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Goal#8: Vancouver will have the best drinking water of any city in the world

Can Trout Lake be a natural swimming lake, reducing the amount of potable water used and improving water quality, through approaches such as an constructed wetland?

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Table of Contents

1. INTRODUCTION

2. HISTORY

3. USE

4. ISSUES

5. POSSIBLE SOLUTIONS

5.1.2 Case Study

5.2.2 Case Study

6. RECOMMENDATIONS

1. INTRODUCTION

1.1 City of Vancouver's Greenest City 2020 Action Plan

The Greenest City 2020 Action Plan is a vision and strategy to establish targets to reduce carbon emissions, waste and improve ecosystems while building a strong local economy, vibrant neighbourhoods, and an internationally recognized city that meets the needs of future generations (City of Vancouver 2012). The Greenest City 2020 Action Plan is comprised of 10 smaller plans, each with a long-term goal and medium-term targets (City of Vancouver 2012). Of most relevance to this study is goal #8.

Goal #8 - Vancouver will have the best drinking water of any city in the world

Water is an essential resource which humans require for food, drinking, hygiene and recreation. The importance of water leads the City of Vancouver's Greenest City 2020 Action Plan to focus its 8th goal on the conservation of water and water quality.

The main targets for this goal are to:

1 meet or beat the strongest of British Columbian, Canadian and international drinking water quality standards and guidelines
2 reduce per capita water consumption by 33% over 2006 levels (City of Vancouver 2012)

This research project will focus on an urban water body in Vancouver which has the potential to optimize ecological, recreational and cultural uses while decreasing the use of potable water. The question posed is:

*Can Trout Lake be a natural swimming lake, reducing the amount of potable water used and improving water quality, through approaches such as an constructed wetland? And are there comparable examples world wide that can be used as a precedent for future works at Trout Lake***?**

> "Water constituted the principle of all things."
> *Thales of Miletus*, 650-560 BC, Greek philosopher

1.2 Subject Site

Trout Lake, situated in East Vancouver within John Hendry Park, is one of a handful of urban lakes (Lost Lagoon, Beaver Lake) in Vancouver. John Hendry Park hosts numerous recreational activities within its playfields and trail systems, and functions as an important destination for recreation and cultural events. However the water body feature of Trout Lake is experienced and known primarily for it's aesthetics and is minimally utilized in the physical sense.

The south side of the lake consists of a man made sandy beach area but water quality issues restrict swimming, with frequent beach closures due to coliform counts above the primary contact maximum allowable by local health authorities.

Figure 1.1: Trout Lake in John Hendry Park

2. HISTORY

2.1 Lake Characteristics

Trout Lake is a deep depression, located in the center of the shallow depression of John Hendry Park. John Hendry Park covers an area of approximately 26 ha. Trout Lakes surface area is 3.9 ha, with a 54m beach shoreline at the southern end of the lake. The area around Trout Lake was once a bog - a low nutrient deep accumulation of peat (dead moss) with a top living layer of sphagnum moss (Sampson and Eyeman 1995). The surface area of Trout Lake is slowly retreating through the natural encroachment of peat (Ker, Priestman & Associates Ltd. 1976). The depth of Trout Lake is about 1m in the northern portion and as deep as 2m in the southern portion (Bluteau *et al* 2005). The lake and surrounding area is underlain with 20’ of soft peat (from surface to 12-20’) over clayey silt (from peat to 22’-30’), followed by grey silty sand (Golder *et al* 1978). The peat layer consists of a thin strata of fibrous peat overlying granular peat (Ker, Priestman & Associates Ltd. 1976). Sand has been placed at the southern end of the lake to create a public beach. The park board provides lifeguard supervision during summer months when the beach is open to public use.

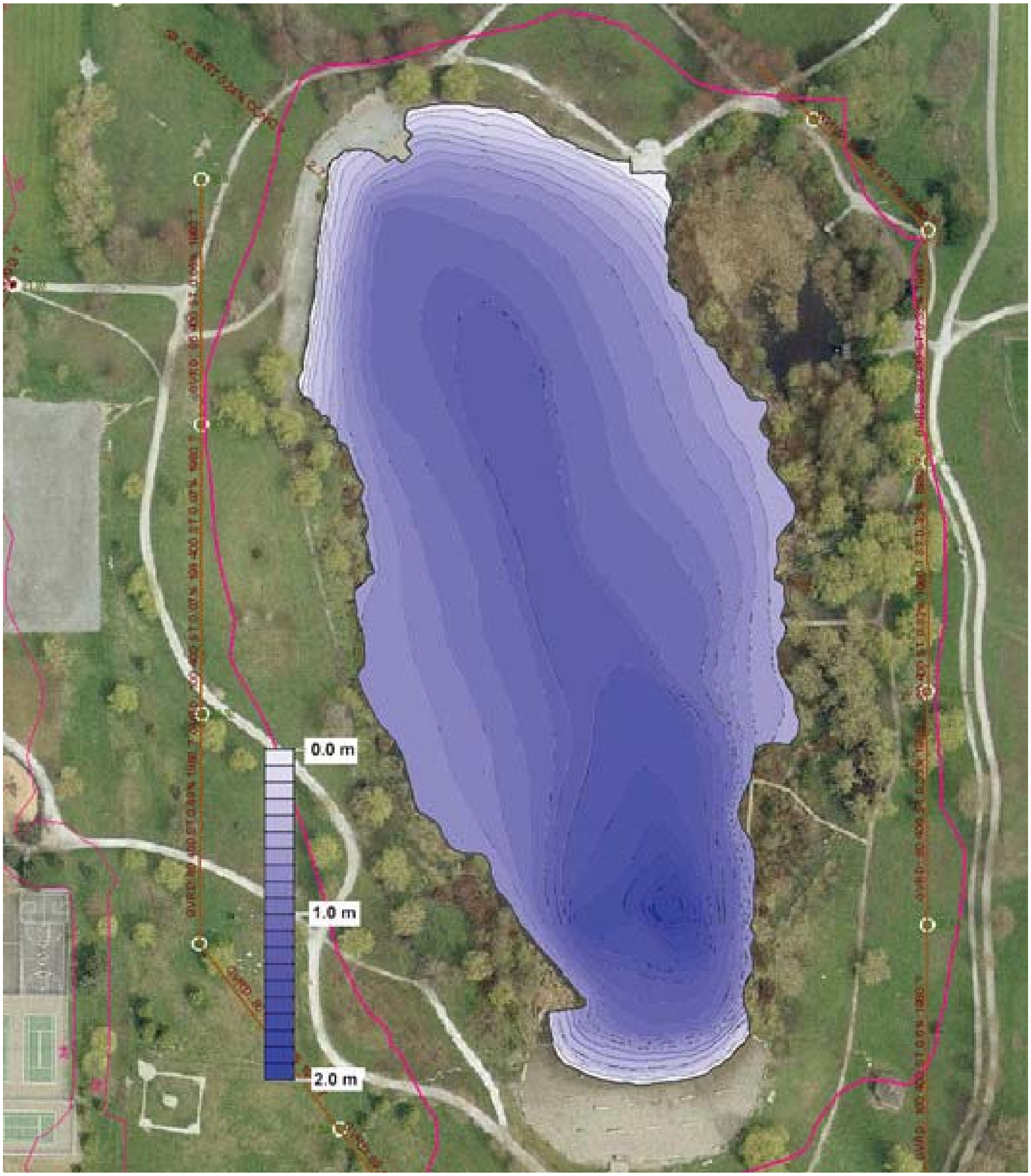

Figure 2.1: Contour Map of Trout Lake, based on field measurements (derived from Bluteau *et al* 2005)

2.2 Catchment Area

The Trout Lake drainage basin is part of the False Creek watershed. In the 1850's, China Creek was the largest stream in the area, flowing out of the north end of Trout Lake and entering False Creek (Sampson and Eyeman 1995). Prior to urban development, the natural drainage catchment of Trout Lake extended to around 550 ha (Ker, Priestman & Associates Ltd. 1976). Through development and storm sewage facilities, the 1976 catchment is suspected to have been reduced by a factor of at least 20 (Ker, Priestman & Associates Ltd. 1976). With the addition of a peripheral perforated pipe around the circumference of the lake, minimal to no surface runoff enters the lake, which could account for the lack of algal blooms, which are usually a problem in urban lakes.

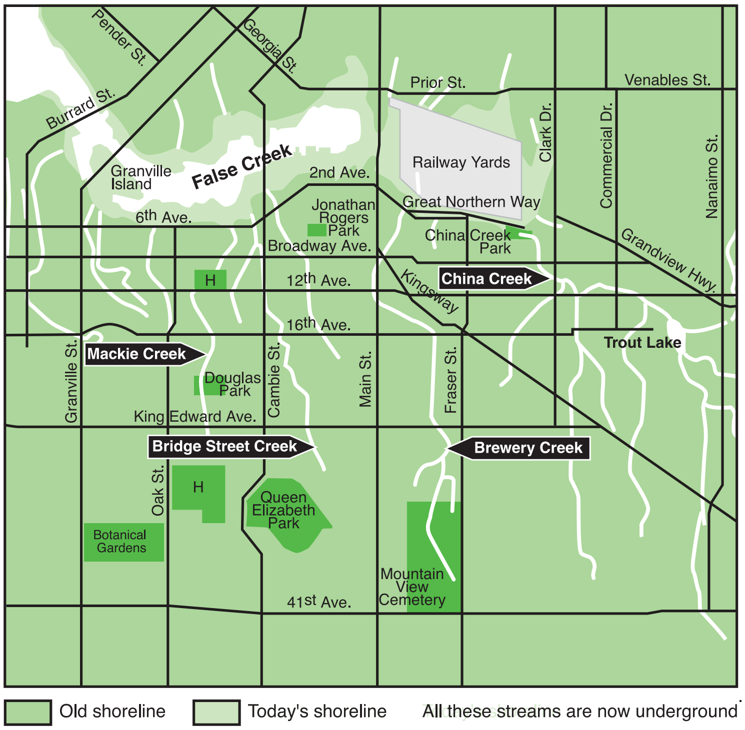

Figure 2.2: False Creek Watershed (Sampson and Eyeman 1995)

2.3 Water Balance in the Lake

Inputs = rainfall + groundwater inflow (seepage) + *potable fountain water* (discontinued summer 2012)

Outputs = evaporation + south pipe leading to the sewer system + *two potential weirs* (east and west)

*surface runoff from park area not included as the peripheral perforated pipe (installed 1984) drains south to Lakewood sewer.

*used to be outflow from the northwestern pipe (Bluteau *et al* 2005) but the lake is too shallow now.

2.4 Groundwater and Surface Water Flow

The direction of groundwater flow is from the surrounding park into the lake (Ker, Priestman & Associates Ltd. 1976, Atwater *et al* 2006). Groundwater inflow from the peat into the lake can influence the lake water quality (Ker, Priestman & Associates Ltd. 1976). The quantity of groundwater inflow would be relatively small due to the low permeability of the peat material (Ker, Priestman & Associates Ltd. 1976). In the spring and fall, the increased precipitation and soil infiltration likely increases the groundwater flow to the lake (Ker, Priestman & Associates Ltd. 1976). On an annual basis, throughflow in Trout Lake is very small (Ker, Priestman & Associates Ltd. 1976). Overland flow from Trout Lake Community Centre roof transferred through a bioswale is also small.

2.5 Ecology: Flora and Fauna

Trout Lake supports a wide variety of wildlife. Waterfowl use Trout Lake for breeding and foraging along the vegetated edges, and swallows forage over the water for insects. Historically, black bears, cougars, deer, elk, wolves and beavers were present (Sampson and Eyeman 1995). The lake was used by migrating chum, coho and rainbow trout, but by the 1940's had to be stocked for fishing (Sampson and Eyeman 1995).

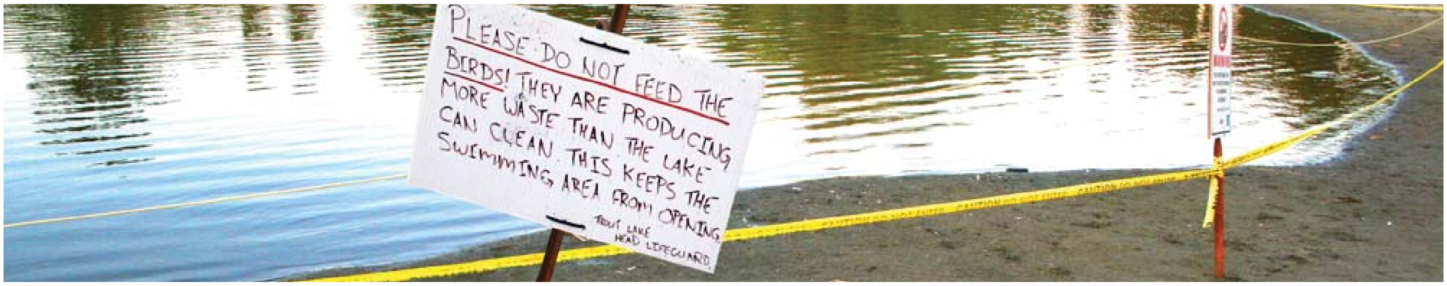

Figure 2.3: Beach Closure 2011. Signs urge people to not feed the birds - considered a primary contributor to the fecal coliform (http://www.straight.com/article-422286/vancouver/quiet-times-beach?page=0%2C1)

2.6 Human Use

Trout Lake was the source of one of Vancouver's first water supplies (Sampson and Eyeman 1995), used initially to provide freshwater via a flume to Hastings Sawmill on Burrard Inlet (Steele 1988). The flume, China Creek, and its tributaries were used by migrating salmon and rainbow trout. To keep the flume operational, beavers dams were removed from the mouth. The drop in lake water level could have been caused by the flume and sawmill operations (Sampson and Eyeman 1995). By 1910, development had encroached around all of the lake (Sampson and Eyeman 1995). By the 1920's, to make the lake safer for children, the water level was lowered to connect the 13th and Victoria sewer infrastructure, the banks were cut and the southern beach was created complete with raft and dressing rooms (Sampson and Eyeman 1995). In the 1930's, Trout Lake was about 12' deep and peat was mined from surrounding soils (Sampson and Eyeman 1995). In the 1970's, hot days attracted nearly 500 swimmers to the lake (Sampson and Eyeman 1995).


Figure 2.4: Trout Lake from the south end, 1908 (photograph from City of Vancouver Archives, part of the Timms Family - Cedar Cottage Collection)


Figure 2.5: Trout Lake skating, 1900 (photograph from City of Vancouver Archives)

Humans have historically used John Hendry Park as a destination for recreation and relaxation. Photos dating back to the early 1900s indicate that Trout Lake would freeze in the winter, providing a natural skating rink for hundreds of people (Sampson and Eyeman 1995). Other historical uses included using the lake a stocked fishery, where 20,000 fingerlings were added for children to fish (Sampson and Eyeman 1995).


Figure 2.6: Trout Lake skating, 1929 (photograph from City of Vancouver Archives)

The storm and domestic sewers polluting China Creek were first reported in 1948, leading to the confinement of China Creek to an underground culvert in 1952 (Sampson and Eyeman 1995). The year of 1968 marked the first closure due to pollution and high bacteria counts (Sampson and Eyeman 1995). After this initial closure, it was decided to increase the flow of freshwater into the lake via a 4" pipe fountain turned on to full capacity to increase inflow (Sampson and Eyeman 1995).

3. USE

As one of a handful of urban water bodies in Vancouver, Trout Lake is a very valuable resource, providing cultural, ecological and recreational ecosystem services. Ecosystem services provide benefits that people obtain from ecosystems (Millennium Ecosystem Assessment 2005).

3.1 Cultural Ecosystem Services

Figure 3.1: Building sandcastles on the beach

Figure 3.2: A man plays guitar by the waters edge

Figure 3.3: A family looks at the ducks from the dock

Figure 3.4: Illuminares 2012 Lantern Festival (http://publicdreams.org/2012/illuminares-2012-trout-lake/)

Figure 3.5: Farmers Market (www.hepburnrealestate.com)

Education/Nature Interpretation - function as an educational tool for visitors as well as community and school groups, create intrigue for people of all ages

Aesthetic - a place to explore, enjoy the atmosphere and view the lake

Spiritual/Relaxation - an opportunity to relax, contemplate and picnic. An important destination for cultural events such as the Farmers Market and the Lantern Festival

3.2 Ecological Ecosystem Services

Figure 3.6: Ducks breeding and foraging on the Lake

Figure 3.7: A family observes a crane by the water

Figure 3.8: Rainwater bioswale garden

Figure 3.9: Family of ducks floating in Trout Lake

Figure 3.10: Great blue heron forages by water edge

Figure 3.11: Crows wash themselves in the water

Cycle Water - Potential to clean water in False Creek

Maintain Biodiversity - Water bodies such as Trout Lake in urban areas create breeding and foraging opportunities for many species, especially waterfowl

Natural Drainage - Rainwater bio-swale recharges ground water from Community Centre before reaching lake

3.3 Recreational Ecosystem Services

Figure 3.12: Child playing near the western shore

Figure 3.13: Toy sail boats near northern dog beach

Figure 3.14: Dog beach

Figure 3.15: Family strolling through the park

Figure 3.16: Beach and lifeguard chair

Figure 3.17: Swimmable area when beach is open

Indoor recreation - newly built community centre with indoor skating rink (original Grandview Community Centre constructed in 1963, renovated and renamed the Trout Lake Community Centre in 1977) (Steele 1988).

Outdoor recreation - biking trails, dog off leash area (north side), numerous play fields

Trout Lake - no boating permitted, swimming beach frequently closed during the summer due to water quality

4. ISSUES

4.1 Fecal Coliform

Animal waste carried to water systems is the source of disease-causing bacteria and viruses. These disease-causing organisms are accompanied by non-pathogenic bacteria such as fecal coliform. Fecal coliform bacteria is not usually disease-causing, but is an indicator organism measured to predict the probability of finding pathogenic organisms in the water. Pathogenic bacteria, viruses and parasites are a cause for concern, with coliform providing a count to determine the risk of infection (Oasis Design 2012). General coliforms indicate the water has come in contact with plant or animal life and are universally present (Oasis Design 2012). Specifically, fecal coliform indicates mammal or bird feces in the water (Oasis Design 2012).

In summertime, the Vancouver Coastal Health Authority monitors coliform levels at all beaches throughout the Vancouver area on a weekly basis in the summer, computing a geometric mean (consisting of 10 results) determines if the lake is suitable for swimming. The geometric mean needs to be below 200 coliform bacteria per 100 mL of water to comply with Canadian Recreational Water Guidelines for "primary contact" recreational activities (which include swimming) (Vancouver Coastal Health 2012). If the count is higher than the 200 coliforms/100 mL level, the risk of infection is increased and the beach is closed for swimming until levels are below the acceptable maximum.

4.2 Trout Lake Water Quality

Poor water quality resulting in the closure of Trout Lake for swimming has been reported for over 40 years (Golder *et al* 1978). A 1976 report, identifies issues of turbidity (cloudiness), algae growth and bacterial problems in the lake (Ker, Priestman & Associates Ltd. 1976). Turbidity in Trout Lake gradually cleared up in the 1980's (Sampson and Eyeman 1995). Due to water quality concerns, Trout Lake was tested for fecal coliform since 1992 by the Vancouver Coastal Health Authority, finding high counts above the swimmable level. The high fecal coliform in Trout Lake has been a recurring problem, in direct conflict with the lake's recreational swimming component.

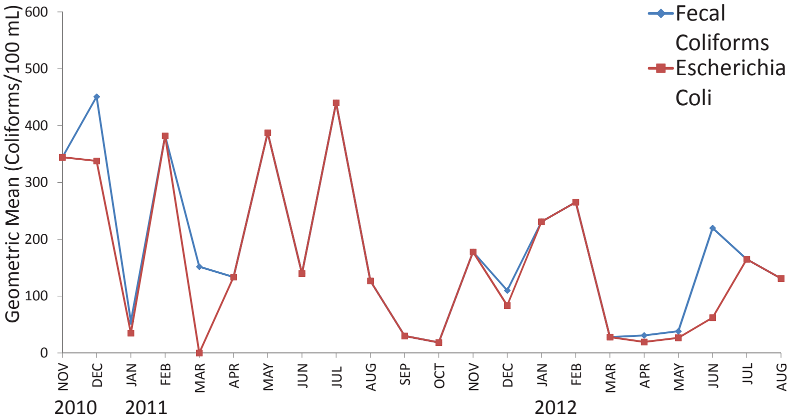

Figure 4.1: Trout Lake Geometric Mean for fecal coliform and *E.Coli.*, sampled monthly from Nov 2010 to Aug 2012.

Figure 4.2: Water warning sign posted during Trout Lake closure (www.mainwriter.com/2010/07/02)

Starting in 2012, if the coliform count is higher than 200 coliform per 100mL, the Trout Lake beach will be closed for swimming and the area will not be patrolled by a lifeguard. The beach will reopen once the geometric mean has decreased below the maximum acceptable level. In the summer of 2012, coliform levels in Trout Lake remained within the swimmable range until July 26th when the coliform geomean in Trout Lake reached 220 coliforms/100 mL, resulting in closure of the beach. It was reopened August 9th when weekly sampling resulted in a geomean of 188 coliforms/100mL. This count is more than double that of any other swimmable beach in the Vancouver area, however all other beaches monitored by Vancouver Coastal Health are saltwater (increased decay rate of coliform) (Fujioka *et al* 1981).

4.3 Potential Coliform Causes

The source of coliform in Trout Lake is assumed to be a persistent, non-point source as the variation in coliform readings between sample sites and sampling events do not appear to correspond to any factors including climatic trends. This variation indicates the coliform is probably not from a point source as readings would be more consistent (Harvey 2012).

It was initially suspected that the coliform counts were a product of dog feces. The effect of this potential cause is minimized by the perforated drain pipe which extending around the circumference of the lake, minimizing surface runoff and hence coliform counts from dog feces. It is currently suspected that the historically high levels of coliform in Trout Lake are caused by bird feces entering the water primarily from ducks and geese (Harvey 2012).

In 1994, volunteers and parks board staff attempted to determine which bird species were responsible for the coliform issues. For two days they kept the gulls away from the lake but allowed the ducks to remain, finding an *E.coli* count four times less than when the gulls had free reign (Thomas 2011). A major contributor to the entrance of bird feces could be the raft which was stationed near the swimming beach every summer(Harvey 2012). Birds use the raft to perch on, depositing feces which inevitably end up in the water. A strategy to minimize the increase of feces due to birds on the raft was employed by placing plastic on the raft and cleaning it each day. This year the raft reached the end of its serviceable life and was not replaced until mid-August.

4.4 Fecal Coliform Decay

$$C(t) = C_o e^{-kt}$$

The first order decay rate (k) varies proportionally with water temperature, ultraviolet (UV) radiation and salinity (Fujioka *et al* 1981). Therefore, if any of these factors are increased, the rate of coliform die off is also increased (Fujioka *et al* 1981). The decay of fecal coliform increases with increased exposure to UV (visible spectrum) (Goheen 2012). As the sun only penetrates the top layer (surface) of the water, creating movement in the water column will increase the ability of UV radiation to break down pathogenic bacteria. Therefore, water moving devices which increase UV exposure will increase the decay rate of coliform, ultimately decreasing the coliform count (Goheen 2012). Additionally, as pathogenic bacteria is strictly anaerobic (prefer more acidic water, pH 5 - 6), creating conditions for beneficial aerobic bacteria (prefer pH 6.5 - 7) will create a less hospitable environment for fecal bacteria (Goheen 2012). To achieve aerobic bacteria conditions requires a decrease in nutrient loading (P, N, NH_3, S) and increase in dissolved oxygen (removing CO_2) (Goheen 2012).

4.5 Stormwater

The recently separated combined sewer pipes provide an opportunity to return stormwater to Trout Lake, using the lake as a cleaning gateway, before entering False Creek. This would reduce combined sewer overflows (CSOs) to Burrard Inlet. The future plans for this area involve a separated stormwater catchment area of 290 ha. This is just over half the original catchment area of Trout Lake, however between paved roads and pipes much less infiltration occurs than originally (Bluteau *et al* 2005). One problem with introducing stormwater into Trout Lake is the risk of nutrient loading, which could exacerbate pathogenic bacteria conditions. Hence, biofiltration techniques are required to decrease nutrient loading.

4.6 Past Measures: Water Injection System

Fountain and submerged pipe

For many years potable water has been injected into Trout Lake as a short-term measure to deal with coliform counts by apparently diluting the coliform. A 2005 study by UBC students determined the potable water fountain has had minimal to zero effect on improving the water quality of the lake. Even with the knowledge of the ineffective fountain and subsequent waste of potable water resources, the fountain has continued to run in past years. In the summer of 2011 the fountain was turned on after the persistent request from a community resident (Harvey 2012), and can therefore be assumed to act as a visual and placebo ‘solution’ to water quality issues in Trout Lake. Considering the minimal contribution the fountain has in the reduction of coliform, it is recommended to keep the fountain turned off to conserve potable water. The City could seek to improve public education regarding the drawbacks to the fountain to increase public understanding and support for long term solutions that may result in swimming opportunities in Trout Lake.

5. POSSIBLE SOLUTIONS

Best Management Practices (BMPs) should first focus on implementing or modifying environmental attributes to prevent initial contamination. Hence, a first approach to the coliform issue in Trout Lake would be to try to eliminate the source of the problem. In this case, if it is birds that are causing the fecal coliform issue, then trying to limit their exposure to the water would be most ideal. Bird exclusion techniques include 5m overhead wires in the beach and water area or the use of border collies as waterfowl harassment.

However, the habitat the lake provides is considered an important ecological ecosystem service and solutions which incorporate the needs of the birds are favoured as Trout Lake is an important resource for all species not just humans. The presence of birds and associated habitat also increases the educational and aesthetic value of the lake. Solutions which maintain the ecological ecosystem services in promoting biodiversity are favoured.

Two primary strategies to improve water quality in Trout Lake while maintaining wildlife were investigated:

5.1 Closed re-circulating system

With limited flow in Trout Lake (Ker, Priestman & Associates Ltd. 1976), a closed system using UV radiation to increase the decay rate of coliform could decrease the risk of pathogenic bacteria and improve near shore water quality (Goheen 2012). With little to no flow in the water and minimal wind, coliform settles on the bottom of the lake. Therefore, water-moving devices which resuspend the coliform increase UV exposure and decay rate of coliform in the beach area (Goheen 2012, Fujioka *et al* 1981). This strategy will improve the water quality where water is moving, therefore water-moving devices situated in the beach area will decrease coliform only in this area.

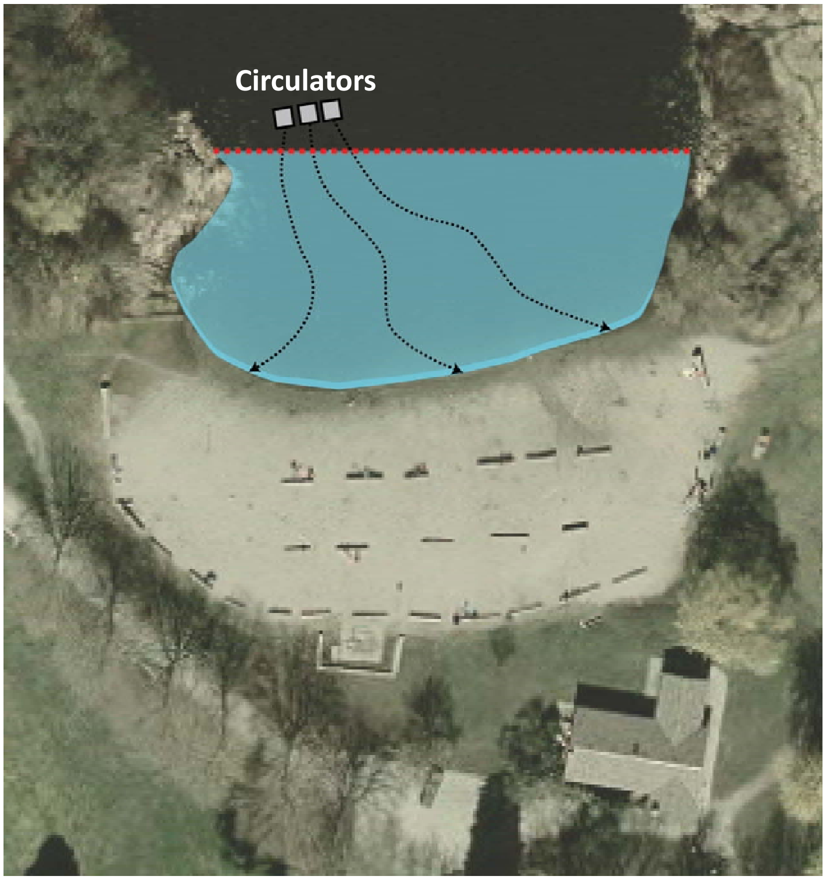

Figure 5.1: Closed Re-circulating System: Conceptual Model

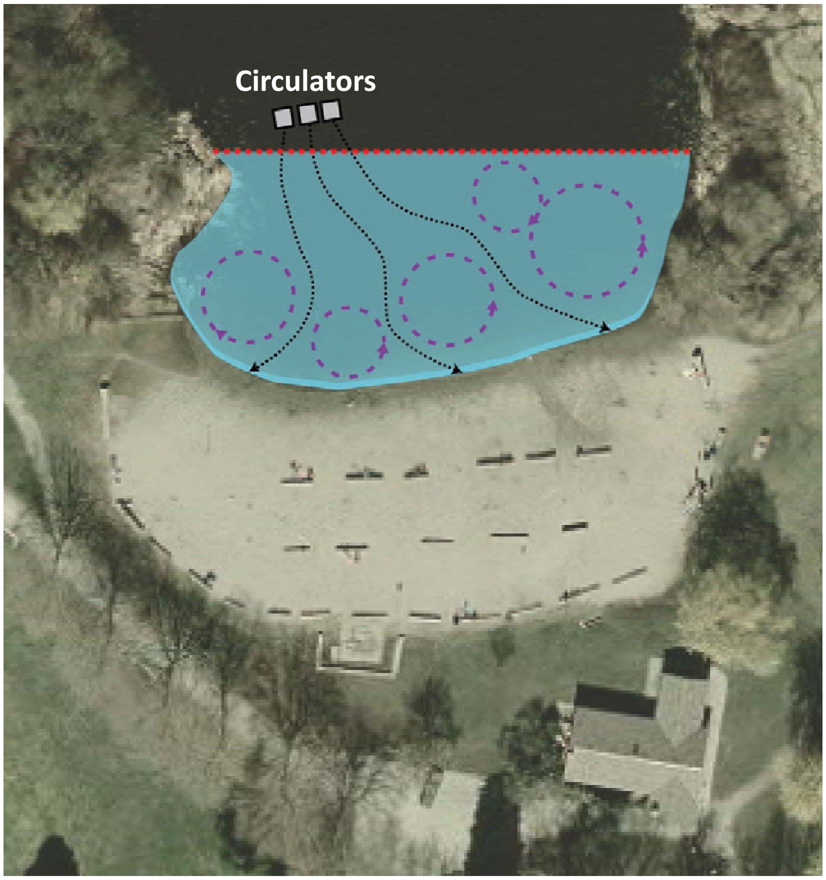

Figure 5.2: Closed Re-circulating System: System Model

5.1.1 Proposed Actions

a. Water-moving Devices

Floating Fountain (aeration)

Will aerate the lake but not directionally move water toward the beach shoreline to resuspend the coliform. The current fountain was found to have minimal effect in diluting the coliform, altering the length of time for concentrations to drop below guidelines by only 0.1 days (Bluteau *et al* 2005).

Figure 5.3
Kasco 3/4hp Fountain
$2,000
medium sized ponds

Figure 5.4
Kasco 1hp Fountain
$6,000
larger ponds and lakes
depth of 6 - 8'

Dock Mounted Lake Circulator

Mixes and agitates stagnant water to resuspend coliform settled on the bottom of the lake. For the size of the swimming area, about 2 - 3 circulators lined up about 1m apart would be sufficient to move the water across the beach (Gress 2012). To reduce injury and liability issues from the motor, the circulators should be mounted to steel posts in the water about 30m away from the swimming area (Gress 2012). The circulators are electrically powered and should be turned on 24/7 in the summer months to maintain the water current. This technique has been used to reduce the coliform counts to nearly zero in many natural swimming lakes in Wisconsin campgrounds (Gress 2012).

Figure 5.5
Kasco Circulator with Dock Mount
$1000
1hp unit, 120 - 240V, circulates 30m
highly efficient, low power consumption
vertical and angled mounting
* image portrays a dock mounted circulator, the circulator for Trout Lake would make use of the dock mount on a steel post in the water
*consider reconfiguring the motors to run with solar energy through the use of solar panels

b. UV Filter

As the sun is not a constant reliable input in Vancouver, it was suggested to supplement water moving devices with an onshore UV filter to increase the decay rate of the coliform (Gress 2012). UV filtration systems can be built to enclose the beach area to prevent outside water from entering, pumping the water through a settling basin to remove suspended solids, and then exposing it to UV light to effectively reduce bacteria concentrations. However, this extreme method might not be necessary as the beach area is relatively small and there is a higher probability of sunny days providing natural UV radiation during the summer months when swimming is occurring. If the coliform persists after applying a circulator solution, the UV filtration system could be considered, but the cost is upwards from $5000 and usually treats millions of gallons of water.

c. Enzymes

Enzyme boosts are easy to apply, boosting naturally occurring anaerobic bacteria and therefore decreasing conditions for pathogenic aerobic bacteria to propagate. In addition to circulators, these enzymes could be added at about a gallon a week, $75 per gallon, through the swimming season to decrease potential algae and possibly help minimize coliform (Gress 2012).

5.1.2 Case Study

Lion's Beach on *Lions Pond*, 1400 Palmer Drive Janesville, Wisconsin
Similar to Trout Lake in size and residential zoning, Lions Beach is a natural spring fed pond which has always provided swimming (Slapak 2012). Aquatic Biologists, inc., a lake and pond management company, employed the use of three mounted circulators to move water over the beach of this 8.3 acre lake (Gress 2012). They kept the electrical powered circulators running 24/7 through the summer, which increased water quality and reduced coliform counts, permitting the beach to remain open for swimming in the summer (Gress 2012). The circulators have not been used since a flood in 2008 flood as coliform counts have remained low (Slapak 2012).


Figure 5.6: Lion's Beach, Janesville


Figure 5.7: UV system (D'Andrea 2009)

Sunnyside Beach, Toronto, Ontario
Situated near the mouth of the Humber River, microbial source at Sunnyside Beach confirmed *E.coli* present from multiple sources, including bird and geese droppings. As it is very costly to redirect flow away from the beach, the city funded a 3 year pilot project to investigate the effectiveness of a closed UV filter system (D'Andrea 2009). An area of shoreline (200m by 30m) was isolated with a curtain, pumping the 6000 m^3 of water through a UV filter for disinfection (D'Andrea 2009). The water quality was significantly improved within the enclosed area with an average of <17% beach closures during the summer months. However, this closed system UV filtration solution cost $975, 000 to cover capital costs for the UV filter system, maintenance (filters frequently clog) and electricity (Stinson 2012).

5.3 Recommendations

If a closed system strategy is employed, it is highly recommended to:

a. Move the water constantly during the summer swimming months
b. Employ the use of a dock mounted circulator to move the water
c. Supplement the circulator with a UV filter if high coliform counts persist

5.4 Benefits

- increased coliform decay rate (k) through increased UV radiation exposure via water moving devices improves Trout Lake water quality through the reduction of pathogenic bacteria
- improves oxygen content in the lake by increasing water movement further reduces coliform counts by creating a less hospitable environment for pathogenic bacteria (anaerobic)
- restores historic water source by maintaining Trout Lake as a natural swimming lake (promotes recreation)
- cost effective

5.5 Drawbacks

- does not address stormwater in new catchment area, therefore will not reduce combined sewer overflows (CSOs) to Burrard Inlet
- closed system will not have any affect on the water quality in False Creek as no flushing is occurring

5.2 City stormwater inputs and outputs, with associated biofiltration techniques

A strategy which incorporates stormwater inputs through the separated combined stormwater piping system could decrease the amount of coliform in the lake by adding treated stormwater with less desirable conditions for pathogenic bacteria than the current lake water. A proposed new catchment area of 290 ha would supply stormwater through biofiltration techniques (such as a constructed wetland), before entering the main body of Trout Lake. In gathering water from the catchment to a point source release in the park, the increased flooding of John Hendry Park will be mitigated by an overflow pipe to the south. This reduces the load of untreated stormwater in the system being sent to Clark Drive. A proposed additional outlet from Trout Lake to False Creek would send overflows of biofiltered stormwater to flush False Creek. Some of this system could be daylighted to reveal the water through a network of ponds.

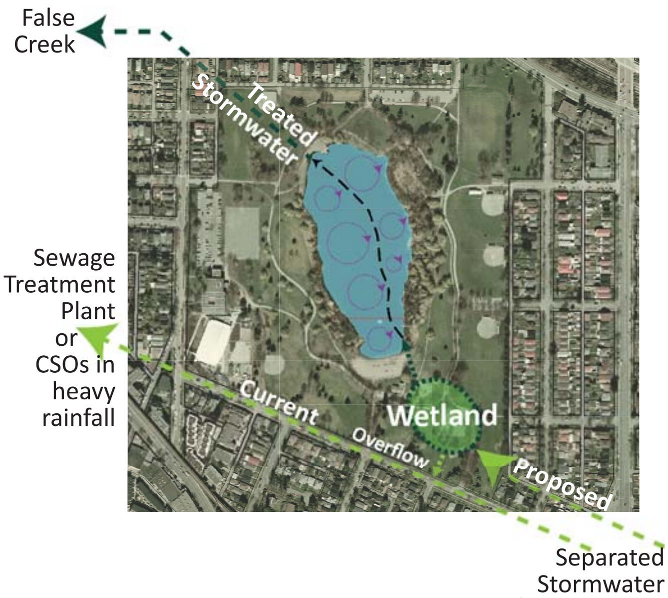

Figure 5.8: City Stormwater inputs and outputs: Biofiltration System Model using a Wetland

Stormwater

The abundance of fecal bacteria in a watershed has been linked to urban areas and impervious surfaces (Koski and Kinzelman 2010). Stormwater has been found to exceed primary contact recreational standards for bacteria regardless of land use in the surrounding area (Koski and Kinzelman 2010). Stormwater BMPs focus on increasing infiltration of groundwater and transpiration, and/or reducing bacteria and pollutant loads through retention and filtration (Koski and Kinzelman 2010). Fecal coliform actually adsorb to suspended particles, with 15 - 30% of fecal bacteria associated with suspended particles in stormwater (Koski and Kinzelman 2010). Bacteria not attached to sediments (up to 50% in stormwater) are difficult to remove because of slow settling rates (Koski and Kinzelman 2010). Introducing stormwater into the lake will increase coliform counts and greatly increase the potential of nutrient loading and heavy metals in Trout Lake (NCDENR 2009). Any stormwater inputs must be cleansed and heavy metals removed prior to entering the lake.

5.2.1 Proposed Actions

a. Wetlands

As important buffers between urban areas and water, wetlands provide water filtering services, habitat, temporary storage, and are aesthetically pleasing. Wetlands incorporate chemical processes of absorption, oxidation and toxins released by plants; biological processes of microbial degradation, ingestion and bacteriophage attacks; and physical processes of sedimentation and UV light exposure (Koski and Kinzelman 2010). Wetlands are increasingly being used to lower pollutant levels in contaminated water including stormwater runoff (Hinds *et al* 2004). Wetlands provide high suspended sediment removal (85%), however they have a limited ability removing nitrogen (40%) and phosphorus (40%) removal (NCDENR 2009).

Coliform reduction varies according to several factors including the type of vegetation, amount of plant coverage, hydraulic retention time, settling of microorganisms and time of year (Karim *et al* 2008, Hinds *et al* 2004). Multispecies wetlands have been found to reduce total and fecal coliforms by 98 to 93 percent respectively over an average 3.8 day retention time (Karim *et al* 2008).

Studies have found that total and fecal coliform bacteria are more greatly reduced in wetlands when aquatic plants are present (Karim et al 2008). This greater reduction of coliform could be due to increased competition for limited nutrients and/or predation by beneficial microbes (Karim *et al* 2008) [nematodes, protoza and ciliates that build the soil, digest organic matter and crowd out harmful microorganisms (Valentino 2012)]. The presence of aquatic plants could create a nutrient rich environment in the rhizosphere zone, increasing the natural flora and potentially promoting predation on coliform (Karim *et al* 2008).

Natural Wetlands

When using natural wetlands for water treatment, the effect to resident wildlife and other ecological ecosystem services must be considered (Koski and Kinzelman 2010). It is also difficult to predict the amount of discharge a natural wetland can treat (Koski and Kinzelman 2010). Engineering parts of a natural system, such as repurposing Trout Lake as a wetland, will disrupt its current ecosystem functioning.

Constructed Wetlands

By building an offline constructed wetland, inflow and outflow capacity can be optimized while increasing the overall habitat value of John Hendry Park and maintaining the current habitat Trout Lake provides.

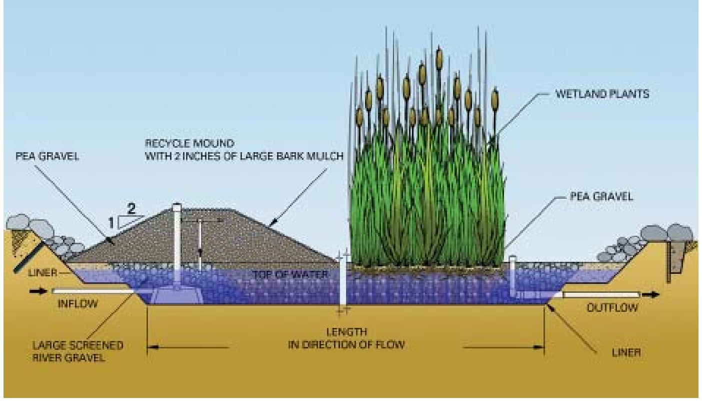

Figure 5.9: *Free Water Surface Constructed Wetlands*
(Natural Systems International 2012)
cheaper to construct
inhibited by ice in colder climates

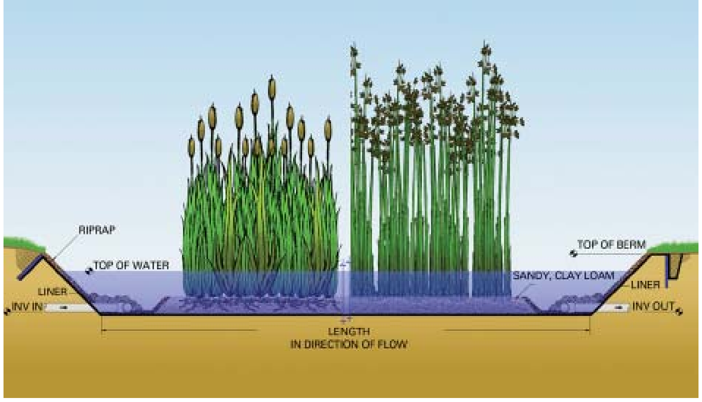

Figure 5.10: *Subsurface Constructed Wetlands*
(Natural Systems International 2012)
require water to percolate through sediment
require more maintenance
higher treatment efficiency in colder climates
(thermal protection)

b. Bioretention with Internal Water Storage (IWS)

Consists of a soil bed planted with non-invasive vegetation, with a 90 degree elbow to the underdrains to create an elevated outlet (NC State University 2009). Bioretention requires a minimum depth to groundwater of two feet to prevent standing water (NCDENR 2009). Has a very high fecal removal ability due to filtration, drying events and sedimentation (NCDENR 2009). In addition, bioretention has high suspended sediment removal (85%), and a medium nitrogen (60%) and phosphorus (60%) removal efficiency (NCDENR 2009). Designed specifically for smaller flows, with medium to high construction and maintenance costs and moderate habitat value (NCDENR 2009).

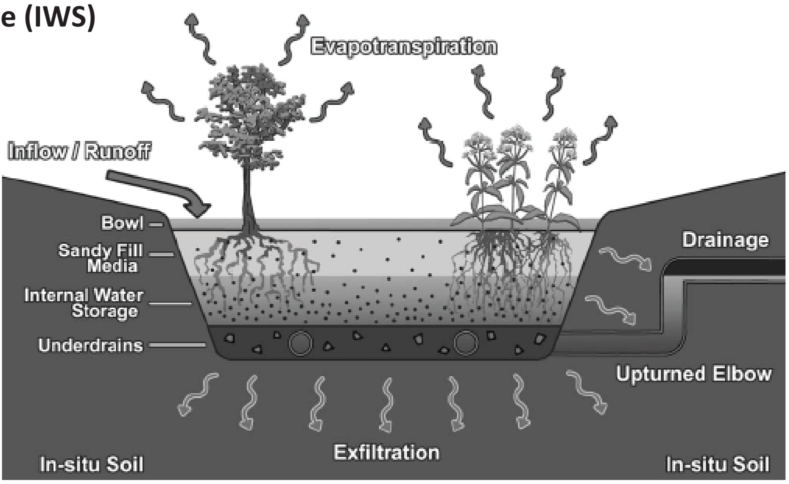

Figure 5.11: *Bioretention with IWS*
(http://wplp.net/f10course/f10coursefiles/bmp_files/BMP_Bioretention_Infiltration(Hu).pdf)

c. Surface Sand Filters

Sand filters involve stormwater entering a dry sedimentation chamber to settle out heavy pollutant particles and then flowing through 18" of sand. Sand filters provide very high fecal removal ability and high suspended sediment removal (85%) (NCDENR 2009). In terms of dealing with stormwater, sand filters have a limited ability removing nitrogen (35%) and phosphorus (45%) removal (NCDENR 2009). Sand filters have a small space requirement, however can only handle smaller flows and would be overwhelmed at the outlet of a large drainage area (NCDENR 2009). In addition, sand filters have high construction and high maintenance costs and low habitat value (NCDENR 2009).

5.2.2 Case Study

Figure 5.12: Bluffer’s Park Beach

Figure 5.13: Bluffer’s Park Beach Contamination Sources (D’Andrea 2009)

Bluffer`s Park Beach, east of Brimley Road, Toronto, Ontario
Constructed wetlands have significantly improved recreational water quality at Bluffer’s Park Beach for swimming (Koski and Kinzelman 2010). Due to historically poor water quality, posted unsafe for swimming >80% of the time, microbial source tracking was employed and identified non-human sources of *E.coli* (D’Andrea 2009). Contamination was caused from the stream outflow from the natural wetland and runoff from the parking lot (D’Andrea 2009). In 2008, a the City of Toronto spent $180,000 to enhance the wetland, including the addition of berms to intercept larger volumes of stormwater and redirect the stream outlet from the main beach area (City of Toronto 2009, D’Andrea 2009, Stinson 2012). As a result of this project, water quality improved and beach closures reported in 2008 and 2009 were <15% (D’Andrea 2009).

Public Bathing Beaches, Racine, Wisconsin
An artificial wetland was constructed to mitigate stormwater associated fecal coliform loading to public bathing beaches (Koski and Kinzelman 2010). Since urbanization of the area, 400 acres of pipeshed is discharged directly onto the beaches (Koski and Kinzelman 2010). In 2000, stormwater fecal coliform concentrations exceeded 1000 coliforms/100 mL , 78% of the time (Koski and Kinzelman 2010). In 2001, mitigation techniques were implemented, first passing stormwater through subsurface treatment (Vortechs System) to separate solids and larger sediments, removing oil and grease, followed by discharge to the constructed wetland (comprised of a series of nine vegetated infiltration basins) (Koski and Kinzelman 2010). After the projects completion, 2003 testing found only 6% of samples exceeded 1000 coliforms/100 mL (Koski and Kinzelman 2010).

Lake Tegel (Charlottenburg district), *Plötzensee*, Berlin, Germany
As many urban lakes exist in Berlin, lakes are closed for swimming instead of treating the water. As swimming is permitted in Lake Tegel, water is treated at a surface treatment plant to decrease algal growth in the lake (City of Berlin 2012). Further, to decrease nutrient loading in swimming lakes such as Plötzensee, the beaches are desludged, decreasing pathogenic bacteria conditions.

5.2.3 Recommendations

If this strategy is employed, it is highly recommended to:

a. Screen stormwater for floatables and biofilter all stormwater diverted to the lake
b. Use an offline constructed wetland to filter the water, which will increase habitat value, can handle bigger drainage catchment areas while being relatively successful at removing nitrogen, phosphorus and suspended sediment from the stormwater.
c. Perform detailed analysis on the amount of stormwater entering the system, including expected summer flow from residential drain tiles
d. Design a wetland big enough to provide long residence times (up to 4 days) for increased nutrient removal and reductions in coliform counts.

5.2.4 Benefits

- improved water quality in False Creek if outflow flushes biofiltered stormwater to False Creek
- reduced combined sewer overflows to Burrard Inlet as stormwater is directed to Trout Lake for filtration
- increased wetland area will increase habitat value in John Hendry Park
- wetlands have zero energy costs and can clean stormwater including removing fecal coliform (Natural Systems International 2012)

5.2.5 Drawbacks

- increased cost to build a constructed wetland
- capital costs to build pipe infrastructure to False Creek
- long residence times (up to 4 days) required for efficient removal of bacteria, nutrient uptake and settling suspended solids, which are more easily met with a larger wetland
- biofiltration requires park area, which might come at the cost of space used by the lake or playfields
- during the summer months, less water is available in the stormwater system to be added to the lake, hence it is harder to change the balance of water to less desirable conditions for the coliform
- could create a bigger coliform issue if a large storm event overflows the system: stormwater overflows will have to be piped directly to the overflow pipe to prevent the wetland from overflowing into the lake
- in building a wetland, coliform in the lake could be increased as the natural organic material in the soil contains coliform and more waterfowl will be attracted to the area

6. RECOMMENDATIONS

6.1 Identify the Source and Increase Sampling Accuracy

a. Initiate microbial source tracking to determine if waterfowl are the main cause of coliform
b. Confirm if dogs are or are not contributing to coliform issue
c. Increase accuracy of sampling fecal coliform in the swimming area, using duplicates as controls

6.2 Immediate Implementation Strategies

a. Keep the potable water fountain turned off
b. Employ closed recirculating water-moving devices to increase summer swimming opportunities
c. Use the dock mounted lake circulator to move the water to increase coliform decay
d. Supplement circulator with UV filter if coliform counts remain high

6.3 Future Implementation Strategies

a. Keep the potable water fountain turned off and increase public education regarding the inefficiencies of this technique and the potential for of the other strategies
b. Study to test if enough water would be in the system for summer flushing
c. Analysis size requirement of wetland for an input/output system strategy

7. CONCLUSIONS

If the issue of concern is coliform counts, than the closed re-circulating system strategy (5.1) is a cost-effective strategy to improve water quality and make Trout Lake a natural swimming lake. Improving the water quality in Trout Lake will increase the habitat value, opportunity for recreation and relaxation in the East Vancouver area, enhance the community appeal and increase the property value. However, as a closed system this method will not improve the water quality in False Creek or reduce CSOs to Burrard Inlet.

If the issue of concern is purely coliform counts and the goal is a natural swimming area, than the City stormwater inputs and outputs strategy (5.2) is not as cost effective or successful in dealing with coliform as low rainfall in the summer months will result in unreliable water additions to the lake. Further, this strategy has the risk of nutrient loading (phosphorus and nitrogen) and heavy metals from the road which require biofiltration (hence the necessity of a biofiltration). This strategy provides a systems approach to deal with water quality issues in False Creek. Bringing biofiltered stormwater into False Creek may improve its water quality, but may increase the challenge of improving the water quality in Trout Lake.

If the issue of concern is the overloaded stormwater system and CSOs into Burrard Inlet, the stormwater input strategy should include stormwater mitigation using street level infiltration methods which encourage natural filtration (reducing the load on the piping system) such as Low-Impact Development (LID), Rainwater Management and Urban Watershed Protection such as pervious pavement, green roofs, bioretention, rain gardens and disconnected gutters (Dunnett and Clayden 2007). Clearly, the definition of the problem and the objectives of the solution will determine which strategy is a best fit.

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