Okeechobee, but the relationship was weaker in the deeper open water. Interactions with nitrogen occurred but reducing nitrogen concentrations increases the risk of nitrogen-fixing cyanobacteria blooms.

Appendix 2. Soil Analysis Summary, August 2020

William Hawrelak Park Rehabilitation

Hawrelak Park Water Quality Feasibility Study

Applied Ecological Services, Inc.

Steven I. Apfelbaum

Summary of Soil Chemistry and Bulk Density Sampling at Hawrelak Park

City staff with AES guidance gathered soil samples from Hawrelak Park to understand the constituents and character of soils and their potential effect on the water quality of Hawrelak Lake. Two soil samples from the top 10cm of the soil profile were obtained and combined for analysis in each of nine soil sampling areas at Hawrelak Park (Figure 1). Soil samples were taken in July, 2020. Soil bulk density samples also were obtained in each of the soil sampling areas in the same time period.

Figure 1. Soil sampling areas at Hawrelak Park

The soil samples were analyzed for constituents and character. The total phosphorus and Kjehldahl nitrogen levels in all soil sampling areas greatly exceeded typical levels in soils (Table 1). The sand-clay percent on average type the soils as clay loams, tending towards loams.

Table 1. Soil constituents and character of soil samples at Hawrelak Park

Soil Constituent	Unit	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
Texture		Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
Sand	50 µm - 2 mm % by wt.	33	28	30	28	25
Silt	2 µm - 50 µm % by wt.	36	39	37	40	46
Clay	<2 µm % by wt.	31	33	33	32	29
Phosphorus	mg/kg	1340	1010	1470	1520	1050
Total Kjeldahl Nitrogen	mg/kg	7510	5700	8280	8380	7850

Soil Constituent	Unit	Soil 6	Soil 7	Soil 8	Soil 9	Average
Texture		Clay loam	Clay loam	Loam	Loam	
Sand	50 µm - 2 mm % by wt.	33	28	32	34	**30**
Silt	2 µm - 50 µm % by wt.	40	41	44	40	**40**
Clay	<2 µm % by wt.	27	31	24	26	**30**
Phosphorus	mg/kg	1060	1380	860	850	**1171**
Total Kjeldahl Nitrogen	mg/kg	6210	10000	5200	5420	**7172**

Three key characteristics of the soils at Hawrelak Park can be described from these data: infiltration rate and potential for soils to contribute phosphorus and nitrogen to the lake.

Infiltration rates. Although sand-clay percentages could be typed as clay loams, the dry bulk density (0.65 to 0.95) was consistent with loamy soil. Shallow groundwater levels are deep enough to not affect infiltration; therefore, the samples with the lowest bulk density and highest sand percentage would have the highest infiltration rates. Regardless of infiltration rate, lateral and downward vertical movement of water through the soil is expected to be moderate to high under dry conditions and would decrease as soil saturation increased due to rain and snowmelt.

Potential phosphorus loading. Phosphorus levels are exceedingly high compared to typical ranges across a wide variety of soils (Table 2). In the soil samples around Hawrelak Lake, phosphorus levels were 644 to 1,380 ppm. These high levels suggest the soil is a potential source of soluble phosphorus. Phosphorus is bound to organic matter in the soil (adsorption) but can be released (desorption) into soil water and move laterally to open water, increasing the concentration of total phosphorus in the water. Barriers to dissolved phosphorus movement can reduce this effect, such as the clay liner of Hawrelak Lake or the downward movement of soil water to groundwater.

Potential nitrogen loading. Nitrogen levels are exceedingly high compared to typical normal ranges (Table 2). Ranges of 6,210 to 10,000 ppm suggest the soil is a major source of soluble nitrogen, which is readily dissolved in soil water and easily carried laterally to open water or downward into groundwater.

Table 2. Desirable range of soil chemical constituents at 0-20 cm depth

Constituent/Characteristic	Units	Desirable Range	
		Low	High
pH		6.2	7.5
Organic matter	g/kg	30	50
Humus	% by weight	2	3
Clay	% by weight	30	
Sand (fine & coarse)	% by weight	30	
Silt	% by weight	30	
Bulk Density	g/cm^2	1.1	1.4
Chloride	g/kg		<0.07
Sulfate	g/kg	.0075	25 .025
Alkalinity	%	.003	.006
Available phosphorus	ppm	16	50
Available potassium	ppm	75	150
Organic carbon	%	48	58
Exchangeable calcium	cmol/kg	700	1300
Available iron	ppm	12	24
Cation exchange capacity	cmol/kg	5	10+
Total Cadmium	Ppm	0.01	1.8

Soil Quality Improvement Strategies

Lowering phosphorus and nitrogen levels in the soil will reduce the probability of these chemicals reaching the open water of Hawrelak Lake. Strategies for accomplishing that are described below.

How Does Soil Phosphorus Pollute Open Water? During a spring thaw and after the early growing season rainfalls, some percentage of the meltwater and stormwater enters the soil and moves laterally and potentially vertically through the rooting zone (rhizosphere) of the turf plants in Hawrelak Park. The water follows the contours of the land surface initially (topographic gradient), then moves with the shallow water table (piezometric surface) until it discharges at an open body of water—the small pond, Hawrelak Lake and the North Fork Saskatchewan River.

When oxygen levels in the soil are low, such as when soil is saturated or during hot summer conditions, phosphorus that is bound molecularly (adsorbed) to soil colloids (i.e., clay and organic matter) but can be dissolved into the soil water (desorbed). That dissolved phosphorus has the potential to enter open water, as described above.

The intact clay liner forming the basin of Hawrelak Lake is likely to limit the movement of dissolved phosphorus into the lake. The small pond and stream near the lake's southwest corner, however, may intercept shallow groundwater with high dissolved phosphorus levels and act as a conduit to move that water directly to the lake's southeast corner. Thus, treating the issues that are known to directly affect the lake water quality—waterfowl, sediment phosphorus release, river water topping-off—may not entirely resolve the water quality problem.

If this is the case, a strategy of binding phosphorus to soil and plant materials is required. The strategy would include increasing the level of organic matter and clays in the soil and planting long-lived deep-rooted plants. These actions together will reduce the amount of dissolved phosphorus in soil water and shallow groundwater.

Assuming the high phosphorus are held in the topsoil, assumed to be a 6-12" thick layer over the entire uplands, the following solutions are the most relevant to consider:

What actions are effective for reducing phosphorus?

1. **Apply lime and iron hydroxide.** Applying a combination of calcium carbonate (lime) and iron will cause the phosphorus to bind to iron compounds in the soil (chelation) and remain in the soil matrix. This will reduce the potential for phosphorus to become soluble and be transported by soil water and surface groundwater.
2. **Apply organic matter and clay.** Apply granular bentonite clay and biochar (a high carbon combustion product) and work this into the upper several inches of soil. This increases the soil's binding sites which adsorb and hold phosphorus.
3. **Plant & harvest deep-rooted, quick-growing, large herbaceous plants.** Plant oil seed sunflower (*Helianthus annuus*), sorghum (*Sorghum bicolor*), sudan grass (*Sorghum x drummondii*) and similar plants that grow quickly and take up large quantities of phosphorus and nitrogen. These herbaceous plants are harvested at the end of each growing season and used outside the watershed. Plants of this type can be invasive and displace other vegetation. The risks of using these types of plants should be considered and control measures in place should be in place before such species are planted.
4. **Intercept and redirect or clean surface runoff and shallow groundwater.** Surface runoff and shallow groundwater can be intercepted by shallow surface swales and directed to treatment areas or sent directly to other water bodies with greater capacity to assimilate high-phosphorus water.

Additional Information Regarding Soil Improvement

Using Iron

Iron can be applied to help tie up phosphorus using rates and formulations as in Table 3. Two fertilizer formulations that may be available and considered for use are listed, with the targeted percentage of the specific mineral/element for each formulation.

Table 3. Micronutrient application rate for soil

Mineral	Application Rate (dry lbs/acre of mineral)	Example Fertilizer Options (% targeted mineral)
Iron	1.5	Ferrous ammonium sulfate (14%), ferrous ammonium phosphate (29%)

To achieve the application rate of the elemental mineral for each macronutrient, please note that the fertilizer formulation will need to be consulted to determine the actual pounds per acre of the fertilizer that will need to be applied to achieve the application rate of the elemental mineral.

Many fertilizer suppliers can create custom premixed micronutrient fertilizers that can be applied as a dry powder or granular spreadable. Do not attempt to spread a dry powder in windy conditions, unless the fertilizer applicator implement can forcefully direct the applied fertilizer downwards to the ground.

Materials should be added only after soil texture and organic matter improvements have been achieved. Micronutrient fertilizers can be spread as a powder or granular material and then tilled into the upper topsoil layer, especially when using a cover crop with the additions.

Improve soil pH and increase calcium and magnesium

Consider applying two types of lime amendments over three years (Table 4). In years 1 and 2, the rates of application should be about 5 tons/acre each year of each lime amendment. In years 3 and 4, the application rate should be revised based on actual re-measurements of soil pH. A starting point for consideration would be to apply about 5 tons/acre.

Table 4. Schedule for pH management of soil

		One-Time Application to Achieve Targeted pH		Annual Projected Applications			
pH Test Results	Targeted pH Level	Pure CaCo3 Application Rate (T/acre)	Agricultural Ground Limestone (T/acre)	Year 1 (T/acre)	Year 2 (T/acre)	Year 3 (T/acre)	Year 4 (T/acre)
5.0	6.2-7.5	16.9	18.0	5.0	5.0	5.0	5.0

Soil pH, calcium and magnesium can be simultaneously adjusted with calcium carbonate, ag-lime or another material (Table 5). The application amounts are approximate but should adjust the pH to an optimal pH range of 6.2-7.5. If alternative materials are used, the soil should be tested before application to ensure the correct amounts are applied.

Table 5. Alternate and supplementary materials for pH adjustment

Material	Calcium (%)	Magnesium (%)	Total Neutralizing Power
Wood ash	23	2.2	
Calcium magnesium carbonate	29	4.0	60-90
Burned lime (CaO)	60-70		150-175
Calcium limestone ($CaCO^3$)	32	3.0	85-100
Hydrated lime ($Ca(OH)^2$)	45-55		120-135
Marl	35	0.5	90-100
Gypsum ($MgSO^4\ 2H_2O$)	23		

The lime recommendation assumes that the lime is rated at 100 percent calcium carbonate equivalence (CCE), a measure of the neutralizing power of the lime. If the lime is guaranteed at below 90 percent CCE, the application rate should be increased proportionally. If the lime requirement to reach a target pH is more than 125 lb per 1000 sq. ft., a split application is recommended over two or more years to adjust the pH gradually and avoid possible nutrient balance problems. If lime is to be top dressed, application should be limited to 100 lb per 1000 sq. ft. in any one year.

Lime is a primary source of calcium. An optimum pH should automatically result in an adequate calcium level if the pH has been adjusted using lime. The lime recommendation is usually the only recommendation made to adjust the soil calcium level.

After uniform application to the soil surface, lime should be thoroughly tilled into the soil for optimal neutralization of soil acidity. Since the liming material can only react at the depth at which it is incorporated, subsurface tillage may be necessary to ameliorate subsoil acidity. Liming soils with a seeding of perennial plants will require little or no tillage. Irrigation and rainfall will slowly leach the lime (which is relatively insoluble) into the soil profile. The proper fertilizer formulation is needed when managing soil acidification, particularly in perennial crop systems where liming is less easily incorporated than in annual or short-term systems.

Over-liming soil has an adverse effect, making the calculation of the amount to add very important. If the pH of the soil is too high, deficiencies of phosphorus and micronutrient deficiencies, as well as molybdenum toxicity, can result.

Once soil pH reaches equilibrium, soils should be tested every 2-3 years. However, if nutrient or pH levels are excessively high or low, sampling should be done each year and applications adaptively managed.

Appendix 3. Technical Advisory Committee Meeting Notes on Alternative BMPs

William Hawrelak Park Rehabilitation
Water Quality Feasibility Study

Preferred Alternative

On September 17, 2002, the Advisory Committee met with the consultant team to discuss irrigation, review the results of the phosphorus loading model, and discuss proposed best management practices (BMPs) for improving water quality in Hawrelak Lake. The following summarizes the input from the Advisory Committee. Followed that is a table summarizing the preferred alternative. Lastly, notes from the September 17 meeting are provided at the end.

Dredge & Manage Geese & River Water – Base Scenario

- A reasonable scenario without much additional cost or effort above what City plans to do.
- **Planting shrubs on islands** to stop goose nesting will generate little public reaction at small cost. This addressed the largest source of phosphorus to the lake, waterfowl. The planting serves a dual purpose in also keeping people off the islands. Will the geese move to the lake edges? Possibly, but it is easier to monitor and remove nests at lake edge and may reduce the density of the nests from nine in 2020 to a lower number in future years.
- City plans to **dredge to clay liner**. This will remove sediment and prevent a phosphorus pulse at ice-out. Preventing rapid build-up of sediment in the future depends on controlling the goose population, stopping algae blooms, and pumping river water without sediment. This would greatly extend the time until the next dredging.
- **Pumping clean river water—only in low-sediment/low-phosphorus periods** is programmatically challenging because topping off the lake depends on lake level, the irrigation needs, and triathlon timing. The need may not coincide with a period of low sediment and phosphorus in the river. A plan for deciding when to pump river water would improve the chances of pumping when sediment and phosphorus are low. Generally, in April-June river sediment is high and phosphorus is much above the 0.025mg/mL lake concentration target. The July-August period has lower phosphorus levels, usually 0.02-0.04 mg/L. City staff can use the EL Smith Water Treatment Facility's daily measurements of sediment and phosphorus to pick days when river water could be pumped at P concentrations closer to the 0.025 mg/mL target, thereby not increasing phosphorus loading to the lake.

Native Vegetation Plantings

- **Install vegetation filter & level spreader for pumped river water** in the ravine at the west side of the lake. The area involved is small and not regularly used by park visitors. This BMP could be designed as a new feature of the park—moving water through the BMP to the lake when water is pumped from the river to raise the lake level. Two designs for a level spreader were proposed. Because pumped lake water is the greatest source of phosphorus in the month it is added to the lake, this BMP is expected to have a demonstrable effect on P loading and lake water quality in those months.
    - In the first option, the ravine would be configured as a cascade of cells and a swale and berm would be constructed at the lake edge to function as a level spreader. The area would be vegetated with perennial, deep-rooted native plants, shrubs, and scattered trees. Water would

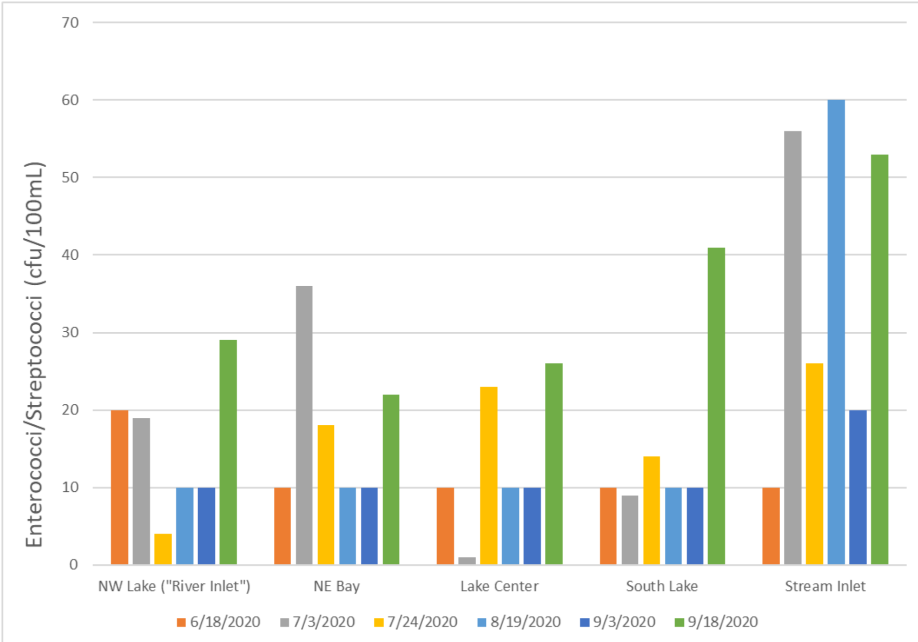
be pumped from the river to the head of the ravine, flow downhill through vegetated cells, spread out in the swale (where some water will infiltrate to shallow groundwater), and overtop the berm to flow into the lake.

    - The second option retains the treatment in the ravine but installs a piped system from the foot of the ravine along the lakeshore to direct water through many holes in the pipe, which will flood an upland vegetated buffer that fringes the lakeshore. Water would then move overland through the buffer into the lake.

- **Install 25-foot wide vegetation buffer in uplands along the shoreline and emergent plants in the shallow water** next to the shoreline. The public reaction to taller vegetation around the lakeshore will dictate feasibility. Snow management and chlorination for the triathlon are not issues for the vegetation that would be planted. A vegetation buffer and emergent zone serves a dual purpose—discouraging goose movement between the lake and lawns and reducing local inputs of surface and shallow subsurface runoff to the lake at relatively low cost. If dense enough, it will discourage goose nesting at the shoreline. The phosphorus loading from surface runoff is the third largest contributor but not much more than the pumped river water. This BMP will serve a dual purpose: filtering overland runoff and making the shoreline less attractive to geese, which would reduce the amount of goose droppings near the lake.

Other BMPs

- **Install an iron enhanced sand filter (IESF) in the recirculating pond-stream system.** This would be installed as a series of cells in the stream receiving the pond water. The pond is filled with lake water by a pump that is separate from the irrigation system. With an IESF installed, the pond-stream system would become a filtration system for the lake by removing phosphorus whenever the stream is flowing. Maintenance of an IESF requires access to a skid-steer to lift the cage containing the filter out and replace the sand and iron filings. The amount of phosphorus being treated affects the replacement time. In general, replacement is needed at six years after installation.
    - Interestingly, although phosphorus levels in 2020 were no higher in the lake at the stream inlet, *Enterococcus* bacteria levels were consistently higher than elsewhere in the lake (see figure below). This suggest a bacteria source at the pond or in the stream. The stream corridor is shaded. Bacteria are known to persist, once established, in shaded streams and move into downstream waters. (In 2020 water quality sampling of Hawrelak Lake, *Enterococcus* counts did not exceed the US EPA standard of 61 cfu/100mL *Enterococcus* in any one sample.)
    - Sand filters remove bacteria from water, but a removal rate of up to 99 percent is possible by adding biochar to the filter. The University of Minnesota's St. Anthony Falls Lab is conducting research on this topic and the results are promising. See http://www.shinglecreek.org/uploads/5/7/7/6/57762663/2019_overview.pdf. In addition to phosphorus removal, a more pressing reason to install an IESF in the stream would be to remove bacteria before it reaches the lake.



- **Install an IESF in the ravine** for additional treatment of pumped river water. This would increase the amount of phosphorus removed from pumped river water and reduce the need for a level spreader because treatment would occur over the flow length of the ravine. Maintenance access would need to be provided for a skid-steer from the perimeter road.
- **Improve the soil quality in the pond-stream watershed**. If shallow surface runoff is adding phosphorus to the lake, that most likely is occurring at the pond where the water table is shallowest in the park. The high phosphorus levels in the soil can be reduced by the addition of lime and iron. This will cause phosphorus to bind to iron and soil particles and reduce the amount of dissolved phosphorus in shallow groundwater. The phosphorus concentrations in lake water at the stream inlet, however, were no higher than at other locations in the lake, and the amount of phosphorus in the overland runoff and subsurface groundwater that reaches the pond-stream system comes from a very area compared to the rest of the park. It may be worthwhile to consider an overall program of soil health improvement that benefits turf growth, rather than focusing on the contribution of phosphorus in subsurface runoff to the lake from the pond.

Summary of Preferred Alternative

The preferred option addresses the two largest sources of phosphorus—geese and sediment. It also addresses a large contributor of phosphorus to the lake in the summer—river water pumping. These BMPs are either planned already (dredging) or involve engineering, earthwork and vegetation establishment—the ravine vegetation filter—which can be completed at a low to medium cost level. O&M would consist largely of vegetation management and erosion monitoring and control.

Pumping clean river water has great potential to reduce phosphorus loading to the lake at low cost, but coordinating this practice is a challenge. For that reason, if river water phosphorus cannot be reduced sufficiently in the vegetation filter approach above, an IESF would be installed in the ravine.

If the load reduction is insufficient to meet the target 0.025mg/mL total phosphorus concentration in all growing season months, installing an IESF in the recirculating stream-pond system would provide continuous phosphorus removal while also reducing this large source of Enterococcus bacteria.

Installing vegetation buffers and emergent plants will intercept and treat runoff from adjacent turf, as well as discourage the use of the planted shoreline by geese. This is a low-cost BMP but the greatest benefit may be to lower the input of phosphorus from goose droppings near the lake. Improving soil health may be more beneficial in turf management than reducing the amount of phosphorus reaching the lake in shallow groundwater, given the depth of groundwater and clay liner of the lake. It may be more important in reducing phosphorus inputs from the pond-stream system where groundwater is shallow.

Table 1. Summary of BMPs in Preferred Alternative

Best Management Practice	Preferred Option to Model P Load Reduction	Add If Load Reduction Not Enough	Load Reduction Potential[1]	Likely Installation Cost[2]	Likely O&M Effort[3]
Plant Shrubs on Islands	Yes		2/3	3	3
Dredge to Clay Liner	Yes		3	1	3
Install Vegetation Filter for River Water	Yes		3	2/3	3
Install IESF in Ravine		Yes	3	1	2
Pump Clean River Water		Yes	3	3	3
IESF in Recirculation Stream-Pond System		Yes	2	1	2
Install Vegetation Buffer & Emergent Plants		Yes	1/2	2/3	3
Improve Soil Quality of Turf		?	1/2	3	3

[1] Load Reduction Potential. 3=high, 2=medium, 1=low

[2] Likely Installation Cost. 3=low, 2=medium, 1=high

[3] Likely O&M Effort. 3=low, 2=medium, 1=high

William Hawrelak Park Rehabilitation
Water Quality Feasibility Study
Model Results & Alternative BMPs

Technical Advisory Committee Meeting Notes
September 17, 2020

Irrigation

Will the City use treated lake water or potable? What standard is the City using for lake water re-use? Can permission be gained to grandfather irrigation at Hawrelak? Can using lake water for irrigation reduce phosphorus loading to the lake? Soon Canada will mandate adding 1 mg/L orthophosphate to potable water to reduce lead levels.

City (Juanita) said the City is not set on source of irrigation water. When blue-green algae are present in the lake, there is a concern about using it for irrigation. The park recently got very dry and needed irrigation. Algae and sludge in lake water also clog the irrigation system. Fairy shrimp have also clogged the system. Using potable water for irrigation is expected to result in higher costs than using lake water. Overall using lake water is more environmentally benign.

Bryan said lake water irrigation is used to manage the lake level. It is challenging to release excess lake water to the river due to permitting requirements. It is rare to pump river water into the lake for irrigation, but if the lake gets too high and threatens the amphitheater, the City will irrigate to lower the lake level. There may be a leak in the clay liner again, because the water level has been dropping somewhat faster than expected.

There are two pumps—one for irrigation and one to keep the little pond/stream system going.

Improving lake water quality should facilitate its use for irrigation and lessen concerns regarding its release to the river—but a permit to do so would still be needed.

The City's standards are that the City allows subsurface irrigation using lake water, but requires potable water or water treatment if irrigation is above the ground—spray, etc. The pump house has a filter and UV set-up to treat bacteria and algae before using it for spray irrigation.

Juanita expects water quality regulations in the future will be more rigorous regarding lake water use for irrigation.

Kim mentioned the possibility of using lake water to distribute irrigation water at ground level without spray (may reduce requirements/concerns).

Alternative Approaches

Juanita thought Base Scenario was reasonable. The City does plan to dredge the lake. She likes the dense plantings of islands to keep both geese and people off them. River pumping may or may not be timed for low phosphorus periods. Public argument for reducing goose numbers is that they are by far biggest contributor and must be addressed to solve the lake's water quality problem. Goose control in the past has been problematic from a public relations standpoint, and this would need to be carefully messaged prior to implementation.

Adding Vegetated Buffer. There was a sense that the public may push back on a vegetated buffer strip in the uplands and an emergent marsh zone in the lake shallows. Juanita also expressed concern regarding snow plowing and storage and its effect on native plantings in the shoreline buffer and emergent marsh area.

(Another staff member said that a pond at the Texaco refinery had fish, possibly from river water that was pumped into it. Fish in Hawlrelak would not be a problem but would likely die out each year due to low oxygen over the winter—shallow lakes with ice and snow are subject to winter kill.)

Bryan was concerned about snow plowing and storage. City provided snow storage location data to AES, as well as chlorine use data for triathlon preparation. The City clarified that snow is plowed off the lake using a front-end loader with a bucket and snow blower. Snowbanks are created by plow trucks along the lake edge. When the banks get too high, a snowblower with an auger is used to lower the height of the snowbank. The loader bucket is also used to lift heavy snow from the lake and move it to the bank or reduce the height of banks by moving it elsewhere. In this way snowbanks are reduced to a height of one foot. There is a concern that the front-end loader would damage the taller vegetation. There is little evidence in photos of the shoreline that the lakeshore edge itself is damaged.

Kim pointed out that if existing vegetation and turf can survive the snow plowing and storage operations, the native plantings of appropriate species will also tolerate the treatment. The perennial, deep-rooted native plant species used in the upland vegetation buffer and emergent zone have growing tips near the ground and grow back each year after winter. If the soil is not damaged and blades and augers don't go below 1 foot above the ground, there will be no damage to the vegetation buffer or emergent plants. Doug mentioned that, if doubts remain, the winter effects of show removal could be tested by planting a portion of the shoreline and evaluating the aesthetic look and recovering of vegetation after a winter.

AES understands that the plants selected for use in the lake must tolerate the chlorine treatments for the triathlon. If phosphorus loading to the lake can be reduced and the sediment removed, however, it may be that chlorination would not be necessary in the future.

Bryan was interested in using the ravine as water quality treatment opportunity for pumped river water. He wondered whether that area would make for an attractive park feature or should it be hidden. How will it look? Kim thought it would be best for the vegetation used in water quality treatment if it were open to the sun and had no continuous tree canopy; scattered trees would be fine around the edges. It might be interesting for park users to observe the water being pumped from the river as it flows through the treatment facility and into the lake.

Bryan asked about filter replacement, a very important issue. Kim said John Gulliver recommends caged filters replaced approximately every 6 years, but design would need to consider flow rates and P levels; likely skid steer could replace filters. Timing of maintenance and the cost. Access for cleanout. Skid steer removal.

Next Steps

AES will summarize a preferred approach based on this input for review by the team. With the team agreement, AES will re-run the phosphorus loading model with the preferred approach to determine load reduction and the monthly concentration in lake. This will determine if additional BMPs are needed. When the preferred approach has final sign-off, AES will provide an opinion of probable cost to construct and maintain the water quality improvement measures.

Rachel will send regulatory requirements for consideration by the consultant team.