A restoration strategy to avert the projected ecological, social and economic risks of Lost Lagoon in Stanley Park, British Columbia

By

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Abstract

The coastal saltmarsh that once made up Lost Lagoon was isolated into a freshwater impoundment to enable the construction of the Stanley Park Causeway in 1916. Water chemistry, water nutrients, and subsurface sediment were collected in August to October 2017, and it was concluded that Lost Lagoon is experiencing, low DO (average 6 mg/L), high salinity (0.9 ppt), high nutrient loading (TP 0.1 mg/L and TN 0.9 mg/L) and has elevated heavy metals (Cd, Cu, Ni, Pb, and Zn). A general biotic inventory was conducted and results indicated a lack of native species diversity and presence of invasive species, for both flora and fauna. Projected future conditions concluded that Lost Lagoon is prone to stratification and higher temperatures, which is expected to further water impairment including, increases in NH_3 and toxic algae blooms. To mitigate this trajectory, a systematic restoration plan was developed to reintroduce tidal flushing into Lost Lagoon from Coal Harbour's western basin, thereby restoring the degraded ecosystem into a diverse coastal saltmarsh. Hydrogemorphology and flow rates were estimated and as a result a 1.3-m wide water channel was recommended. A planting and long-term monitoring plan that will aid in revitalization of a coastal saltmarsh was developed, alongside a preliminary project budget and schedule. The project feasibility and public response were discussed as constraints, with emphasis on furthering this proposed restoration plan with professional engineering, and First Nations and public consultation.

Keywords: restoration; urban wetland; saltmarsh; intertidal ecosystems; ecological projections

The Lost Lagoon

It is dusk on the Lost Lagoon,
And we two dreaming the dusk away,
Beneath the drift of a twilight grey,
Beneath the drowse of an ending day,
And the curve of a golden moon.

It is dark in the Lost Lagoon,
And gone are the depths of haunting blue,
The grouping gulls, and the old canoe,
The singing firs, and the dusk and you,
And gone is the golden moon.

O! lure of the Lost Lagoon,
I dream tonight that my paddle blurs
The purple shade where the seaweed stirs,
I hear the call of the singing firs
In the hush of the golden moon.

By, Emily Pauline Johnson (1911)

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List of Acronyms and Abbreviations

B.C.	British Columbia
BCIT	British Columbia Institute of Technology
BIAP	Burrard Inlet Action Plan
CCME	Canadian Council of the Ministry of Environment
COV	City of Vancouver
FIDQ	Fish Inventory Data Queries
FTW	Floating Treated Wetlands
HHWMT	Higher High Water Mean Tide
IBA	Important Bird Area
IPCC	Intergovernmental Panel on Climate Change
KWL	Kerr Wood Leidal Associates Ltd.
LLWMT	Lower Low Water Mean Tide
PMV	Port Metro Vancouver
SPES	Stanley Park Ecological Society
SLR	Sea Level Rise
VPB	Vancouver Park Board

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Chapter 1. Introduction

Coastal salt marshes are among the world's most valuable wetland ecosystems. They are highly productive with a structural complexity that supports a wide diversity of aquatic and terrestrial organisms. They act as natural flood buffers, critical nutrient sources, and nurseries and resting grounds for migratory species. They have myriad cultural and social benefits, such as resource extraction, recreation, and ecotourism (Barbier et al. 2011, Fourqurean et al. 2014). Coastal marshes are also one of the planet's most efficient blue carbon sinks; by sequestering carbon in their vegetation and sediment, they effectively support climate change mitigation (Macreadie et al. 2013).

However, wetlands in general are among the most degraded, damaged and destroyed ecosystems in the world (Gibson et al. 2007, Barbier et al. 2011). Since the time of European expansion, over half of the world's wetlands have been lost (Smardon 2009). In Canada alone, over 20 million hectares (ha) have been permanently drained or destroyed (Environment Canada 1991, Davidson et al. 1999). While marshes constitute only 2.3% of the coastline in British Columbia (B.C.), they are being lost at an accelerating rate (Emmett et al. 2000, Gibson et al. 2007). The leading cause of marsh degradation and loss is climate change that influences sea level rise (SLR), and land use changes such as urban development, large-scale industrial projects, and agriculture (MacKenzie and Shaw 1999, Kearney and Rogers 2010). Consequently, the practice of wetland restoration can create positive feedback loops. By mitigating the processes that are the leading cause of marsh degradation, restored wetlands contribute to the overall vitality of aquatic ecosystems which are integral to the success of life on this planet. In addition, wetland restoration will expand policies to protect wetland ecosystems.

This report is an applied research project designed to assess the environmental conditionof Lost Lagoon, a degraded freshwater impoundment located within the boundaries of Stanley Park, in the City of Vancouver, B.C. The main project goal is to determine the restoration strategies required to return Lost Lagoon to its natural ecological state as a coastal saltmarsh. The primary objectives are to: (1) assess current conditions of Lost Lagoon and anticipated future conditions if it remains on its current trajectory; (2) identify Lost Lagoon's current social, economic, and ecological characteristics and contrast them with those of a prospective restored saltmarsh and (3) create a restoration plan to restore Lost Lagoon to its former coastal marsh ecosystem through the utilization of reference ecosystems and historical analysis.

This report is divided into five chapters. Chapter 1 introduces the project site and outlines the project purpose and rationale. Chapter 2 explores the historic, present, and projected future conditions of Lost Lagoon with and without restoration. Chapter 3 describes the methods, results, and discussion for an environmental assessment of the project site. Chapter 4 details the restoration plan, and Chapter 5 concludes the study with suggestions for further ecological restoration.

1.1. Site Description

The project site is Lost Lagoon, a 16.6-ha freshwater impoundment located on the south periphery of Stanley Park, in the Coastal Western Hemlock Biogeoclimatic Zone of B.C. (Pojar et al. 1987). It is situated west of the Stanley Park Causeway (Highway-1A) and Coal Harbour, a section of Burrard Inlet in the Georgia Basin of the Pacific Ocean (49.29577° N 123.14028° W) (Figure 1). Lost Lagoon is one of Vancouver's main freshwater wetlands on the unceded territory of the Tsleil-Waututh, Musqueam, and Squamish First Nations. The Ministry of Environment (MOE) classifies Lost Lagoon as a lake, however it better reflects a shallow open water wetland. It has a relatively flat bottom and an average depth of 1.2-m. The Vancouver Park Board (VPB) and Stanley Park Ecological Society (SPES) have co-managed Lost Lagoon since entering into the Joint Operating Agreement in 1997.

Figure 1. Lost Lagoon in Stanley Park, Vancouver, B.C. west of Highway-1A (Stanley Park Causeway) and Coal Harbour (figure created on iMapBC).

The landscape surrounding the wetland is moderately flat, ranging from sea level to a 20% slope with an underlying layer of shale (Worcester 2010). There are few native fish and herptile species in the water, although many resident and transient birds occupy the impoundment throughout the year. Aside from a patch of vegetation in the northeast corner, there are limited aquatic and riparian vegetation communities. A 1.8-km pedestrian trail borders the water and can be accessed from North Lagoon Drive. The Stanley Park Nature House, an ecology centre, is located on the southeast shore of the impoundment and a concrete border along the building inhibits vegetation establishment along this stretch of shoreline. There is a First Nations midden site located on the north shoreline, where birds and small mammals have been observed digging up ancient shells.

There are five main ecosystems that make up Coal Basin, the area in which Lost Lagoon is situated (Figure 2). Furthest west is (1) Second Beach, containing an outdoor swimming pool facility and a playground along the coastline of English Bay. A small grove of trees divides the south boundary of the playground and a small golf course called Stanley Park Pitch and Putt, which borders the southwest end of Lost Lagoon. Next is (2) Ceperley Meadow, a shallow vegetated wetland that connects to (3) Ceperley Creek, which leads into the west end of (4) Lost Lagoon. About 25-m from the east edge of Lost Lagoon runs the Stanley Park Causeway, a section of Highway 99. East of the causeway is (5) Coal Harbour, a bay in Burrard Inlet in the Pacific Ocean. Coal Harbour is home to extensive private and commercial marine activities associated with the Port of Vancouver.

Coal Basin was not always this developed. Since time immemorial, Lost Lagoon was connected to Coal Harbour. The 1916 construction of the Stanley Park Causeway isolated the lagoon from the ocean, creating a freshwater impoundment. The area has been more difficult to manage ever since. A combination of evident and undetermined ecosystem stressors has created an urgent need to assess restoration options for Lost Lagoon.

Figure 2. Main ecosystem units in Coal Basin: (1 Green) Second Beach, (2 Purple) Ceperley Meadow, (3 Yellow) Ceperley Creek, (4 Red) Lost Lagoon, and (5 Blue) Coal Harbour in Vancouver, B.C. (photos retrieved from Google Earth and P. Woods).

1.2. Project Purpose and Rationale

Although Lost Lagoon is an established wetland, it is fed by chlorinated city water to maintain its water levels. It is also influenced by numerous anthropogenic stressors, most prominently the presence of a barrier that restricts tidal movement. The purpose of this applied research project was twofold. Firstly, it helps determine to what extent Lost Lagoon is degraded by developing a better understanding of its current and projected future conditions. Secondly, it suggests what remedial action is required to increase structural complexity for native marine species and blue carbon storage, as well as providing numerous ecological, social, and economic benefits to the surrounding environment.

A main focus of the study is to evaluate the ecological, social, and economic values that can gained from removing the tidal barrier that is preventing Lost Lagoon from existing as a diverse coastal saltmarsh. To carry out this project, a thorough investigation of the impoundment and its environs were conducted to determine the many factors influencing its current ecological status. The projected risks and benefits that are derived through this radical intervention are demonstrated through data collection and analysis, a literature review, and professional consultations. Additionally, this report builds on approaches for successful coastal restoration and demonstrates alternative ways information can be delivered to the public within the emerging field of ecological restoration.

Chapter 2. Site Conditions

2.1. History of Lost Lagoon

An effective starting point for restoration is to understand the history that lead the project site to its current conditions. In this case, about 100 years ago, Lost Lagoon was a fully functioning coastal saltmarsh (Figure 3). High tide would reach as far as Second Beach and low tide would expose about 17 ha of mudflats. The low-gradient intertidal ecosystem provided refuge for many marine species such as marine fish, shorebirds, waterfowl, crustaceans, and invertebrates (Steele 1985, Stehr et al. 2001). The vegetation structure and composition were not well documented, however common intertidal species such as salt grasses (*Spartina* spp.), rushes *(Juncus* spp.) and sedges (*Cyperus* spp.), were presumed to have colonized the shoreline.

The area was primarily inhabited by the Tsleil-Waututh, Musqueam and Squamish First Nations (VPB 2011). It was given the name Ch'ekxwa'7lech, meaning "gets dry at times", when low tide exposed the mudflats and clams were harvested (Steele 1985, Kluckner 2006). However, as the population grew in Vancouver, so did the demand for better access from downtown to Stanley Park and the North Shore. In 1909, the city put forward a proposal to expand Highway 99 1A, known today as the Stanley Park Causeway (Steele 1985). By 1916, 2.2 km of the Causeway was constructed and considerably upgraded until 1962 (Worcester 2010).

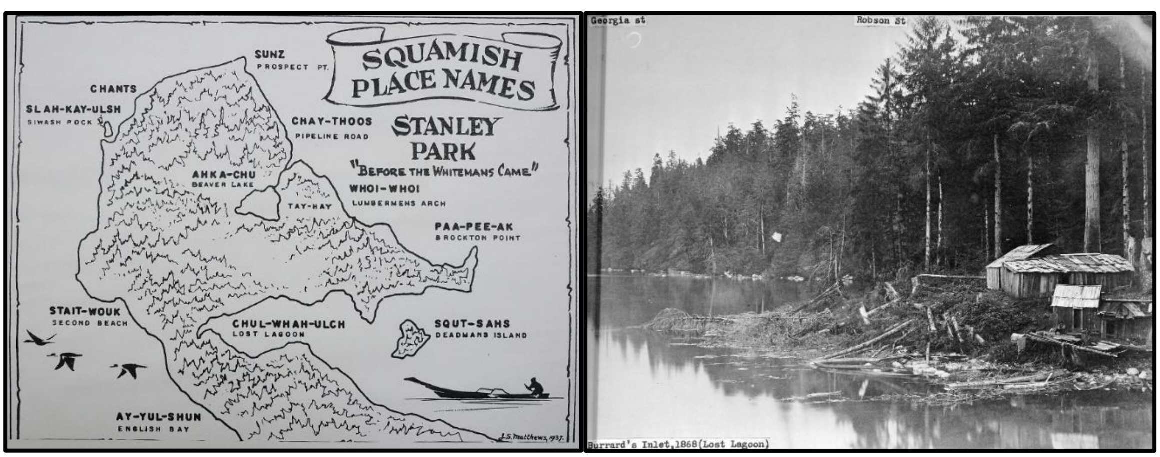

Figure 3. A map of Stanley Park in the time when Lost Lagoon (Chul-Whan-Ulch) was connected to the ocean (left) and a photo of the original coastal saltmarsh at high tide in 1868 (right) (Photos from Vancouver archives 2017).

Ultimately, this anthropogenic alteration eliminated Lost Lagoon from being a coastal saltmarsh. Over the years Coal Basin endured drastic changes in its terrestrial and aquatic landscapes (Figure 4 and 5) and the vegetation structure, species diversity, and physical and biological processes of Lost Lagoon were altered (Steele 1985, Worcester 2010, Van Loon-Steensma and Vellinga 2013).

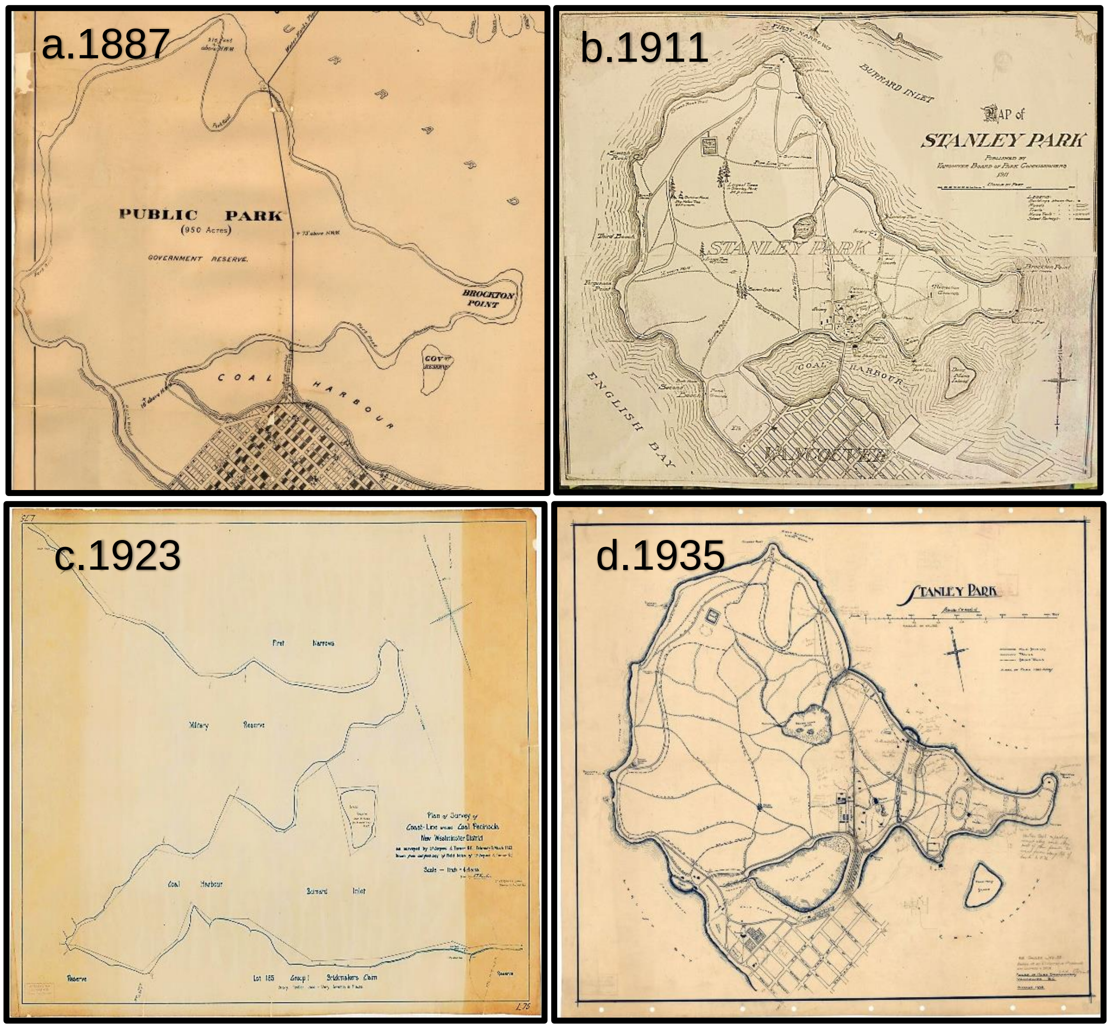

Figure 4. Historical maps showing a variation of 'improvements' to the Lost Lagoon's landscape over the years where, (a) Lost Lagoon is connected to Coal Harbour with free-flowing ocean water under a bridge, (b) advanced development of public access into Stanley Park, still with free-flowing ocean water into Lost Lagoon, (c) a sketch to survey Causeway expansion and (d) the first overview of Lost Lagoon as a captive body of water after full Causeway construction. (Photos edited from the Vancouver archive accessed in 2017).

Initially, the Causeway design included pipes that connected the impoundment to Coal Harbour; however, they were deactivated in 1923 (Worcester 2010). At that time, the natural water supply to sustain the impoundment was insufficient. A pipe that feeds treated municipal water into Lost Lagoon was installed at the head of Ceperley Creek (VPB 2011). A one-way flap-gate control valve was installed at the east end of the impoundment to allow water outflow and prevent ocean water inflow. However, saltwater incursions take place (Worcester 2010).

Figure 5. Construction of Stanley Park Causeway in 1916 in Vancouver, B.C. (photo from the Vancouver archives).

In September 1929, the B.C. Fish and Game Protection Association stocked Lost Lagoon with 100,000 cutthroat trout (*Oncorhynchus clarkii*) and rainbow trout (*Oncorhynchus mykiss*) and the Stanley Park Fly-Fishing Association was created (Worcester 2010, VPB 2011). The stocking however, was only temporarily successful due to unsuitable water conditions for trout. Other fishkill events have periodically occurred such as one in 1994 that killed 561 fish (FIDQ 2017, Worcester 2010).

In 1936, an electrical fountain made of creosote treated timber and concrete was installed in the southeast portion of Lost Lagoon (Friedrichs and Henley 2016). It has required a great deal of maintenance over the years and is currently under repair. In 1938, a pedestrian trail bordering the impoundment was constructed and Lost Lagoon was established as a wild bird sanctuary (FIDQ 2017, Worcester 2010). A Park Board

Feeding Program would empty feed into Lost Lagoon's southeast shore for a captive swan population but it was withdrawn in the early 2000s (Steele 1985, Worcester 2010). Despite being a constructed wetland as a result of urban development, Lost Lagoon is recognized for birding and its aesthetically pleasing views. However, the degraded ecosystem is a shifted baseline and its need for restoration is hidden behind a facade of social attachments, as the public have become accustomed to the urban green space it provides.

2.1.1. Previous Studies

There have be a number of restoration projects previously conducted on Lost Lagoon (Figure 6). Many of which were carried out by SPES, Kerr Wood Leidal Associates Ltd. (KWL), EcoStewards, and students from both British Columbia Institute of Technology (BCIT) and Capilano College. These included, monthly bird surveys, development and maintenance of a sanctuary island, weekly water chemistry sampling, a bathymetric map, and updating an online database called iNaturalist with identified plant and animal species that occupy the area. A report titled 'State of the Park for the Ecological Integrity of Stanley Park' (SOPEI), documents the conditions of ecosystems within Stanley Park. A restoration project occurred in 2001 when a 3,563 metres squared (m^2) biofiltration wetland was constructed to intercept stormwater runoff from the Causeway (Worcester 2010 and VPB 2011). It was dredged once in 2011 but there has been no recent monitoring of its biofiltration success until this study.

Figure 6. Previous restoration efforts in Lost Lagoon., Vancouver, B.C. A sanctuary island (left) and the biofiltration wetland (right) (photos by D. Mackinnon 2017 and P. Woods 2003, respectively).

2.2. Current Conditions of Lost Lagoon

Despite previous restoration efforts such as the biofiltration wetland, Lost Lagoon is under the influence of many anthropogenic stressors. It undergoes excessive sediment infilling, receives high quantities of contaminated runoff and nutrients, and supports an unmanaged and partially unknown community of invasive and non-native species (Worcester 2010, VPB 2011). Furthermore, saltwater incursions result in brackish conditions and recent low water levels are facilitating warmer temperatures making a suitable environment for excessive algae growth (Harris 1986, Eskuenik et al. 2012, Manganelli et al. 2016).

Counterintuitively, Lost Lagoon is a unique wetland that holds many values for the community and freshwater species such as beavers, ducks, and songbirds. Over the past century, humans have grown accustomed to the large wetland, providing them with tangible and intangible benefits such as, recreation and urban green space for general well-being. This report recognizes these values while conducting an assessment of Lost Lagoon's current water quality, and non-native and invasive species to better understand its ecological trajectory with and without restoration.

2.2.1. Water Quality

Although Lost Lagoon is considered a freshwater wetland, saltwater enters periodically from the flap-gate connected to Coal Harbour. This creates brackish conditions resulting in a strongly stratified water profile, ultimately creating a stressful environment for aquatic organisms (Padman 1991, Misra and Chaturvedi 2016). These water conditions coupled with warm water temperatures, reduce dissolved oxygen (DO) concentrations to less than 5 ppm (parts per million) which does not support the growth, reproduction and overall survival of many aquatic species (Gilmore et al. 2018). These conditions promote hypolimnial anoxia, which is the depletion of DO in the bottom of the water profile (Harris 1986). Invasive species, specifically common carp (*Cyprinus carpio*) are hypoxic-tolerant, as they can withstand this type of environment and are therefore the dominant species in Lost Lagoon (Malekpouri et al. 2016). Due to their spawning and foraging behaviors that disrupt benthic sediment, common carp are the catalysts of the highly turbid environment in Lost Lagoon (Badiou and Goldsborough 2015).

Aside from precipitation (1,258 mm annually), groundwater and seepage from adjacent streams, the only significant source of freshwater input is chlorinated municipal water from a city pipe. The pipe flushes water at a rate of 466 liters per minute (L/m) (over 300,000 cubic metres (m^3) per year), however, is turned off in periods of dry weather for water conservation (Worcester 2010). The amount of potable city water consumed per year varies but is generally an economic loss. For example, in 2013, a total of 86,715 m^3 of water was used compared to 1,069 m^3 in 2016, and 0 m^3 in 2017 (N. Page, 2017 personal communication). Apart from the city water, the other main but minimal sources of water input include, Stanley Parks' Lost Stream, an ephemeral stream, the flap-gate connected to Coal Harbour, a storm drain, and the culvert attached to the biofiltration wetland (Figure 7). Despite these five inputs Lost Lagoon experiences extremely low water depths without the constant supply of freshwater from the city pipe.

Figure 7. Freshwater inputs for Lost Lagoon, Vancouver, B.C. (image developed on Google Earth Pro and modified from Woods (2018) hydrology survey).

Apart from the one biofiltration wetland, there is little control over the quantity of contaminants leaching into Lost Lagoon. About 500 m of the Causeway runs along the east of the impoundment, supporting a heavy volume of traffic, with about 68,000 vehicles per day (Ministry of Transportation and Infrastructure 2014). While the

Causeway is the primary point source of runoff, this study considers other possible sources such as urban fill from adjacent areas. Runoff contains pollutants such as hydrocarbons, heavy metals and toxic organic compounds, and it advances the rate of poor water quality by adding high levels of nutrients, specifically nitrogen (N) and phosphorus (P) (KWL 1999). The excess nutrient loading from anthropogenic sources such as, industrial runoff, fertilizers, and bird feed, maintains Lost Lagoon's eutrophic system. Thus increasing biological activity in the shallow warm water, promoting algae growth and furthering oxygen depletion in the hypolimnion (Manganelli 2016, Gilmore et al. 2018). Over the last couple decades, Lost Lagoon has experienced a number of toxic algae blooms containing, *Anabaena*, *Anacystis*, *Microcystis*, and *Nodularia* species, and it is currently subject to more perpetual blooms (Figure 8) (VPB 2011) (see 2.4. Projected Future Conditions for further detail).

Figure 8. Algal bloom events from 2009 (top left and bottom right), 2003 (top right), and 2013 (bottom left) in Lost Lagoon, Vancouver, B.C. (photos by P. Woods).

Results from a water bacteria study conducted by the VPB in 2004 indicated high levels of *Escherichia coli*, *Aeromonas* spp., *Streptococcus* spp., *Clostridium* spp., and *Salmonella* spp. (Worcester 2010). In freshwater systems, the presence of *E. coli* is a primary indicator that the water is contaminated as it is a harmful fecal bacteria (Health Canada 2012). Resident waterfowl (mute swans and cygnets) were found contaminated with *E. coli* levels that exceeded the U.S. Environmental Protection Agency's recommendation by four-fold (VPB 2011). Another factor taken into consideration is the fountain installed in Lost Lagoon. Although it is thought to aid in water aeration, it increases evaporation and ejects contaminated water about 30 m into the air (Friedrichs and Henley 2016).

2.2.2. Vegetation

The current vegetation community in Lost Lagoon bears little to no resemblance to its original saltmarsh conditions. A forest fire in 1885 and old-growth logging practices between 1860 and 1886 influenced the regeneration of native species such as hardhack (*Spiraea douglasii*) and willow (*Salix* spp.) (Bakewell 1980). However, the majority of the remaining vegetation are introduced or invasive species such as, yellow flag iris (*Iris pseudacorus*), purple loosestrife (*Lythrum salicaria*), Himalayan blackberry (*Rubus armeniacus*), cutleaf blackberry (*Rubus laciniatus*), English ivy (*Hedera helix*), Giant hogweed (*Heracleum mantegazzianum*), Japanese knotweed (*Fallopia japonica*), Bittersweet nightshade (*Solanum dulcamara*), and American black nightshade (*Solanum americanum*) (Worcester 2010).

There is a lack of aquatic vascular plants. Most noticeable is the lack of benthic, submerged, floating, and emergent aquatic plant life (D. MacKinnon 2017, personal observation). The dominant plant life in Lost Lagoon is thought to be primarily planktonic with cyanobacteria contributing the largest amount of biomass. The highest abundance of vegetation is concentrated in the northeast of the impoundment, which was planted for the biofiltration wetland (Table 1 Appendix A).

2.2.3. Fish, Birds and Small Mammals

There is a lack of native wildlife species within Lost Lagoon as well as documentation of historic records of species diversity (Worcester 2010, FIDQ 2017).

Many of the species that would have once occupied Lost Lagoon when it was an inshore marine saltmarsh (e.g., clams, oysters, salmonids, otters) are now replaced by aquatic wildlife that are able to withstand harsher conditions such as, shallow, stagnant, and turbid, brackish and freshwater amidst an urban environment (Steele 1985, Er et al. 2005, Butler 2015).

The invasive common carp is the dominant fish species present in Lost Lagoon. Prickly sculpin and three-spined stickleback are also present (FIDQ 2017). It is unlikely that other fish species occupy the waters, however the fish community has not been rigorously determined to date (Worcester 2010). The presence of herptile species are few; however, a small number of introduced Red-eared sliders (*Trachemys scripta*) reside in the impoundment (Worcester 2010, N. Page personal communication 2017). Disowned pets such as two non-breeding Western painted turtles (*Chrysemys picta*) have also been observed (N. Page, personal communication 2017). A single, large, garter snake was observed in the grasses alongside Lost Lagoon (P. Woods 2018, personal communication). American bullfrogs (*Rana catesbeiana*) and Northern Green frogs (*Lithobates clamitans melanota*) have established themselves in the biofiltration wetland, Ceperley Creek and Ceperley Meadow (Worcester 2010). Both frog species are at high risk in open water and along Lost Lagoon’s exposed shoreline from predation by great blue heron and mammalian predators. Tadpoles in the biofiltration wetland are actively preyed upon by mallard adults and juveniles (P. Woods 2018, personal communication).

Counts of many native bird species reliant upon Lost Lagoon’s aquatic ecosystem have been in a state of decline over many years (Vancouver Bird Advisory Committee 2015). The decrease in waterfowl counts has been particularly noticeable over the past decade, where some once numerous species have declined, likely due to reduced continental and regional populations (Er et al. 2005, Badzinski et al. 2006, Worcester 2010). Many of such species are migratory and winter resident waterfowl (Worcester 2010, Vancouver Bird Advisory Committee 2015).

For example, Lesser Scaup (*Aythya affinis*), which once had winter counts in the many 100’s (1998), and peak roosting counts of about 2,000, have fallen to less than 10 observed on a single day throughout winter months (2017-2018), and Greater Scaup

(*Aythya marila*) have not been recorded in 2017-2018 on routine weekly visits to Lost Lagoon (Vancouver Bird Advisory Committee 2015, P. Woods 2018, personal communication). Mergansers (*Mergus merganser* and *Lophodytes cucullatus*) and pied-billed grebes (*Podilymbus podiceps*) observed from 2006 to 2017, record a change in the proportion of prey species captured, with a decrease in captured three-spined stickleback (*Gasterosteus aculeatus*) and an increase in Prickly sculpin *(Cottus asper*) (P. Woods 2018, personal communication). Further study on forage species and their avian predators should be conducted to obtain a thorough understanding of bird counts.

Since 2010, there has been evidence of a family of resident beaver (*Castor canadensis*) activity (Worcester 2010). Peak population reached six individuals in the summer of 2017 (P. Woods 2018, personal communication). Beaver foraging activity has significantly altered the riparian zone bordering Ceperley Creek, Lost Lagoon and the biofiltration wetland. Beaver dam building has also raised water levels, saturating soils and tree root systems. Other small mammals occupy the surrounding landscape such as, raccoons, squirrels, coyotes, minks, skunks and bats (Kluckner 2006). Many of these wild animals are encouraged to reside in the area, as they tend to receive a large portion of their diet from litter and hand feeding by the public (Table 2 and 3 in Appendix B).

2.3. Environmental Status of Coal Harbour

Coal Harbour, is a section of Burrard Inlet that extends from the entrance of Stanley Park to Hallelujah Point in the Pacific Ocean off Vancouver, B.C. (49.29581°N, 123.13446°W). The resources in Burrard Inlet are managed by Tsleil-Waututh First Nations, Port Metro Vancouver (PMV), the MOE, and the Vancouver Coastal Health Authority. There have been numerous studies conducted on the ecological conditions of Burrard Inlet such as, Burrard Inlet Ecological Action Program 2011, the Burrard Inlet Action Plan (BIAP), and the Burrard Inlet Ambient Water Quality Objectives 1990 by MOE Water Management. BIAP involves ongoing research that provides up-to-date information on trends and status of water quality and species diversity of the area aimed at improving the overall ecological conditions of Burrard Inlet. Non-governmental organizations such as SPES, Pacific Wildlife Foundation, and Wild Bird Trust also help monitor local water quality and wildlife.

Coal Harbour experiences mixed-diurnal tides ranging from 3 to 4.18-m, producing well-circulated water (Lilley et al. 2017, Tide Forecast 2018). At low tide the intertidal zone reaches about 30 to 150 m exposing muddy and silty flats, and a man-made seawall along the shoreline fragmented the original intertidal and subtidal habitat (Stehr et al. 2001, Worcester 2010). The water in Coal Harbour is brackish due to the four main freshwater tributaries leading into the inlet, namely Lynn Creek, Indian Arm, Seymour River and Capilano River (Levings and Samis 2001). Water salinities average 20 to 25 parts per thousand (ppt) and are less than 10 ppt in summer (Lilley et al. 2017). The water is well oxygenated, averages of 6.5 milligrams per liter (mg/L) of DO and pH ranges from 6.5 to 8.5 (Nijman 1990). The maximum water temperature in shallow waters of Coal Harbour reaches an average of 20°C, 15°C in deeper areas and about 7°C or less in the winter (Lilley et al. 2017).

A large number of marine species inhabit and migrate through this part of Burrard Inlet, and it is considered an Important Bird Area (IBA). Many of B.C.'s keystone salmon species use these waters. Namely, pink salmon (*O. gorbuscha*), coho (*O. kisutch*), chum (*O. keta*), sockeye (*O. nerka*), Chinook (*O. tshawytscha*), steelhead (*O. mykiss*), and cutthroat trout (*O. clarkii*) (Levings and Samis 2001) (Table 4 in Appendix B).

The main stressors in Coal Harbour are pollution and contaminated discharges, primarily from port activities (e.g., cargo ships, bulk loading operations, and fishing vessels) and urbanization (e.g., motorized vehicles, sewage effluent, and stormwater runoff) (Nijman 1990, Tkalin et al. 2001). Other incidents add to water impairment in Coal Harbour, such as the one in 2011 at Brockton Point, when the Greater Vancouver Sewerage and Drainage District was fined for discharging untreated wastewater into Burrard Inlet (Metro Vancouver 2014). These types of activities result in many localized impacts such as, introduction of pathogens, suspended sediments, and elevated levels of heavy metals (primarily copper, zinc, lead, and nickel), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) (Lilley et al. 2017). They also tend to alter the water pH, increase sulfur and DO concentrations, and cause underwater noise pollution (Worcester 2010, Lilley et al. 2017).

Influences from climate change have shown a decline in forage fish species in Burrard Inlet and future projections raise concern due to SLR (Levings and Samis 2001). Recent observations on the loss of forage fish species have likely reduced the number of their predators (Butler et al. 2015). For example, herring (*Clupea pallasii*) northern anchovy (*Engraulis mordax*), and surf smelt (*Hypomesus pretiosus*) populations were present in larger numbers in the past and have shown a decline in recent years, similar to their predators, loons and grebes (Butler et al. 2015).

Despite these factors, the future for Coal Harbour is promising as it will benefit from BIAP goals that aim to improve the overall integrity of Burrard Inlet by 2025 (Lilley et al. 2017). Previous studies also concluded a number of contaminants exceeded the legal water quality guidelines, which led the B.C. MOE to set objectives that protect water quality in Burrard Inlet such as, implementing sewer reduction programs (Lilley et al. 2017).

2.4. Projected Future Conditions

Considering Lost Lagoon is subject to many stressors causing deteriorating ecological conditions, steering it far from its natural ecological trajectory, it is expected that the present ecosystem may continue to destabilize and pose many risks to humans and biodiversity. Declining water quality and native species diversity is probable, coupled with increased saline conditions and primary production of algae, which make for a favorable environment for invasive and toxic species (IARC 2010). To study whether water quality and native species diversity will continue to decline field data were collected (see Chapter 3 Data Collection).

According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, climate change will continue to cause an increase in atmospheric temperatures (IPCC 2014). Average yearly temperatures in Metro Vancouver have been projected to increase 1.7°C by 2050 and 2.7°C by 2080 (City of Vancouver 2012). These climatic changes may impact the function, composition and structure of aquatic systems (IPCC 2014). This includes alterations to aquatic food webs, nutrient cycles, circulation and stratification patterns, pH, sediment transport, and increases in storm surges, sea levels, salmon spawning failure and invasive species establishment (Lilley et al. 2017, PCIC 2017). While projected future climate change will continue to influence drier summer seasons and warmer winters, Lost Lagoon's water quality is projected to severely worsen.

Firstly, prolonged summer droughts may cause extremely low water levels due to increased evaporation, reduced precipitation, and limited freshwater renewal due to the city pipe being shut off for water conservation. Shallow water may increase the concentrations of nutrients, heavy metals, and organic and inorganic pollutants and promote higher water temperatures, which may accelerate the rate of eutrophication (Esukenik et al. 2012, Manganelli 2016). Secondly, the sea level of Burrard Inlet has been projected to rise about 20 to 120 cm by 2100 (Lilley et al. 2017). Intermittent saltwater incursions may become more frequent in Lost Lagoon, in turn, increasing salinity levels.

When two water bodies of different salinity concentrations and temperatures meet, a density gradient called a pycnocline is formed (Kjerfve and Magill 1989). Under these projected circumstances, the water profile in Lost Lagoon will become vertically stratified, with an upper layer (epilimnion) of warmer freshwater and a lower layer (hypolimnion) of dense cooler brackish water (Padman 1991). Subsequently, reducing circulation between the upper and lower layers, which require strong winds or increased hydraulic flow to mix nutrients and oxygen throughout the water profile (Padman 1991). Mixing of water in Lost Lagoon is influenced by a variety of factors including, the local climate, runoff, water temperature, salinity, and the rise and fall of the tide in Coal Harbour. However, Lost Lagoon is generally a closed system making it a low-energy environment. It experiences minimal water mixing from low wind action and marginal hydraulic flow. Therefore, a stronger density and thermal stratification in the future will likely advance the rate of water impairment.

Based on the elevation, latitude, and projected climatic conditions, Lost Lagoon is expected to shift from a dimictic shallow open water wetland (mixes in the spring and fall and is iced over and stratified only part of the year), to a warm monomictic wetland (mixes once a year, is not iced over and is stratified most of the year) in winter, and a meromictic lake (does not mix and is stratified all year) in summer (Lewis 1983). Stronger stratification will increase interactions between the sediment-water interface

(Cousins et al. 2010). This may result in an anoxic sediment layer that releases nutrients, orthophosphate, ammonium, and toxic compounds such as, ammonia and hydrogen sulfide (Harris 1986, Cousins et al. 2010). This will likely cause an increase in algae growth, furthering oxygen demand and hypolimnial anoxia. The projected increase of saltwater may also contribute to eutrophic conditions by increasing available P from chloride desorption and sulfate reduction processes (Dijk et al. 2015).

While saltwater incursions will continue advancing salinity stratification, oxygen depletion, and eutrophication, they will also further osmotic stress on riparian freshwater vegetation. Salinity may also release reactive nitrogen (ammonium as NH_4^+) from sediments that have high cation exchange capacity (e.g., sediments with clay content) and decrease nitrification (Ardón et al. 2013, Dijk et al. 2015). This will also contribute to eutrophic conditions and alter biogeochemical processes (e.g., increase sulfide and NH_4^+) which will harm aquatic organisms (Dijk et al. 2015). Additionally, increased salinity results in higher pH, meaning more un-ionized ammonia (NH_3) is converted and released (Diricx et al. 2013).

The most toxic form of nitrogen is NH_3 due to its lack of charge, making it effective at passing through the gills of fish (Diricx et al. 2013), posing sub-lethal effects on aquatic organisms and eliminating future opportunities for species establishment. It is derived from nitrogenous waste such as, plant decomposition, animal metabolic waste, anthropogenic production (fertilizers, cleaning products and pharmaceuticals), and produced by micro-organisms (Meulenbelt 2011). Elevated concentrations accumulate in fish tissue and cause hyperplasia (gill damage), and affect growth rates, development, metabolic processes, and overall survival (EPA 2013).

The threshold levels of NH_3 are dependent on water pH and temperature and vary among species. For most freshwater organisms, a range between 0.53 to 22.8 mg/L is tolerable, however longer exposure times may cause acute or chronic damage. For example, common carp in Lost Lagoon can tolerate high levels of about 17 mg/L, whereas trout and salmon can only withstand 0.2 to 2.0 mg/L (Nordin et al. 2009, Diricx et al. 2013). In the future, projected higher water temperatures and pH may increase the toxicity of NH_3 in Lost Lagoon (EPA 2013). On the contrary, algae uptakes NH_3, therefore excess amounts will not be an issue until colder months when algal blooms tend to decline. However, under future climate change projections, Lost Lagoon's water temperature is expected to rise, which will likely result in increases of NH_3 and cause adverse effects to all aquatic species.

Increased salinity may also lead to higher concentrations of sulfate, which may increase sulfate-reducing organisms that produce hydrogen sulfide (H_2S) (Lamers et al. 2013). Acidic bedrock, like Lost Lagoon's underlying shale, may also stimulate the production of H_2S (Slomp 2013). Projected warmer water temperatures and stratification may support a productive epilimnion from excess nutrient loading and algae growth, while the algae decay and causes anoxic conditions in the hypolimnion. At this time, if there is an increase in H_2S, it may initiate euxinia conditions, causing a toxic environment for aquatic species (Dunnette et al.1985, Slomp 2013).

According to Vancouver Regional Development (2011), the population of Metro Vancouver is predicted to reach about 3.4 million people by 2041. To a certain degree, anthropogenic pressures can be expected to escalate over time and Lost Lagoon may encounter more polluted runoff and nutrient enrichment. Excess N and P primarily derived from domestic and industrial waste are the key nutrients that cultivate algal blooms (Health Canada 2012). Given the projected future conditions (i.e., shallow warm water, limited hydraulic flow, salinity fluctuations, and excess nutrient loading), Lost Lagoon will provide optimal conditions for primary production of cyanobacteria (blue-green algae) (Ardón et al. 2013).

Eutrophic conditions combined with algae growth will influence the abundance of toxigenic cyanobacterium such as, *Microcystis aeruginosa*. Toxic unicellular-colonial microcystin species produce chronic hepatotoxins that attack liver, acute neurotoxins that attack the nervous system, and irritant-dermal toxins that irritate the skin (Esukenik et al. 2012, Manganelli 2016). Microcystin-LR is commonly found in algal blooms in freshwater systems and is classified as Group 2B carcinogen, meaning it is possibly carcinogenic to humans (IARC 2010, Manganelli 2016). Humans, pets and wildlife will likely die or be severely harmed by accidental ingestion of this algae. Additionally, aquatic species will be at risk from oxygen depletion and from the cyanobacteria's ability to suffocate respiratory systems (Manganelli 2016). While algae decomposition will deplete oxygen, it will also influence the release of dissolved N, P and metals stored in benthic sediment, furthering anaerobic and anoxic conditions.

It will be impossible to maintain a stable freshwater wetland without city-supplied water and without such a supply, economic and ecological losses will mount and recreational opportunities will be at stake. Winter skating on Lost Lagoon will no longer take place, as warmer temperatures may prevent the water from freezing. Moreover, the projected climatic conditions that influence hypereutrophic conditions will likely pose problematic health and safety issues that could prohibit public access to Lost Lagoon.

Into the future, it is expected that the deterioration of Lost Lagoon's water quality may jeopardize the health of humans and animals (IARC 2010). It may also restrict access to Lost Lagoon, create aesthetically unpleasing views, and cause foul odors from organic decomposition and H_2S (Health Canada 2012). To avoid this fate, one effective restoration strategy would be to re-introduce tidal flushing into Lost Lagoon.

The introduction of tidal flushing will dilute the excess nutrients and accumulated heavy metals, and it will support destratification, which will eliminate anoxic conditions. Moreover, species diversity, of both flora and fauna are likely to increase from the restored structural complexity of an intertidal ecosystem. Experimental eelgrass plantations, measuring blue carbon potential, and ongoing monitoring of marsh succession will be research initiatives that involve the community. Such initiatives will provide educational opportunities for interested working groups, provide nursery and feeding grounds for marine species including, B.C.'s keystone salmon. Marine birds from Burrard Inlet will be able to feed on forage fish species and microbial communities, as well as use the vegetated shoreline for refuge. Overall, by reconnecting the captive body of water to ocean, water quality will likely improve, while providing structural complexity for native species and ecosystem services that are socially valuable.

A main concern regarding saltmarsh restoration is that Lost Lagoon is one of three large water bodies in Vancouver, and for about a century, local residents have grown familiar to its urban green space. It is therefore important to consider public response to change and integrate Vancouver resident values into the restoration plan. Negative public scrutiny is expected but will be alleviated by the means of educational workshops and surveys that will spread awareness on the ecological, social and economic benefits of tidal restoration. Additionally, this restoration plan is designed to account for both anticipated future changes and ecological, social and economic values. There are a number of projected values lost and gained with and without restoration (Table 1). Overall, it is evident that by restoring the impoundment, more values are gained than lost.

Table 1. Summary of ecological, social and economic issues regarding the restoration of Lost Lagoon, Vancouver, B.C.

Values	Without restoration	With restoration
Ecological		
Lost	• Ecosystem integrity • Ecosystem diversity • Decreased water conservation	• Biological and physical displacements of freshwater species • SLR effects
Gained	• Freshwater biota can remain in the area	• Improved water quality • Support native species diversity • Minimize invasive and harmful species • Remove barrier to provide fish passage • Aquatic species nursery and feeding grounds • Functional intertidal community • Blue carbon system • Climate change mitigation from blue carbon storage and action plan for SLR
Social		
Lost	• Public health and safety • Educational opportunities • Recreation opportunities • Freshwater sourced from city water	• Temporary traffic route alterations • Emotional attachment to freshwater system • Smell of sulphur at low tide
Gained	• Social connection to a novel urban ecosystem is preserved	• Secure public safety and health • Diversified urban green space • Educational opportunities and community engagement for restoration • Provide safe public access • Partner with nature groups and schools
Economic		
Lost	• Cost of maintenance (e.g., weeds, invasive fish) • Cost of city water and water supply system	• Restoration project cost
Gained	• Money not used in restoration can be used in maintenance of a freshwater system	• Increased monetary values from ecological restoration and expanding green urban spaces • Educational workshops and collaboration for project funding, support, and resources.

2.5. Desired Future Conditions

A highly productive intertidal ecosystem with natural tidal flushing is the long-term goal for Lost Lagoon. The desired conditions are to have it restored to a coastal saltmarsh that ultimately support blue carbon sequestration, nutrient cycling, adequate fish passage, wildlife use, and public access. The salinity gradient would support beds of eelgrass (*Zostera marina*), in turn providing a substrate for invertebrates and refuge for juvenile marine fish. The restored saltmarsh would also consist of native intertidal vegetated communities (e.g., sedges and rushes) providing a high production of food resources for fish and wildlife (e.g., invertebrates and a microbial community). Hundreds of migratory and resident birds are expected to occupy the intertidal area, revitalizing an extension of the IBA.

If these saltmarsh processes and functions evolve successfully, within five to ten years post-restoration, the system is expected to begin to passively restore. To reach this point, a great deal of human intervention is required. To better achieve this, reference conditions are targeted to restore Lost Lagoon to a higher quality and more diversified coastal salt marsh while accommodating today's anthropogenic influences.

2.6. Reference Conditions

Lost Lagoon's historic conditions were not well documented and many coastal lagoons near the study site do not possess the same ecological characteristics that the restoration plan sets out to achieve. Therefore, a combination of reference sites were used. The physical landscape of the tidal basin that existed before 1916 was used as a guideline for the area that the restored coastal marsh would occupy. Historic records on the original native marsh vegetation, marine wildlife and aquatic organisms are limited; however, certain species that were expected to have colonized the area were used as a reference for this restoration plan.

The nearest reference site, Maplewood Flats in North Vancouver, B.C. (49.305575° N 123.000160° W) was chosen based on its tidal mudflat characteristics and proximity (about 14 km) to Lost Lagoon. Its vegetation structure comprises of eelgrass beds and the intertidal community is well established with fish, clams, mussels, oysters, invertebrates and marine birds. Maplewood Flats is a conservation area yet undergoes similar urban influences as Lost Lagoon. However, this area has not been altered by a transportation passage and possesses an open connection to the ocean. As a result, a second ecological analog was chosen.

Esquimalt Lagoon (48.427756° N, 123.467048° W) located on the south of Vancouver Island in Colwood B.C., is a shallow 90 ha lagoon connected to the Salish Sea. It is impacted by urban pressures such as, polluted runoff, channel alterations, and human disturbance. Simultaneously, it has intact coastal marsh conditions such as native species composition and structure. Three freshwater creeks feed into the lagoon making it brackish and the northeast section of the lagoon is connected to the ocean, where tidal flushing occurs daily under a wooden bridge (Figure 9).

Figure 9. Reference site Esquimalt Lagoon in Colwood, B.C. The red arrow indicates the Ocean Boulevard Bridge (image to the right) where tidal exchange occurs (photos from Google Earth and D. MacKinnon 2018).

Esquimalt Lagoon is also a Migratory Bird Sanctuary and highly accessible to the public. It closely resembles the future desired state of Lost Lagoon and its historic state when it was connected to the ocean. The hydraulic flow and mixing that occurs in this reference site is the primary feature that is designed into the restoration plan for Lost Lagoon. Both physically and biologically, Esquimalt Lagoon possesses conditions that the restoration of Lost Lagoon strives to achieve.

Chapter 3. Data Collection

3.1. Methods

This chapter sets out the methods and processes used to collect data to characterize and quantify specific environmental parameters of Lost Lagoon and confirm that Lost Lagoon is in need of restoration. Inventories are assembled from historical records, literature reviews and field data collection for water quality, heavy metals in surface sediments, and fish, bird and wildlife counts.

3.1.1. Water Quality Inventory

To collect general trends of water chemistry, a YSI multi-parameter water quality meter was used at 14 locations over the course of three months: August through October 2017. The measurements included: water temperature, DO (mg/L), salinity, and pH. The impoundment was divided into seven zones based on hydraulic functions and physical characteristics namely the (1) inflow (2) outfall, (3) biofiltration wetland, (4) the area directly outside the biofiltration wetland, (5) pelagic zone (deep area), (6) the littoral zone (shallow area) uninfluenced by inflow or outflow, and (7) a heavily altered area along the south cement wall. Two sample sites were selected at random in each of these zones (Figure 10).

The water depth, GPS location, and the parameters under review, were recorded and compiled for analysis in Excel. SPES provided water chemistry measurements from 2016 and 2017, and the averages of the same parameters from August, September and October were extrapolated. This sampling regime allowed the detection of variable conditions in comparison to those measured weekly by SPES at predetermined locations. Lastly, the water chemistry parameters from Coal Harbour were inferred from Burrard Inlet Action Plan and Assessment of Burrard Inlet Water and Sediment Quality 2000. Lastly, a water sampling report for the reference site, Esquimalt Lagoon by Nep2ne Consulting (2002) was used for comparison.

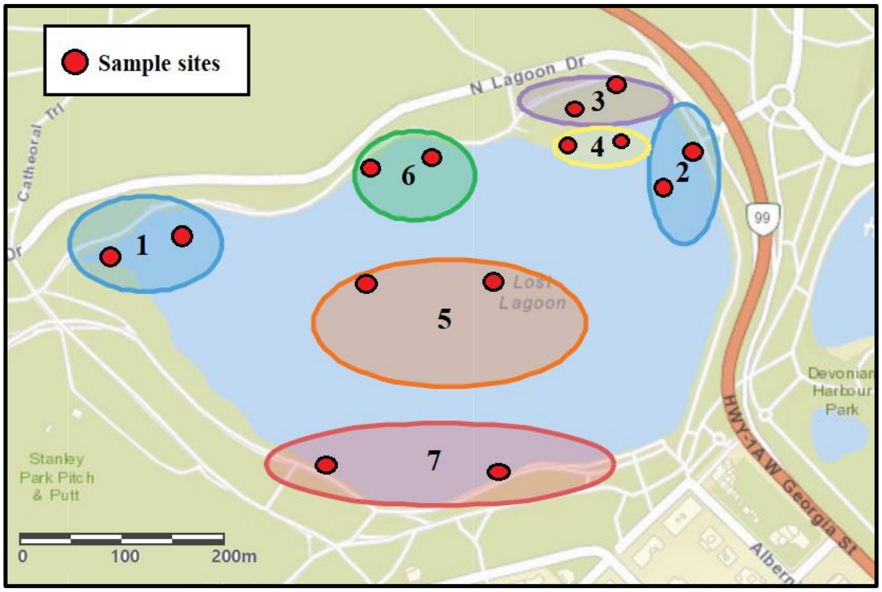

Figure 10. Site locations for water chemistry August-October 2017 in Lost Lagoon, Vancouver, B.C. Zone 1 (blue) inflow, Zone 2 (blue) outfall, Zone 3 (purple) biofiltration wetland, Zone 4 (yellow) outside biofiltration wetland, Zone 5 (orange) pelagic zone, Zone 6 (green) littoral zone, and Zone 7 (red) heavily altered area.

For water nutrient samples, the total nutrients collected were total ammonia nitrogen (TAN) (the sum of NH_3 and NH_4^+), total nitrogen (TN), total phosphorus (TP), and dissolved orthophosphate. Six nutrient water samples across three sites were collected on 30 October 2017. The three sites were selected based on the differentiating water zones within the impoundment: Site 1 (Site LO) was located in the east of Lost Lagoon in the outflow to the Causeway (49.29646°N, 123.13751°W), Site 2 (Site LI) was located at the inflow at the head of Ceperley Creek (49.295580°N, 123.14410°W), and Site 3 (Site BB) was located outside the west border of the biofiltration wetland (49.29681°N, 123.13963°W) (Figure 11).

The water temperature, pH, DO, salinity, and depth at each site were recorded. For quality control, replicate samples were taken and the glass sample jars were rinsed out three times with water from the given site. Samples were collected by a plunge and scoop method at the water surface. Each sample was preserved with sulfuric acid and stored at 4°C. Directly after field collection, they were brought to ALS Environmental, in

Burnaby, B.C. for analysis. Upon arrival it was discovered that dissolved orthophosphate could not be tested due to the small sample jar size.

The Total N in water by colour was analyzed by the APHA Method 4500-P 'Persulphate Method for Simultaneous Determination of Total Nitrogen and Total Phosphorus' and National Environmental Methods Index Nemi method 5735. Total P was tested using procedures from APHA Method 4500-Phosphorus. A colourimetric determination was made after persulphate digestion of the sample. Ammonia was tested by using modified procedures outlined by Watson et al. (2005).

The results were analyzed using the B.C. Working Water Quality Guidelines (WWQG) by the MOE Aquatic Life, Wildlife and Agriculture by the Water Protection and Sustainability Branch (2017). The Lower WWQGs, a concentration that is safe for aquatic life, equivalent to Canadian Council of the Ministry of Environment's (CCME) Threshold Effect Level, or Interim Sediment Quality Guidelines, was compared to the Upper WWGQs, a concentration that if exceeded, would likely be lethal or cause adverse effects to aquatic life (Water Protection and Sustainability 2017). The water quality criteria for nutrient levels that affect aquatic life in lakes by the MOE (2001), measures TP in micrograms per liter (µg/L) and were converted to mg/L for this report. Lastly, water nutrients from a study in 2015 conducted by the Vancouver Parks Board was used to compare and observe trends.

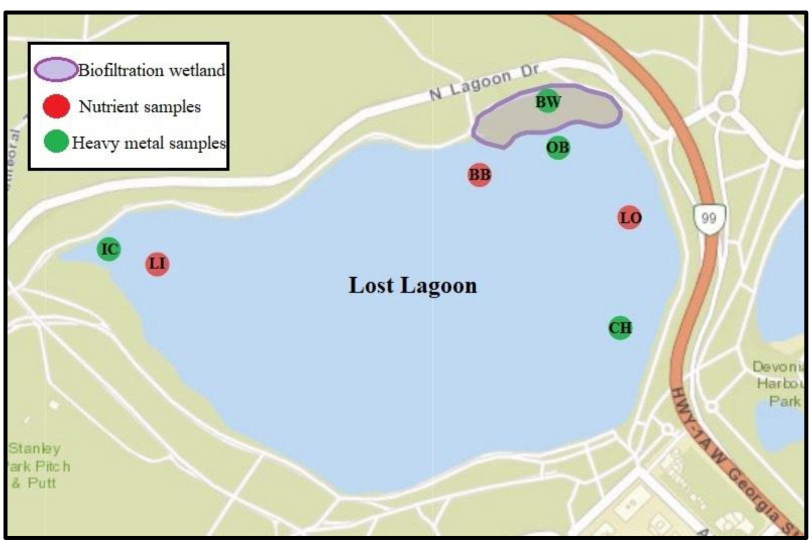

Figure 11. Site locations for sampling heavy metals (green) and water nutrients (red) in August 2017 in Lost Lagoon, Vancouver, B.C.

3.1.2. Heavy Metals Inventory

Four samples of surface sediment were collected by a Ponar grab sampler on 13 October 2017, to be analyzed for heavy metals. The site locations were selected along a gradient that represented contrasting water flow characteristics of Lost Lagoon. Namely, Site 1 (BW), in the biofiltration wetland (49.29760°N, 123.13805°W), Site 2 (OB), directly outside the biofiltration wetland (49.29704°N, 123.13944°W), Site 3 (IC), center of the inflow at the head of Ceperley Creek (49.29612°N, 123.14471°W), and Site 4 (CH), at a runoff entry point into the impoundment near Coal Harbour (49.29690°N, 123.13748°W) (refer to Figure 11). The protocols used were from Part D of Soil and Sediment Sampling on Lake Bottom, from the B.C. Sampling Manual procedures published by the MOE.

At each site, the date, time and weather conditions were recorded. Water depth was measured at the location where the grab sampler was dropped. The colour, structure, texture, odour and presence or absence of debris in each sample were recorded. With a plastic spatula, a portion of each grab sample was scooped into a glass jar and stored in a cooler at 4°C. These samples were brought to ALS Environmental for further analysis. There were 18 total metals measured in the sediment samples, namely, Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Silver (Ag), Thallium (TI), Tin (Sn), Uranium (U), Vanadium (V), and Zinc (Zn).

The ALS Environmental laboratory followed procedures from the B.C. Environmental Laboratory Manual 2007, Soil and Sediment method, Section B Physical/Inorganic and Miscellaneous Constituents. The sediment samples were mixed and dried at approximately 60°C and sieved through a 10/2 mm filter with deionized water at a 1:2 ratio of sediment to water (MOE 2007). The pH was then measured with a pH probe. The results were analyzed using the B.C. WWQG: Aquatic Life, Wildlife and Agriculture by the Water Protection and Sustainability Branch, MOE 2017. The distances from each site to the Causeway were measured and the GPS coordinates were logged into iMapBC, a tool to view and analyze geographic datasets stored in the B.C. Geographic Warehouse.

These results were developed into tables and graphs in Excel, to demonstrate the varying metal concentrations within the impoundment and biofiltration wetland. To extrapolate the elevated metals in Lost Lagoon, Site BW was omitted to avoid skewed results. According to the B.C. WWQG (2017), and the Interim Sediment Quality Guidelines (ISQG), also known as the Lower Sediment Water Quality Guidelines (SWQG), the sediment with a safe level of contaminants will not adversely affect aquatic life. The Canadian Probable Effects Level (PEL) also known as the Upper SWQG, is a level of contaminants that if exceeded, will adversely affect aquatic life (Water Protection and Sustainability 2017).

3.1.3. Bird, Fish and Small Mammal Inventory

The biotic community of Lost Lagoon was determined based on information from the State of the Park Report for the Ecological Integrity of Stanley Park (SOPEI), the website iNaturalist, and from professional observations and consultations. The categories of birds, fish and small mammals were divided into categories; namely, introduced species, native species, invasive species, and species of concern. The species that would benefit from the restoration (i.e., conversion from a freshwater impoundment to a coastal salt marsh) and the species that would be negatively affected, were determined.

The current fish community residing in Lost Lagoon was determined by examining historical records, making personal observations, and consulting with fish experts. Historical data was extracted from the B.C. Ministry of Environment's Fish Inventory Data Queries (FIDQ) database. Lost Lagoon Lake watershed code 900-034300 under the 'Single Waterbody Query' was searched, and the results provided a biophysical inventory of stocked fish and native species from 1929, 1931, 1942, 1995, and 2007. Other inferences were made from the types of fish species and communities that could inhabit Lost Lagoon based on environmental conditions of the area.

3.1.4. Biotic and Abiotic Factors

To contrast 'before' and 'after' restoration scenarios, the key abiotic (e.g., basin topography, substrate, sediment materials, tidal regime, water chemistry, SLR) and biotic (e.g., intertidal vegetation, aquatic organisms) factors that are influenced by spatial and temporal changes, were studied. Data were categorized according to traditional environmental assessment categories and spread over five temporal periods defined by changes to the environment in the past, present and future. Namely: 1) Pre-Causeway – coastal salt marsh, 2) Causeway construction, 3) Completed Causeway – freshwater lagoon, 4) Restored tidal flow, and 5) Post restoration – coastal salt marsh.

3.2. Results

3.2.1. Water Quality

Salinity from the sample inside the biofiltration wetland (0.05 ppt) was the only parameter that differed greatly between sites. This outlier was removed to average the total salinity over the three-month period. One of the sample sites in the littoral zone (Zone 6) was excluded in the results as it was too shallow for proper submersion of the YSI multi-parameter sampler. The water chemistry averages in Coal Harbour, Esquimalt Lagoon (reference site) and in Lost Lagoon from 2016 and 2017 differed slightly, with the largest variance in the salinity range between the ocean (reference site and Coal Harbour) and the impoundment (Table 2, see Table 4 Appendix B for all averages). The pH, temperature and salinity increased slightly from 2016 to 2017, and the DO decreased. Coal Harbour's water chemistry parameters are collected from summer and winter, therefore reflect a greater variation in compared to 2016-17, which were collected in the fall. The reference site parameters reflect values that support marine aquatic life.

Table 2. Average water chemistry parameters over three months (August to October) in 2016-17 in Lost Lagoon, Coal Harbour and Esquimalt Lagoon (reference site), B.C. year-round, with the CCME recommended standards for freshwater aquatic life.

Water chemistry parameters	Averages 2016	Averages 2017	Averages Coal Harbour	Reference Site	CCME Freshwater Aquatic Life
pH	6.9	7.3	6.5 – 8.5	8	6.5 – 9
Temperature (°C)	21.3	24.5	7.0 – 20.0	11.4	>35 or <0
Salinity (ppt)	0.8	0.9	25.0 (winter) <10.0 (summer)	33	0
DO (mg/L)	6.6	6.0	6.5	13.9	5.5 – 9.5

The water nutrients did not vary greatly between the replicate samples or between the sites and the averages of TAN and TP from this study were compared to a study in 2015 (Table 3). According to B.C. WWQG (2017), the lethal amount of ammonia for freshwater aquatic life is 1.23 mg/L, where pH is 7.3 and temperature is about 24° C. Whereas the Canadian Water Quality Guidelines for the Protection of Aquatic Life indicates ammonia toxicity at 1.08 mg/L. The results from this study show that Lost Lagoon did not exceed either threshold limits. While TP and TN do not have lethal levels, they were present in high amounts. In comparison to the 2015 study from the same time of year, the average TAN (0.007 mg/L) and TP (0.111 mg/L) were higher in 2017.

Table 3. Averages of water samples for TAN, TN and TP in August 2017 in Lost Lagoon, Vancouver, B.C.

Nutrients (mg/L)	Site LO	Site LI	Site BW	Study 2015
TAN	0.008	0.007	0.007	0.006
TN	0.949	0.948	0.953	-
TP	0.110	0.111	0.114	0.063

3.2.2. Heavy Metals

Notably, the actual time scale of the sediment samples collected for this study have not been determined beyond recognizing that it has taken an unknown number of years for the heavy metals to accumulate. Therefore, further research by coring and segmenting the cores into sedimentary layers could reveal greater variation beyond the resolution achieved in this study. All the heavy metals except for about two thirds (As, Be, Hg, Pb, Ti, U and V), were found in higher concentrations inside the biofiltration wetland. Table 4 shows the three elevated heavy metals that are most detrimental to aquatic life that were found in higher concentrations within the main body of Lost Lagoon. Site IC had the highest concentrations of each elevated heavy metal.

Table 4. Elevated heavy metals (mg/kg) in higher concretions inside Lost Lagoon than inside the biofiltration wetland, in 2017, Vancouver, B.C.

Heavy Metals (mg/kg)	Site BW	Site OB	Site IC	Site CH
As	5.1	7.5*	6.7*	4.8
Pb	83.0	58.8	105.0*	57.3
Hg	0.092	0.093*	0.228*	0.077

*Higher concentrations

Out of the 18 total metals tested, Cd, Cu, Pb, Ni and Zn were well above the ISQG (Table 5 in Appendix B). They were averaged from all four sites, and for a second time excluding the biofiltration wetland (Site BW) (Table 5). This was done to avoid skewed results, as based on this analysis, the biofiltration wetland demonstrated itself to be successful in trapping about 50% of the heavy metals before entering the impoundment. The average Cu concertation from all four sites was above the PEL (Table 5). The average pH for all samples was 6.1. The ISGQ and PELs were derived from MOE Water Protection and Sustainability (2017) and CCME (1999).

Table 5. Comparison of freshwater ISQG and PELs from the averages of elevated heavy metals with and without the biofiltration wetland (Site BW) in August 2017 in Lost Lagoon, Vancouver, B.C.

Heavy Metals	Averages of all sites (mg/kg)	Averages without Site BW (mg/kg)	ISQG (mg/kg)	PEL (mg/kg)
Cd	1.8	1.6	0.6	3.5
Cu	202.5*	97.0	35.7	197.0
Pb	76.0	73.7	35.0	91.3
Ni	24.3	22.3	16.0	75.0
Zn	305.3	176.0	123.0	315.0

*Exceed the PEL

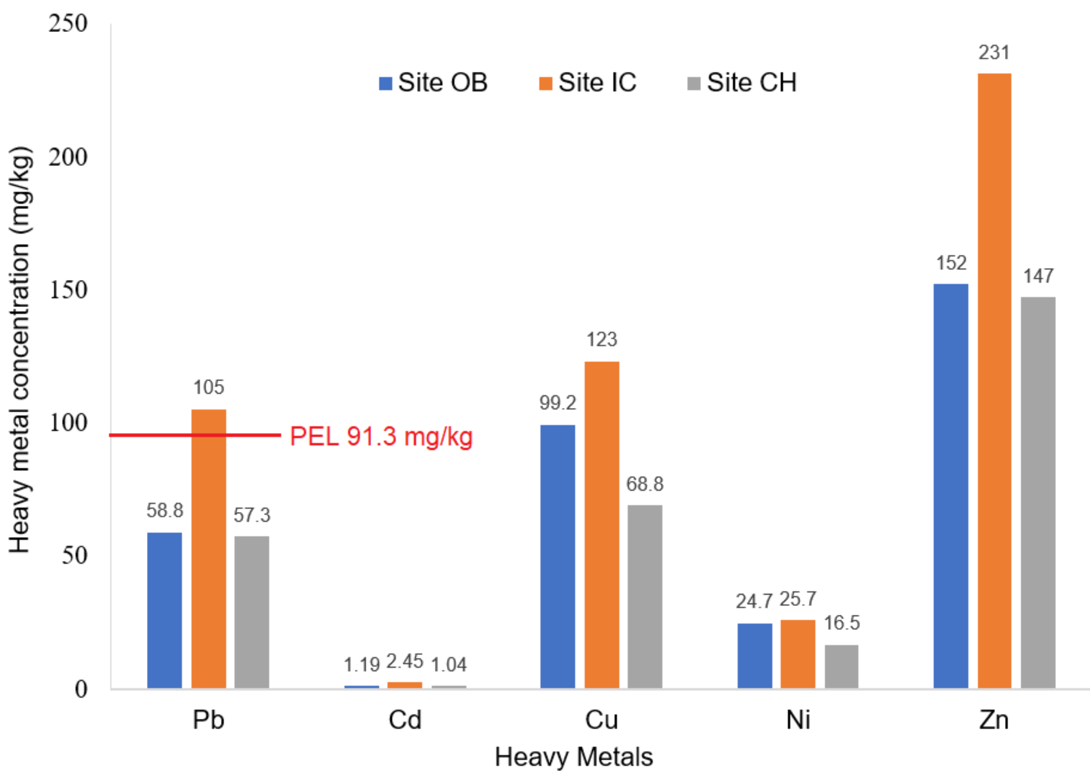

Figure 12. Elevated heavy metal concentrations in Site OB (outside biofiltration wetland), Site IC (inflow at Ceperley Creek), and CH (Coal Harbour) in August 2017 in Lost Lagoon, Vancouver, B.C. The PEL (Probable Effect Level) for Pb in Site IC is denoted by the red line.

The inflow of Lost Lagoon (Site IC) was found with the most elevated metals, specifically Cd (2.45 mg/kg), Cu (123 mg/kg), Pb (105 mg/kg), Ni (25.7 mg/kg), and Zn (231 mg/kg) (Figure 12). At this location, the Pb concentration surpassed the PEL by 13.7 mg/kg.

3.2.3. Bird, Fish and Small Mammal Inventory

The fish, birds and other main wildlife species that occupy Lost Lagoon and Coal Harbour were compiled (Appendix A in Tables 2, 3 and 4) and inferences on bird counts were speculated. The current wildlife community in Lost Lagoon is mainly dominated by invasive species (e.g., the invasive common carp and the invasive Canada goose (*Branta Canadensis*)) and supports species that are non-native (e.g., red-eared sliders (*Trachemys scripta*) and North American beaver (*Castor canadensis*)). The majority of wildlife using the area are avian species and for the most part, their life histories suggest that they may not be adversely affected by a switch to a coastal saltmarsh as they likely do no rely on Lost Lagoon as their primary aquatic resource.

Other aquatic species will easily adapt to the resorted environment. For example, a gradual change in salinity will not be a harmful transition for threespine stickleback. Many juvenile Pacific salmon (*O. gorbuscha*, *O. kisutch*, *O. keta*, *O. nerka*, *O. tshawytscha*, *O. mykiss*, and *O.* clarkia) enter Burrard Inlet from Indian River, Port Moody Arm, and Seymour River in spring and summer, and migrate through Coal Harbour (Levings and Samis 2001). An open tidal channel from Coal Harbour into Lost Lagoon would include a passageway into a protected area for feeding, cover, and osmoregulation for marine fish. In addition, microbial communities and invertebrates will reestablish and become a local food source for marine fish; in turn, providing forage species for birds and small mammals (Kuwae et al. 2012).

3.2.4. Biotic and Abiotic Factors

The major changes that Lost Lagoon has undergone and is projected to undergo with restoration, were divided into three time periods during five distinct ecological states in order to help identify what conditions can be achieved and when. There are a number of key abiotic and biotic factors that existed pre and post-Causeway construction, and those that will be greatly altered from restoration (Table 6).

In the past, Lost Lagoon was a fully functional intertidal ecosystem with well-established coastal saltmarsh and mudflat characteristics. The water exchange from diurnal tide cycles, assisted in maintaining Lost Lagoon's native marsh vegetation and marine organisms. Contrary to today, this ecosystem was not influenced by as many stressors and was able to support a diverse coastal saltmarsh with intertidal mudflats. However, from 1916 onwards, the construction and use of the Causeway deteriorated the natural marine ecosystem and initiated the destabilizing conditions of Lost Lagoon that are observed today.

Table 6. Key abiotic and biotic factors within Lost Lagoon of past and present conditions as well as future restoration scenarios in Vancouver, B.C.

Timeframe		Abiotic factors	Biotic factors
Past	Pre-Causeway – coastal saltmarsh	• Full tidal flushing • Suitable water quality for marine organisms	• Native marsh vegetation communities • Native marine organisms
	Causeway construction	• Altered landscape to create an impoundment • Brackish conditions • Sediment loading and erosion • Contaminated runoff • Industrialization impacts	• Altered structural complexity • Excluded marine organisms • Destroyed marsh vegetation • Obstructed fish passage • Increased human impacts • Reduced atheistic values
Present	Completed Causeway	• Poor water quality • Contaminated runoff • Excess nutrient input • Low DO, water levels, diversity • Strongly stratified water profile • Erosion	• Introduction of non-native species • Invasive species establishment • Toxic algal blooms • Fish kill and osmotic stress on vegetation from salinity incursions
Future	Restored tidal flow	• Freshwater removal • Saltwater inflow • Sediment discharge • Full tidal flushing • Diluted contaminates and nutrients	• Adequate fish passage • Increased marine species diversity (e.g., salmonids, invertebrates, marine birds) • Introduction of native plants • Increased biofilm communities
	Post restoration – coastal saltmarsh	• Full tidal flushing • Exposed mudflats • Suitable water quality for marine organisms and saltmarsh vegetation • Efficient nutrient cycling	• Communities of intertidal and marine organisms • Stable food web • Increased human access and values • Blue carbon sequestration

3.3. Discussion

3.3.1. Water Quality

The recorded water chemistry parameters indicated poor water conditions within the impoundment. For example, adequate fish growth, reproduction, and survival largely depends on adequate DO concentrations in the water profile (Neilan and Rose 2014). The average DO level for the survival of adult salmonids is about 6.5 mg/L, and it is lethal when it is less than 3.0 mg/L for more than three days (Carter 2005, Neilan and Rose 2014). For salmon and trout eggs, DO levels less than 11.0 mg/L will delay hatching, 8.0 mg/L or less will impair growth and lower survival rates, and any concentration under 6.0 mg/L will cause eggs to die (Carter 2005). The time of year, time of day and sources of water inflow and outflow will influence DO levels. Therefore, this study alone cannot ascertain a yearly DO trend. From August to October 2017, the average level of DO in Lost Lagoon was 6.0 mg/L and a study by EVS Environmental Consultants, showed that in the same year in July, the DO of Lost Lagoon was 11.2 mg/L at the inflow and 6.0 mg/L at the outflow (VPB 2011). In both studies, the lowest level of DO is slightly below the threshold (8 mg/L) recommended for many aquatic life (e.g., salmonids) (Neilan and Rose 2014). This is a concern if Lost Lagoon remains isolated, as many species would not be able to survive in these conditions.

The salinity in Lost Lagoon is high (average 0.9 ppt) for a wetland classified as freshwater. Meaning the water conditions are oligohaline, which is brackish water with salinity that ranges from 0.5 to 3.0 ppt (Pawlowicz 2013). In part, this explains why little freshwater vegetation and aquatic organisms are able to establish. Willow trees (*Salix sp.*) on site are unable to tolerate this level of salinity and have shown osmotic stress (Worcester 2010, Dijk et al. 2015). Denitrification for reactive N becomes less common in high saline conditions and is instead released as NH_4, stimulating eutrophic conditions (Ardón et al. 2013).

Excess nutrient loading in warm water temperatures with decreasing volume and minimal discharge and circulation, will result in algal growth (see section 2.4. Projected Future Conditions). Cyanobacteria, a common participant of algal blooms, depletes oxygen and has damaging effects to humans and wildlife (Misra and Chaturvedi 2016). Decreasing water levels not only lower nutrient dilution rates and increase temperatures, it also impacts water pH, subsequently increasing the toxicity of ammonia (Nordin et al. 2009). This study adds to the suggestive evidence that Lost Lagoon is experiencing excessive nutrient loading (TP 0.11 mg/L and TN 0.95 mg/L in 2017 fall period). High water temperatures, climate change projections and city water conservation practices suggest that Lost Lagoon will undergo shallower and warmer water temperatures in the near future. Therefore, toxic algal blooms are expected to occur more frequently, with resulting catastrophic effects on resident wildlife and domestic animals.

Quamichan Lake, in Cowichan Valley on Vancouver Island, is an example of what the future conditions of Lost Lagoon could become. Over the past two years five domestic animals have died from wading in Quamichan Lake from algae blooms containing cyanotoxins (Barron 2017, Cowichan Watershed Board 2018). To avoid these occurrences in Lost Lagoon, restorative action is mandatory. To prevent excess nutrient inputs, the City of Vancouver (COV) needs to establish effective stormwater and drainage plans for this area of Coal Basin. Phosphorous adsorbs on soil particles and enters waterways through stormwater runoff, primarily sourced from animal wastes, specifically bird fecal matter, and possibly from lawn fertilizers (Gedan et al. 2009). By restoring tidal flushing, the concentration and residence time of TN and TP will be reduced. Constant water renewal would promote DO levels adequate for native marine organisms, increase nutrient cycling and dilute contaminated runoff. Restoring marsh vegetation (i.e., purification plants) will also aid in absorbing nutrients that it comes in contact with.

3.3.2. Heavy Metals

Elevated concentrations of heavy metals can cause severe harm to aquatic organisms such as cell damage, altered metabolic processes, bioaccumulation of contaminants in the food web, and decreased osmoregulation abilities (CCME 1999, Sinclair et al. 2015). Human values such as, recreation, and health and safety, are also compromised if elevated heavy metals persist in a water body. To better manage and reduce concentrations of heavy metals, it is important to gauge the type and quantity that have accumulated in the sediments and the rate of soil-water erosion that is causing their release. It is equally important to determine the point and non-point sources.

Increases in water hardness and temperature need to be considered when analyzing heavy metal concentrations, as they directly influence the ability of heavy metals to bind, adsorb, or absorb, causing them to become more abundant and toxic (Sinclair et al. 2015). Heavy metals may become more harmful to aquatic life if the pH of the water is low (i.e., acidic or soft water), as they will dissolve more readily. The average pH of Lost Lagoon (7.3) and Coal Harbour (6.5 to 8.5) are levels of low ecological risk. However, the flushing rate is limited in Lost Lagoon and over time, the accumulation of contaminated runoff and influences of climate change may chemically alter the pH causing accelerated leaching of dissolved heavy metals. Primary production has also shown to control the accumulation of heavy metals from the atmosphere, further suggesting that algae blooms in Lost Lagoon increase heavy metal bioavailability (Duan et al. 2014).

Notably, the lower and upper SWQGs for heavy metals differ between freshwater and saltwater. Therefore, the PEL for some of the metals sampled in this study may not be accurately represented as a result of the brackish conditions that occasionally occur in Lost Lagoon. To obtain more accurate averages, five or more samples per site should be taken over a longer time period. Toxicity trends are also challenging to determine when there are no previous values from Lost Lagoon for comparison. However, the sediment samples collected in this study confirmed that elevated heavy metals are present in Lost Lagoon.

Aside from the biofiltration wetland, there is marginal uptake and filtration of heavy metals due to the limited vegetation on site. While Lost Lagoon is located about 25 m from the Causeway, combustion of fossil fuels, tire wear, and brake pad corrosion contribute to the polluted runoff into the impoundment (Huber et al. 2016). As a result, high concentrations of heavy metals were anticipated. This study revealed that out of the 18 heavy metals tested, Cd, Cu, Pb, Ni, and Zn were found in the highest concentrations. These metals can cause acute or chronic effects to aquatic organisms if they are disturbed from the sediment, depending on physical and chemical factors. These factors include the concentration and bioavailability of the heavy metals, water pH, salinity, alkalinity, temperature, sediment material, length of exposure to the heavy metal as well as the species’ sex, size, and life stage (Zhang et al. 2014, Huber et al. 2016).

For example, Cd can bioaccumulate and disrupt the embryonic and larval stages of sensitive aquatic organisms such as, salmonids and invertebrates (Meador 2015). In contrast, species that can withstand harsh conditions such as Lost Lagoon's common carp, are able to tolerate high Cd concentrations. As another example, according to the B.C. WWQG (2017), elevated concentrations of biologically available Cu can cause damaging effects to the survival, growth and reproduction of aquatic organisms. Cu in the form of copper sulfate ($CuSO_4$) is an effective algaecide, which could further destabilize Lost Lagoon's water quality if it were to be used to control algae blooms in the future (Wang et al. 2017, Zhou et al. 2017).

Other heavy metals found elevated in Lost Lagoon could become acutely and chronically toxic to aquatic life. In high concentrations, Pb causes growth deformities and death when water pH is low but has not shown bioaccumulation in higher trophic levels. Some species, including invertebrates are able to adapt to increasing Pb concentrations (Water Protection and Sustainability 2017). Similar to many other heavy metals, Ni can affect the cell membranes of aquatic organisms, however its tendency is to be only moderately toxic (Water Protection and Sustainability 2017). The last of the highest concentrated heavy metals in Lost Lagoon was Zn, which depending on its bioavailability, will bioaccumulate and readily bind to soil (Water Protection and Sustainability 2017).

In the data collection for Lost Lagoon, the sediment sample directly outside the biofiltration wetland (Site OB) was expected to contain lower concentrations of heavy metals, given its proximity to the biofiltration system. However, As, Be, Co, Hg, Ti, U and V were elevated, suggesting that either the filtration system does not successfully entrap all metals, or not all of the runoff is being directed into the biofiltration wetland. These elevated levels may also be due to the fact that the water levels among sites vary, which may cause different dilution rates, making some sites (e.g., Site OB) more concentrated than others (e.g., Site BW).

Similarly, a total of seven heavy metals, As, Be, Hg, Pb, Ti, U and V were found in higher concentrations from both Sites OB and IC compared to inside the biofiltration wetland (Site BW). This variation among metal concentrations is likely due to the location of the site and is important to consider for the reason that other sources of runoff are entering Lost Lagoon. This explains why the largest amount of elevated metals were observed in Site IC. It was the furthest site from the biofiltration wetland and is located in the inflow from Ceperely Creek, which potentially carries contaminated runoff from adjacent ecosystems such as the urban fill that makes up Ceperley Meadows, Second Beach and the pedestrian trail. Other possible point and non-point sources may include unidentified storm sewers, freshwater creek outfalls, Stanley Park Drive, and North Lagoon Drive.

This study alone cannot conclusively identify the level of ecological risk that the sediment heavy metals pose on Lost Lagoon's ecosystem and surrounding environment. However, it is important to control heavy metal accumulation over time in order to prevent adverse effects to aquatic organisms. By restoring tidal flushing, continuous water renewal will assist in diluting heavy metals, and establishing native plant species, will assist in entrapping and filtering contaminated runoff (refer to Planting Plan 4.5.5. in Chapter 4).

3.3.3. Birds, Fish and Small Mammals

The wildlife community of the restored saltmarsh is expected to reflect the historical marine and terrestrial ecosystem of Coal Basin. The majority of species currently found occupying Lost Lagoon are either non-native or invasive. In contrast, keystone marine species such as, Pacific salmon and marine birds from Burrard Inlet, are expected to occupy a restored and extended area of the coastline. Particularly, local waterbird species currently showing declining numbers (e.g., loons, grebes, seaducks, and shorebirds), would benefit from a restored saltmarsh and marine ecosystem resulting from biofilm growth on exposed mudflats.

Biofilms are a microbial community including, bacteria, diatoms, and organic detritus that are abundantly formed on mudflats and are an important part of the aquatic food web (Kuwae et al. 2008). They are a major food source for invertebrates and many avian species, primarily herbaceous shorebirds (Kuwae et al. 2012). Studies have shown that western sandpipers (*Calidris sp.)* rely heavily on biofilms as a food source and that their bills and tongues have evolved to effectively graze in thin layers (Kuwae et al. 2008). Sandpipers inhabiting Coal Basin, would benefit greatly from feeding on intertidal biofilm that will grow on the exposed saltmarsh flats (Kuwae et al. 2008). Current coastal wetland loss and degradation, threatens microbial biofilms. Restoring Lost Lagoon to an intertidal coastal saltmarsh will support these vital intertidal micro ecosystems, and in turn, assist in sustaining shorebirds and the aquatic food web.

In the summer of 2017, a muddy shore was exposed as the level of water in Lost Lagoon decreased. The appearance of mud coincided with the return of shorebirds to Lost Lagoon. Four shorebird species, namely, Greater and Lesser Yellow-legs (*Tringa melanoleuca* and *T. flavipes*), Dowitchers (*Limnodromus* spp.), and Dunlin (*Calidris alpine*) were identified and had not been observed over the previous 10 plus years in Lost Lagoon. The arrival of a fifth species, Least sandpiper (*Calidris minutilla*), had been recorded only sporadically over the same period (P. Woods 2017, personal communication). This event suggests that a restored intertidal zone and saltmarsh would draw in shorebirds by providing them with food obtained from mudflats exposed at low tide.

The salt or brackish water of a restored saltmarsh may negatively affect only a limited number of bird species. Those that are seasonal winter residents, arrive in small numbers, and have more specialized habitat requirements (e.g., Hooded merganser and American Coot). The three primary, local, resident, waterfowl species namely, Canada Geese, Mallards, and Wood Ducks, will demonstrate their ability to adapt to a change in Lost Lagoon's ecosystem by relocating to other areas within Stanley Park. The majority of waterfowl (e.g., bay, diving ducks, and mergansers) and water bird species (e.g., loons, cormorants, herons, and kingfishers) that have been recorded from Lost Lagoon, also routinely utilize Stanley Park's marine resources. Additionally, the biofiltration wetland will continue to provide refuge for Lost Lagoon's resident and migratory wetland-dependent species.

3.4. Conclusion

It was concluded that the current water and sediment quality, and native species diversity are in poor conditions relative to a stable freshwater wetland and a restored coastal saltmarsh. It was also determined that ecological degradation in Lost Lagoon will continue if no restoration takes place. Consequently, restoring it to its original saltmarsh conditions, would benefit not only the ecosystem as a whole, but society as well.

Chapter 4. Restoration Plan

Based on the information reviewed (Chapters 1 and 2), and the data collection and analysis of environmental parameters (Chapter 3) this Restoration Plan for Lost Lagoon has been prepared. The plan includes active and passive restoration strategies to return Lost Lagoon to a diverse coastal saltmarsh.

4.1. Restoration Goals

The main goals for this restoration plan are to encompass First Nations cultural values and respond to Vancouver residents' goals to restore ecosystems within the city incorporating both recreational access and educational opportunities. The primary client for this project is Nick Page, Biologist for the Vancouver Park Board. His vision for Lost Lagoon is to see it returned to a low-energy tidal marsh with functioning intertidal communities, alongside an additional small freshwater wetland to support existing biodiversity. After conducting research on Lost Lagoon, it has been determined that reconnecting it to the ocean through Coal Harbour will achieve the main project goal, which is to restore the degraded system to a functional coastal saltmarsh.

4.2. Engagement – First Nations, Agencies, Stakeholders, and Interest Groups

Lost Lagoon is located on Tsleil-Waututh, Musqueam, Squamish, and Musqueam First Nations territory. Consequently, it is integral that First Nations be consulted prior to restoration. Moreover, Traditional Ecological Knowledge (TEK) needs to be paired with Scientific Ecological Knowledge (SEK) to achieve collective and successful ecological restoration. Tsleil-Waututh has signed an agreement to support the restoration of Lost Lagoon, with an understanding that remaining details will undergo further consultation. This will be done through the Stanley Park Intergovernmental Working Group, made up of a number of members, including Tsleil-Waututh, Musqueam and Squamish First Nations representatives that manage strategic planning in Stanley Park. The restoration plan will be amended to accommodate First Nations ideas and interests in advance of any action being taken.

The recommendations proposed in this report require the involvement of a number of agencies, stakeholders and interest groups. To re-establish tidal flushing into

Lost Lagoon, a water license for modifications to the watercourse will need to be approved under the authority of the Provincial Water Act through Forest Lands and Natural Resource Operations. To conduct fish collection, a fishing permit from Fisheries and Oceans Canada will be obligatory, and protocols under the Fisheries Act will need to be strictly practiced. The research staff that partake in fish collection will need to take an Animal User Training course if not already granted. It will also be integral that the public be kept well informed throughout the restoration process and be given the opportunity to voice their opinions and concerns. In doing so, regional and community needs can be integrated into the restoration plan and meaningful participation will likely transpire.

To advance public support, surveys will be circulated in the spring of 2018, soliciting public feedback on the restoration project. Short (average 3-minute) surveys will be managed through two kiosks, one at the entrance to Lost Lagoon by North Lagoon Drive and one on the Drive by Ceperley Meadows, beginning bimonthly in August 2018 through to October 2018. This time period will provide the opportunity to gather insights and perspectives on the restoration plan and general ecological knowledge of Lost Lagoon from both locals and tourists. Two short online surveys will also be circulated to gain a greater participation rate and diversity of people. Sign-up sheets for the surveys will be placed in the Stanley Park Nature House, City of Vancouver Parks Board Offices, and local universities, colleges and environmental groups. The first survey will go out in June 2018, followed by a second one in August 2018. Public response will be encouraged by promoting positive ecological, social and economic benefits for Vancouver residents for taking the time to fill out the survey.

To attain significant results, the surveys will include a comment section and 10 questions that categorize participants by the number of times they visit Lost Lagoon from a weekly to yearly basis, if they are a resident of Vancouver, how much time they spend in Coal Harbour, and additional questions that will help the invigilator gather if the participant has a general understanding of the past, present and future conditions of Lost Lagoon with and without restoration. The second follow-up survey will be developed in accordance with the largest concerns extracted from the results of the first one. Survey results will be analyzed by multiple working groups to attain unbiased results and any issues that arise will be addressed. The results will be generalized into three categories:

supported, indifferent, and unsupported. If results indicate greater than 40% are unsupported, more effort will be put towards public relations to address the concerns.

Interpretive signage will also be placed at the Stanley Park Nature House and along the pedestrian trail in the summer of 2018. As of March 2018, Vancouver Bike Tours in Stanley Park share a brief narrative overview of the restoration plans for Lost Lagoon. The project manager's contact information is provided to the individuals who would like to follow up with any inquiries.

Aside from future engagement, the research for this restoration plan has already involved several individuals with relevant and professional backgrounds that have been listed in Table 7.

Table 7. Personnel involved in the development of restoration on Lost Lagoon in Vancouver, B.C.

Action	Organization	Contact	Information
Academic Supervisor 08/2016 – present	MSc in ER at BCIT	Ken Ashley ken_ashley@bcit.ca	Provided guidance and consultations for research
Project Coordinator 08/2016 – present	VPB	Nick Page nick.page@vancouver.ca	Consultations for research
Sample Analysis	ALS Environmental	Jerry Holzbercher jerry.holzbecher@alsglobal.com	Chain of Custody/ Analytical Request Form and study sample results
Meeting 08/2016 – 10/2017	SPES	Maria Egerton conservation@stanleyparkecology.ca	Provided reports on Lost Lagoon
Meeting 31/10/2017	Fisheries and Oceans Canada (emeritus)	Dr. Colin Levings colin.levings@dfo-mpo.gov.ca	Aquatic life in Lost Lagoon and Burrard Inlet
Meeting 20/08/2017	KWL	Patrick Lilley p.lilley@kwl.ca	Sediment sampling protocols
Meeting 11/2017 – present	Naturalist	Peter Woods rpeterwoods@shaw.ca	Local knowledge and photographs
Meeting 11/01– 9/02/2018	Society for Ecological Restoration Western Canada	June Pretzer junepretzer@yahoo.com	Provided reference site information

4.3. Climate Change

The recommended provincial guideline to alleviate SLR impacts, proposes incorporating an increase of 10 mm/year in the restoration design (B.C. MOE and Ausenco Sandwell 2011). This restoration plan recommends constructing vegetated buffer zones and berms to plan for SLR and carbon capture. The climate stations that should be continually monitored for changes in SLR, potential storm surges and general weather conditions, are Point Atkinson Station (number 7795 and 6638), Vancouver Station (number 7735 and 6664), and Stanley Park Station (number 2333) (PCIC 2017).

Although it is beyond the scope of this study, a more beneficial approach would be to develop a SLR action plan for the entirety of Stanley Park. It is recommended that such an action plan be established by interpreting existing data and projecting future climate scenarios in order to address anticipated climatic changes in general and SLR in particular. A successful action plan alongside this restoration plan, would support the Blue Carbon Initiative, an international organization that is geared toward conserving and restoring coastal aquatic ecosystems to mitigate climate change. In the meanwhile, this report highlights the values of wetlands and blue carbon sequestration services provided by coastal saltmarshes, which helps increase awareness on attainable climate change mitigation strategies.

4.4. Restoration Strategies

Based on the findings from this applied research project, it is recommended that Lost Lagoon be returned to a coastal saltmarsh by reconnecting it to the ocean through Coal Harbour. This can be achieved through a matrix of remedial actions including, fish removal, water elevation control, berm construction, water channel installation, the execution of a planting plan, and long-term monitoring and care.

4.4.1. Fish Collection

The first recommended field task to launch the restoration process is to undertake fish collection and salvage. Majority of the dominant fish species, common carp, need to be collected and removed by gillnet fishing procedures and bottom trap nets. A Fishing Permit from the MOE has already been approved for a catch and release sampling method; however, an additional Fraser River Area Scientific License, will need to be requested. This licensing application will be requested for gillnet fishing and trapping in the Coastal Pacific Region through the National Online Licensing System of the Department of Fisheries and Oceans Canada. A fisheries operation in the Lower Mainland (e.g., CB Island Fisheries) will need to be contacted to arrange pickup for fish processing. The fish carcasses may be used for fertilizer, animal feed and/or compost. Once the operation is approved, the fish collection design outlined below must be carried out in spring 2019.

With the use of the Stanley Park Nature House boat, three gillnets will require to be set in evening hours at the following predetermined locations: Site W, at 49.29574° N, 123.14193° W, running east to west, Site S, at 49.29495° N, 123.14225° W, running west to east, and Site N, running north to south from 49.29653° N, 123.13889 ° (see Appendix B Figure 1 for map showing gillnet locations). These locations were selected based on the deepest points from Lam, Preoteasa and Rasmus (2011) bathymetric map. Different gillnet mesh sizes will be required to target the desired species. Based on this project site, it is recommended that nets measuring 30 m by 5 m with 35 mm and 50 mm mesh sizes be used to target common carp.

After approximately 12 hours, gillnets will need to be pulled. The success rate of the fishing round(s) will be scored out of three, where one (1) rates as successful (greater than 50 fish caught), two (2) as passable (20 to 50 fish caught), and three (3) as fail (less than 20 fish caught). If any of the rounds score a three (3), the gear or sampling location will require adjustment and be re-attempted until a score of one (1) or two (2) is attained. Sonar devices and bait may be used to locate and condense the common carp if there are difficulties capturing them. If bycatch or untargeted fish species are caught during this process, they must be noted and dealt with accordingly. For example, live threespine stickleback can be released, as they will likely adapt to saltmarsh conditions. Alternatively, they can be relocated to a freshwater system and the gear can be adjusted to target larger species.

To further increase success rate of fish collection, two bottom trap nets with mesh size targeted for common carp should be placed in Lost Lagoon. The first sites are located in southeast and northeast and the second sites located in deepest North portion and in the west near the entrance to Ceperley Creek (see Appendix B Figure 1 for map showing bottom trap net locations). Fish need to be salvaged from the nets twice a week and should be set for seven days at each location if the success rate scores a 1 or 2.

4.4.2. Weir removal

The second restoration recommendation is to assess partial tidal exchange between Lost Lagoon and Coal Harbour. This control measure will be facilitated by removing the weir on the existing flap-gate located at 49.29637° N 123.13687° W (Figure 2 in Appendix C). Although this will likely result in a minimal exchange of water due to the flap-gate size and structure, the onset of hydraulic flow will aid in the initiation stages of restoring a coastal saltmarsh. The initial opening will allow for observations of the bi-directional flow of water in and out of the impoundment. To some extent, it will generate the outflow of freshwater into Burrard Inlet at low tide and introduce saltwater into Lost Lagoon at high tide. Monitoring water levels at high tide during this phase will be crucial to ensuring that overflow does not occur.

This control measure will allow for the observation of the quantity of water that can be mixed during tidal flushing and will result in increasing the dilution rate of the contaminated impoundment water. For the long term, water quality goals set out by BIAP will aid in reducing water pollution from Burrard Inlet altogether. Un-captured common carp will be killed due to the increase in salinity but will temporarily serve as a food source for marine birds. Low tide will also provide a larger shoreline to work with for the subsequent phase of restoration.

4.4.3. Excavation and Berm Construction

The third phase, prior to fully re-introducing tidal flushing, is to prepare the site for full inundation of saltwater. It is recommended that the cement walls along the south edge of the impoundment be excavated to increase the total restored intertidal area. This will be facilitated during a window of ebbing and low tide, as a result of the weir removal. The excavated sediment can be used for berm construction around the midden site to protect it from erosion and flooding, and along the impoundment shoreline where it is subject to SLR. Additional soil may be required to increase a viable substrate for vegetative growth along the constructed berms to support a buffer zone and stabilize banks. In the event that the invasive yellow flag iris population increases on site, an excavator can be used for its removal during the same time as berm construction.

4.4.4. Restoration of Full Tidal Flushing

The first restorative option to re-introduce tidal flushing into Lost Lagoon is to remove the tidal barrier. The most effective method would involve the replacement of the Stanley Park Causeway with an improved version of its historic bridge structure. From an ecological perspective, this is the most suitable option, as observed in Esquimalt Lagoon where a bridge structure provides, full hydraulic mixing, adequate fish passage, and safe public access. However, there are limitations to the extent of changes that can be made to the Causeway. Diverting traffic for a prolonged period of time during construction would not be feasible. As a result, a second option to re-introduce tidal flushing into Lost Lagoon, is to create an open channel connecting both bodies of water. By installing a partially open water channel (e.g., flume) under the Causeway along the pedestrian and bike underpass, water exchange would occur (Figure 13). It will be necessary to comply with the provincial guidelines for fish passage in culverts. To maximize sunlight in the water channel to increase fish use, a grate along the top 70 m of the channel would support marine fish passage and permit pedestrian use overhead (Fairfill and Witheridge 2003).

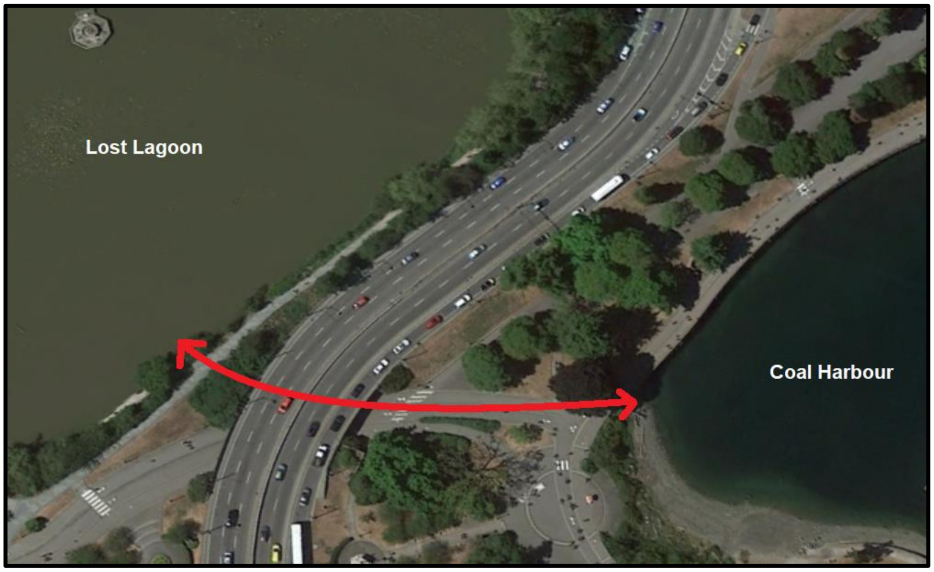

Figure 13. Proposed water channel installation connecting Lost Lagoon to Coal Harbour, B.C. Channel head located 49.1742.11° N 123.81398° W extending 130 m east to 49.174314° N 123.8842° W (photo created on Google Earth Pro).

Traffic routes will be diverted for a short period (estimated two weeks) for water channel installation. Advanced notification (two months pre-construction) utilizing traffic signs on West Georgia Street, the Stanley Park Causeway, and the Lions Gate Bridge will be necessary. The construction needs to be carried out at night during low tide and could start as early as the fall of 2018 or winter 2019 depending on approvals, funding and work schedules. It is also recommended that planting vegetation around exposed infrastructure may require to be more aesthetically acceptable.

4.4.4.1. Hydraulic Sizing

Implementing a water channel will be a complex procedure. The B.C. Ministry of Transportation and KWL will need to be consulted to ensure any existing pipes under the Causeway do not obstruct the proposed pathway. Moreover, hydraulic flow and discharging capacity of the created waterway will largely depend on the tidal cycles in Coal Harbour, which vary greatly on spatial and temporal scales. Detailed computations and assistance from hydraulic engineers such as, Northwest Hydraulic Consultants Ltd., will be an asset to this phase of restoration. As a result, channel geometry and hydrodynamics such as, hydraulic sizing, grade at which the water channel is constructed, material used, and the depth and orientation cannot be pre-determined given the scope of this study.

In light of this restoration plan, estimates are made from a general understanding of hydrogeomorphology and the tidal flushing that is projected to occur between Lost Lagoon and Coal Harbour. Saltmarsh flooding will largely depend on the tidal cycles in Coal Harbour. The most up to date higher high water mean tide (HHWMT) and the lower low water mean tide (LLWMT), will need to be included in the design as they will help model the quantity of water that will enter the impoundment. Fisheries and Oceans Canada (2018) describes the HHWMT as the average of all higher high waters from 19 years of observations, and the LLWMT as the average of all lower low waters from the same time. The Chart Datum (CD) from the flap-gate control valve in Coal Harbour reads, HHWMT as 4.4 m and LLWMT at 1.1 m, with a 3.3 m difference between them. The most recent CD values will need to be gathered from the Canadian Hydrographic Services to attain more precise and results before finalizing a hydraulic design.

Another factor that will influence the hydraulic flow will be the size of the water channel constructed. To determine appropriate hydraulic sizing, the flow rate and tidal regime were estimated. Flow rate (Q) is measured in units of volume per unit of time, which results in m^3/min or L/min. In order to understand how much water will move between Lost Lagoon and Coal Harbour with the service of a water channel, various hydraulic flow calculations were completed using the following assumptions:

- Two tidal events per day where a full tidal cycle is 12 hours,
- Tidal velocity is between 50 to100 cm/sec
- Surface elevation of Lost Lagoon is equal to surface elevation of Coal Harbour,
- Inlet and outlet of the water channel are at the same elevations,
- Length and material of constructed water channel does not affect flow rate, and
- Ground water exchange between Coal Harbour and Lost Lagoon does not occur, i.e., porosity equals zero.

To calculate the volume of water that the basin of Lost Lagoon holds, the surface area was inferred from two sources and averaged to reduce margin of error. Worcester's (2010) State of the Park Report, measured Lost Lagoon to be a total of 16.57 ha (165,700 m^2) and the measured polygon surface area on Google Earth Pro was a total of 163,686 m^2, resulting in a mean surface area of 164,693 m^2. To gather the estimated volume of Lost Lagoon's basin, the surface area was multiplied by the mean depth of 1.4 m, equaling 230,570 m^3.

To gather the amount of water exchange that would occur between Lost Lagoon and Coal Harbour, specific tidal characteristics were estimated. According to the Government of Canada CD 2018 Tide Forecast for Station No. 7735 Vancouver, the average tidal range is 4.18, and the average time between high and low tide is about 6 hours (360 minutes). With these values, the hydraulic flow can be estimated. The flow rate is expressed as volume over time or Q = V/t. Where Q is flow rate (m^3/sec), V = volume (m^3) and t = time (min). Therefore, $Q=\frac{230{,}570\ m^3}{360\ min}$ equaling a total of 640.47 m^3/min. Theoretically, about 640.5 m^3 of water per minute would need to move through the water channel, assuming that the entire volume of Lost Lagoon is renewed every tide cycle. There exist different standard rates of oxygen depletion (e.g., 0.1 mg/L/day), depending on the water temperature, biological oxygen demand and the nature of the water. In this case, a full water renewal twice a day (i.e., two tide cycles) to maintain a stable aquatic system is not required. As a result, the total amount of water was divided in half, equaling 320.23 m^3/min.

To determine the diameter and cross-sectional area of the water channel, standard values were used for water velocity (50 to 100 cm/sec). A flow rate equation to solve for the diameter was used $\left(\sqrt{\frac{4 * Q}{\pi * \text{velocity}}}\right)$. It was concluded that when Q is 320.2 m^3/min and velocity is 50 cm/sec and 100 cm/sec, the diameter of the water channel would need to be 3.6-m and 2.6-m, respectively. These are both relatively large making it challenging to implement given the project constraints (e.g., substantial construction on the Causeway).

Based on the general mean oxygen depletion rate of 0.1 mg/L/day, it was determined that a minimum of a 10% water exchange could maintain a stable saltmarsh to meet the project goal (e.g., Livingstone and Imboden 1996, Clarke et al. 2002, Rippey and McSorley 2009.). Resulting in about one full water renewal of the total volume of water in Lost Lagoon every 10 days. Where Q is 64 m^3/min (640 m^3/min * 0/1 mg/L/day) a water channel would need to have a diameter of about 1.3 m. In the case where the existing weir continues to actively exchange water from the ocean to the site, a smaller size water channel could be used. To determine the water channel size various water velocities, flow rates and percent water renewal per day were calculated (Table 8).

Table 8. Hydraulic sizing estimates for the proposed water channel connecting Lost Lagoon and Coal Harbour, Vancouver, B.C.

Water renewal/day (%)	Velocity (cm/sec)	Flow rate (m^3/min)	Water channel diameter (m)	Cross sectional area m^2
50	50	320.2	3.6	10.2
50	100	320.2	2.6	5.3
10	50	64.0	1.6	2.0
10	100	64.0	1.1	0.9

A number of additional considerations must be included in the design. Firstly, it is important to note that the flushing rate will also depend on the volume of water that the basin of Lost Lagoon can withstand and the inter-tidal prism. The tidal prism (P) for Lost

Lagoon is the total volume of water entering from Coal Harbour at high tide and leaving at ebb tide, including freshwater inputs. To calculate the inter-tidal prism, the tidal ranges and friction forces that occur in Coal Harbour need to be determined. Once these parameters are inferred, P can be calculated using $P= (H)(A)$, where H is the average tidal range (m) and A is the average surface area (m^2). Since the difference between high tide and low tide is not as great in a shallow basin such as Lost Lagoon, a smaller P and a longer residence time may occur. A more detailed assessment of the exact parameters that determine the tidal prism will need to be made.

Secondly, exposed infrastructure will require protection and must be aesthetically pleasing. Thirdly, depending on the sediment material, dredging may need to occur at the invert of the water channel in order to make it the same elevation as Coal Harbour. Lastly, flood management control for the entire tidal basin will have to be reviewed, and a weir, control valve, or self-regulating tide gate (SRT) may need to be installed on the ends of the water channel to prevent water overflow and to mitigate undesirable odors from plant decay and sulfur.

4.4.5. Planting Plan

Planting native halophyte species in Lost Lagoon will aid in initiating natural ecological processes and functions of a saltmarsh. If it reaches natural succession it should provide structural complexity that supports intertidal marine species. The plant species selected are effective at bank stabilization, bio-sequestration, entrapping contaminates, and accumulating sediment which will flocculate and gradually facilitate saltmarsh development (Kjerfve and Magill 1989, Emmett et al. 2000, Smardon 2009, Van Loon-Steensma and Vellinga 2013). Some of the species composition, structure and diversity in the reference site Maplewood Flats, are used in this planting plan, particularly the eelgrass beds.

By overlaying a bathymetric map on Google Earth Pro, the tidal basin of Lost Lagoon was divided into four zones (Figure 14). Namely, the transitional zone (about 16,850 m^2 or 10% of tidal basin), high marsh (about 30,140 m^2 or 19% of tidal basin), mid marsh (about 44,860 m^2 or 28% of tidal basin), and low marsh (about 69,670 m^2 or 43% of tidal basin). The mean high water (MHW), mean low water (MLW), and mean tide level (MTL) of Coal Harbour were considered when creating the marsh zones, to aid in determining the distribution of each plant species, as each zone differs in elevation and therefore period of inundation.

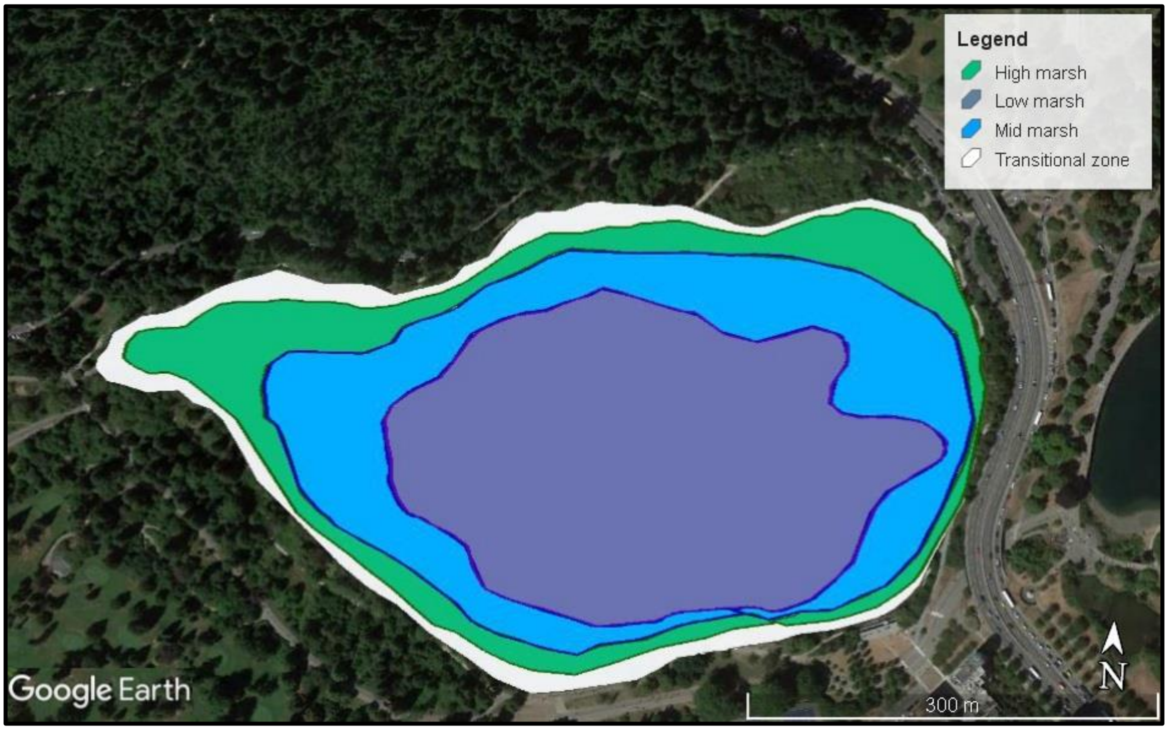

Figure 14. Projected marsh zones in Lost Lagoon, B.C.: transitional zone (white), high marsh (green), mid marsh (blue) and low marsh (purple) (photo created on Google Earth Pro).

A combination of submergent and emergent aquatic vegetation is recommended for the completion of this restoration project (Table 9). The density and species of plants in each marsh zone were selected based on their plant ecology to maximize establishment and growth. The B.C. Landscape and Nursery Association Standards (2012) must be reviewed for quality control in addition to this report. Peel's Nursery Ltd. in Mission B.C. and NATS Nursery Ltd. in Langley, B.C. are recommended as examples of firms that could serve as the main suppliers.

Table 9. Plant species selected for the Planting Plan for saltmarsh restoration in Lost Lagoon, Vancouver, B.C.

Common name	Scientific name	Plugs	Supplier
Transitional Zone			
Snowberry	*Symphoricarpous albus*	410	NATS Nursery
Common California aster	*Symphyotrichum chilense*	525	NATS Nursery
Cattail	*Typhia latifolia*	100	Peel's Nursery
Red-flowering currant	*Ribes sanquineum*	100	Peel's Nursery
Thimbleberry	*Rubus parvifloru*	360	Peel's Nursery
Nootka rose	*Rosa nutkana*	360	Peel's Nursery
High Marsh			
Saltgrass	*Distichlis spicata*	2050	NATS Nursery
Hardstem bulrush	*Scirpus Acutus*	450	Peel's Nursery
Pacific silverweed	*Potentilla anserina*	500	Peel's Nursery
Water sedge	*Carex aquatilis*	360	Peel's Nursery
Mid Marsh			
Seacoast bulrush	*Scirpus maritimus*	500	NATS Nursery
Lynbyei sedge	*Carex lynbyei*	500	Peel's Nursery
Common rush	*Juncus effuses*	360	Peel's Nursery
Low Marsh			
Pickleweed	*Salicornia rubra*	3000	NATS Nursery
Seaside arrow grass	*Triglochin maritima*	1000	NATS Nursery
Low Marsh Experimental Plots			
Eelgrass	*Zostera marina*	500	Shoots
Quoted Total Cost			**$3,500.00**

4.4.5.1. Planting Specifications

The rate of plant colonization may be influenced by a number of factors such as, sediment, animal browsing, salinity, elevation, and water conditions. Control measures for each of these factors are enclosed in this report. If the underlying sediment in the transitional and high marsh zones lack organic material, a delivery of soil and sand mix may be required to initiate plant growth. It will need to be spread above the HHWMT to avoid direct flushing.

Assuming the waterway is successfully installed, planting should be scheduled during low tides in spring 2019 before the first growing season and will take place over two to three days, weather permitted. During this time, meetings will be held to ensure health and safety are top priority and to review planting specifications. All plugs must be handled with care and the packaging and trays must be disposed of offsite and recycled.

Each plant species must be distributed into the allotted zones as indicated. Plugs must not be buried too deep, too shallow, or j-rooted in the soil. All holes must be filled and closed properly to ensure the plants are secured in place and to avoid plug saturation. Plant spacing and percent cover for each zone was based on general plant ecology and maximizing cover with space left for natural colonization.

The transitional zone varying from 1 to 25-m from the high marsh is the highest margin above MHW, therefore inundation will not occur. It should be planted with *Symphoricarpous albus, Rubus parvifloru* and *Rosa nutkana*, each with 10% cover, spaced 2-m apart throughout the south and north edges. On the west edge between Ceperly Creek and Lost Lagoon, a dense area of vegetation is necessary for biofiltration. This will require 10% cover of *Symphyotrichum chilense* and *Ribes sanquineum* with 3-m spacing*,* and 15% cover of *Typhia latifolia* with 2-m spacing.

The high marsh zone is not inundated for long periods, however, with SLR, storm surges and king tides, the plant species selected for this zone must be tolerable of prolonged wetted and saline conditions. For this reason, 50% cover of *Distichlis spicata* should be planted along the high edge of this zone with 2.5-m spacing. The remaining area should be planted with a mix of 10% cover of *Scirpus Acutus* with 3 m spacing, 10% cover of *Salicornia brachiate* with 1.5-m spacing, and 10% cover of *Potentilla anserina* with 3-m spacing. Spread along the border of the high marsh and mid marsh zone with 2-m spacing, 10% cover of *Carex aquatilis* should planted.

The mid marsh zone is projected to be below the MHW, and therefore frequently inundated. It should have a 20% cover of *Carex lynbyei* with 2-m spacing, and *Juncus effuses* and *Scirpus maritimus* should cover 20% cumulatively with 2-m spacing along the north and south edges. For the most part, the low marsh zone will be permanently inundated, as it resides within the MLW. It is recommended to have 2-m spacing for 30% cover of *Salicornia rubra*, and along the border of the mid and low marsh, 30% cover of *Triglochin maritima.* This zone will also encompass 30% cover of *Zostera marina* for an experiment described below. After the planting plan has been executed iNaturalist will need to be updated.

4.4.5.2. Eelgrass Experiment

Eelgrass (*Zostera marina*) increases the structural complexity of an intertidal marine ecosystem, supporting nutrient cycling, carbon capture, erosion control, and nursery and feeding grounds for fish, invertebrates and birds (Balsby et al. 2013). To increase saltmarsh development in Lost Lagoon, a small-scale eelgrass experiment is recommended to be carried out after the saltmarsh begins to passively restore (one to two years post restoration). The main purpose of this experiment will be to study whether eelgrass beds can increase in biomass in Lost Lagoon's tidal basin, and to monitor its ability to serve as a substrate for marine organisms, specifically, out-migrating salmonids, zooplankton, and invertebrates. High eelgrass shoot density will be used as a biological indicator of saltmarsh successes. This experiment will also aim to increase knowledge regarding the importance of eelgrass conservation and blue carbon sequestration. It will in turn allow for the fine-scale mapping of eelgrass communities along the southern coast of B.C.

Many eelgrass transplant studies in the past have proved difficult in attaining a high success rate. They also highlight the importance of appropriate site selection (e.g., Durance 2002, Wright 2013 and Balsby et al. 2013). The success rate for eelgrass establishment will depend primarily on the site elevation, substrate, and available light, and secondarily on salinity, current velocity, temperature, and pH (Environment Canada 2002). On the coast of B.C., there are three ecotypes of eelgrass with specific environmental gradients. The three ecotypes and their ideal growing elevations are: *typica* in intertidal zones, *phillipsi* favouring 0 to -4-m elevation, and *latifolia* -0.5 to -10-m (Environment Canada 2002).

Three experimental eelgrass revegetation treatments will take place in 21,000 m^2 (2.1-ha) of the lower marsh zone in Lost Lagoon. Each treatment will be replicated three times. Before transplanting, general water quality parameters (e.g., temperature, DO, salinity, and pH) should be measured to ensure conditions are suitable for eelgrass establishment. Transplanting is labour intensive and will have to be done on a small spatial scale to reduce cost and minimize impacts on site. Sediment containing high concentrations of Cu has shown to negatively affect eelgrass by being translocated to all regions of the plant (Nielsen et al. 2017). Therefore, before on-site dispersion of plants and seeds, experts will be required to determine sediment quality, specifically Cu concentrations.

In the first experimental plot and replicate sites (treatment 1), a total of 3,000 m^2 (0.3-ha) should consist of transplanted mature eelgrass from a donor site (e.g., Tsawwassen eelgrass beds) that have intact living rhizomes and a minimum of five nodes. If conditions warrant, treatment 1 should take place in early spring 2020 before the growing season, during low tide. The plots should be located in the southwest pelagic zone covering about 14% of the lower marsh. Adult plants should be planted directly into the sediment with 0.5-m spacing along a transect as recommended by Ruesink (2018).

In the same year using the same technique, the second plot and replicate sites (treatment 2), a total of 3,750 m^2 (about 0.4-ha), should be planted with at least 500 eelgrass shoots that have washed ashore and been collected from the tidal flats near the Roberts Bank Coal Terminal and Tsawwassen Ferry Terminal in the Fraser River Delta. The collected shoots should be divided into age classes with the youngest ones used for direct planting in Lost Lagoon and should be submerged in mesh bags during transport. The shoots should be planted in the east end of the lower marsh zone with about 17% cover. The older plants will be prorogated to carry out treatment 3 the following year.

Specific procedures to collect and plant eelgrass seeds were determined by Marion and Orth (2010) and should be followed in accordance with this plan. In May 2021, the third plot and replicate sites (treatment 3), a total of 10,500 m^2 (about 1-ha), should be sowed with matured eelgrass seeds in the highest elevation of the lower marsh zone along the northeastern edge. Treatment 3 covers the largest portion of the experiment site (50%), as seeds are prone to being washed away and have lower probability of germinating than shoots and mature eelgrass plants.

Eelgrass monitoring and success rates should be measured using the procedures set out by Ruesink (2018). Monitoring details can be found in section 4.7.2. Vegetation Surveys.

4.5. Project Constraints

This project faces a number of constraints; primarily, the feasibility of reintroducing tidal flushing and the public's response to the project objectives. To alleviate the former constraint requires professional assessment of the ecohydraulics that are proposed to return Lost Lagoon to an intertidal ecosystem. The estimations made for hydraulic flushing are based on a variety of assumptions and will need further examination to secure a suitable design. The latter constraint requires a concerted effort to be put towards public education and adhering to social issues that may arise. The solution to minimize any public insecurity regarding the proposed restoration project is through education. Interpretive signage, open houses, and workshops will help educate the public on Lost Lagoon's past, present and future ecological conditions with and without restoration. Keeping the public up to date with the progress of the project will also encourage community engagement and support.

4.6. Alternative-Restoration Strategies

In the event that reconnecting Lost Lagoon to Coal Harbour is unfeasible, there is a list of short-term alternative restoration options provided below. They each involve maintaining the impoundment as a freshwater system with the intention to increase ecological, social and economic values.

- Construct floating treatment wetlands (FTW) for water purification.
- Conduct a nutrient budget to determine primary nutrient sources.
- Improve the COVs drainage network plan around Lost Lagoon by identifying storm sewers and determining the amount of freshwater input and contaminated runoff that enters the impoundment.
- Construct rainwater treatment systems throughout Coal Basin to reduce contaminated runoff.
- Construct an additional biofiltration wetland between Ceperley Creek and Lost Lagoon to filter contaminated runoff entering from the west.
- Reduce dependency on municipal water by capturing and directing more stormwater into the biofiltration wetlands.
- Upgrade and maintain the flap-gate control valve to prevent saltwater incursions.

- Dredge Lost Lagoon to remove contaminated water and cap sediments with new material.
- Excavate shoreline and plant riparian vegetation.
- Install pumps or an aeration system (e.g., fine bubble linear aeration) to uphold water renewal.
- Assess the economic and social cost to achieve any or all of these choices.

Supplementary fieldwork would be required to assess whether each recommendation would successfully restore Lost Lagoon as a freshwater system.

4.7. Monitoring and Maintenance Plan

Conducting long-term and short-term ecological evaluation of the restored site is required for professionally delivered ecological restoration. Immediate saltmarsh recovery is not to be expected, therefore, effective maintenance and monitoring of saltmarsh vegetation, water quality, hydraulic performance, fish passage, and marine species occupation will be carried out. Minor corrections will be made if any issues are identified, which are carried out in detail in the following sections. All data will be recorded onto a live document and as information accumulates overtime, monitoring and evaluating trends will become more effective. Lost Lagoon is in a highly accessible location, making monitoring efforts and performance standards achievable for the next 10 years through a collaboration of working groups. Restoration managers, SPES, COV Parks Board, local communities, and schools will all be encouraged to participate in the maintenance and monitoring of the restored coastal saltmarsh.

4.7.1. Goose Exclosures

Due to the prevalent number of invasive Canada geese that reside in the area, control measures to minimize grubbing and browsing of saltmarsh plugs will be compulsory. Two large (20 x 20-m) and three small (10 x 10-m) goose exclosures will need to be constructed to fence the saltmarsh plantations immediately after the planting is executed. The large exclosures will be made of green coloured snow fence and anchored with metal poles (2-m high) to avoid decay. They will be constructed in the mid zone and high marsh zone. The smaller exclosures will be constructed in the transition zone made of stainless 3 cm mesh with untreated wooden poles (2-m high). Favourable graminoid species will be planted in the transitional zone outside of the exclosures to provide an alternative browsing source to deter the geese from feeding on the marsh plugs. Fencing can be removed once the vegetation matures, expectedly and a half to two years post-implementation. See section 4.9.1 for goose exclosure monitoring.

4.7.2. Vegetation Surveys

Vegetation surveys will ensure that the saltmarsh species are established in each vegetated zone. A cost-effective approach will consist of 10 transects along the marsh gradient and a 0.25 m^2 quadrat every 10-m to estimate vegetation cover, species identification, canopy height, herbivory evidence, site disturbance, and sediment description. The GPS locations will need to be recorded and used biannually with a different set of transects to be used the subsequent year to avoid excessive trampling. Sediment grain size and elevation changes should be recorded along each transect. Invasive species such as purple loosestrife and English cordgrass (*Spartina anglica*), will need to be noted and removed as soon as possible. All surveys should be repeated bimonthly in spring and fall for 10 years to gain representative trends that will demonstrate variability over time. Trained volunteers, students, and staff from SPES and Vancouver Parks Board will all be encouraged to participate in carrying out these surveys.

To ensure goose exclosures do not break or trap debris, biweekly monitoring will need to take place for the first six months, followed by once a month for the subsequent 12 months, otherwise until removed. Observations of browsing by Canada geese will need to be recorded and fencing adjustments can be made accordingly.

Shoot density and percent cover will be the primary methods to monitor eelgrass. If each treatment is successful, 10 years of monitoring twice each spring and summer during lowest daytime tides will be required to evaluate each age class. Each treatment will be evaluated and compared based on preliminary planting success, eelgrass density, and survivorship. The use of a 0.25 m^2 quadrat every 5-m along five transects in the lower marsh will determine percent cover and shoot density. The most successful, cost-effective and labour free treatment will be determined and can subsequently be conducted on a larger scale.

4.7.3. Water Quality

A monitoring program for water quality will be conducted by a team of experts and in later years, by trained volunteers and/or students. Two locations, both nearshore and offshore sites will be selected in each marsh zone and will be used for the entirety of 10 years. Monitoring will be conducted monthly for the first three years to note any early fluctuations in water quality. For the remaining seven years, seasonal monitoring should occur four times per year. These water quality inspections will include taking general water chemistry samples, water nutrients, bacteriological and toxicological surveys, and identifying point sources of pollution to reveal trends in water quality. Depending on the results, a strategic plan will be established to minimize the identified pollution sources and to circumvent water impairment. A hydrology model for the tidal basin of Lost Lagoon should also be developed and accessible online for future studies.

4.7.4. Hydraulic Performance

To ensure effective tidal flushing in Lost Lagoon, the constructed water channel and flap-gate will need to be monitored shortly after installment for its hydraulic performance. If the infrastructure needs maintenance, engineers will be required to resolve performance issues, and upgrades will be made when necessary.

4.7.5. Marine Species Occupation

To ensure adequate fish passage, the water channel, grate, and flap-gate will need to be monitored and maintained. Debris will need to be removed by hand if it is obstructing fish passage. This can be noted by fish counts that will take place at the head and invert of the water channel and within Lost Lagoon at high tide. Inspections should occur at high tide on a biweekly basis for the first year post-restoration, and bimonthly in the spring and fall for the following nine years. Fish collection by pole and seine nets can be used to carry out a more detailed assessment if required.

To estimate other marine species occupation in the coastal saltmarsh, species identification and their numbers should be documented and uploaded to iNaturalist. Marine bird occupation will need to be monitored from stand and point surveys on a monthly basis. Invertebrate surveys should be carried out twice a year and compared with relevant BIAP data. An assessment of the relocation of freshwater species will need to be carried out; particularly, the resident beaver population.

4.7.6. Carbon Capture

Long-term monitoring of carbon capture in the restored marsh will support the Blue Carbon Initiative. It will also target the local community and interest groups to become aware of blue carbon and its connection to coastal restoration. The vegetation and sediment quality should be examined in their ability to sequester and store blue carbon over time. Monitoring stations will be set up two years post-implementation. Carbon should be measured in megagrams (Mg) or metric tons of carbon per ha. After data have been collected, the trends in the rate of carbon capture can be observed. If deemed successful, this study can be applied on a larger scale.

4.7.7. Metrics-of-Success

Project success will be represented by an increase in intertidal productivity, native species diversity and a natural successional recovery of a diverse saltmarsh ecosystem. Long-term restoration success will be measured through monitoring. The project will be considered successful if 50% of the designated area has re-developed its native vegetation cover after a five-year period, and if Pacific juvenile salmon and marine birds occupy the saltmarsh within one year or less, post-restoration.

The conclusions from this research suggested that a coastal saltmarsh would yield more value and services for humans and wildlife than the current freshwater impoundment (e.g., recreational access, improved water quality, native vegetation establishment, and feeding grounds for native marine fish, invertebrates, mammals, birds, and herptile species), making it a successful candidate for the re-introduction of tidal flushing. A restoration and monitoring plan was developed to focus on water renewal, adequate fish passage, native marsh vegetation establishment, climate change mitigation, and public values. It indorses communication and collaboration with First Nations as well as the local community. Restorative success for each project objective will be achieved and measured (Table 10).

Table 10. Summary of the success measured for each project objective and overall goal for the restoration of Lost Lagoon, Vancouver, B.C.

Goal: Provide recommendations to restore Lost Lagoon to a functional coastal marsh		
Objectives	**Actions**	**Success**
Establish the past, current, and anticipated future conditions of Lost Lagoon	Measure water quality	14 sites sampled over 3 months and SPES water quality data attained for comparison.
	Conduct species inventory	Vegetation and wildlife are limited to non-native and introduced species.
	Analyze ecological and historical reference conditions	Reference site(s) reflect desired species composition and diversity, has full tidal flushing and undergoes anthropogenic influences.
Identify the ecosystem, social, and economic goods and services of the freshwater impoundment and the restored saltwater marsh	Identify biotic factors that will alter from marsh restoration and those that will benefit from marsh conditions	A greater number of native flora and fauna will benefit from restoring Lost Lagoon to a saltmarsh. Restored area yields more value and services for humans and wildlife.
	Identify abiotic factors that will be affected in the absence of restoration	Tidal flushing eliminates toxic algae blooms and provides ecological, social and economic values. A freshwater/brackish system exists in Ceperley Meadows.
Create a restoration plan to restore Lost Lagoon to its former coastal marsh ecosystem	Collaborate with First Nations and conduct public outreach	Effective communication with First Nations and the public through open houses and surveys.
	Weir removal	Water exchange occurs directly after weir is removed and low tide exposes >30% of the shoreline.
	Excavate cement wall and create berms	Berms mitigate SLR and provide suitable substrate for riparian growth.
	Introduce tidal action via water channel installation and weir removal	Tidal flushing is restored by the water channel installation with adequate fish passage, while Causeway remains in operation in 2018-19.
	Fish collection	>80% of common carp are captured in first gillnet and/or bottom trap round.
	Create a native marsh vegetation planting plan	Selected plants establish after the 1st year with <10% browsing and natural succession occurs 2-5 years post-restoration. Eelgrass beds cover 50% of the lower marsh after 6 years and aid in blue carbon sequestration.
	Create a detailed restoration, maintenance and monitoring plan	The plans are strictly followed for 10+ years and the community are involved throughout this time.
	Create a project budget and schedule	Plans remained within project budget and schedule and preliminary tasks accelerate the quality and effectiveness of executing the restoration project.

4.8. Budget

The forecasted costs for the Lost Lagoon restoration project include a contingency and is graded as a Class D estimate, meaning that it is about 20 to 30%

accurate. The preliminary estimates for equipment needs, labour sources, machinery, field tools, infrastructure, and monitoring and maintenance to carry out the restoration design are enclosed in this report (Table 1 in Appendix C). Whenever feasible, the labour and supplies will be locally sourced. The budget is broken down into a number of categories with six main restoration tasks and the grand total for the project budget is forecasted (Table 11). A total of 12% provincial tax needs to be added to the total cost, as well as the cost of inflation given that it is a multi-year project and for diverting traffic during the construction phase. To date, financial contributions have not been determined. Follow-up studies will likely take place and be integrated into some of the monitoring and maintenance costs.

Table 11. Forecasted grand total costs for the Lost Lagoon Restoration Project 2017-2019 in B.C.

Category	Forecast Cost
Project Management	$160,000.00
Hydraulic Engineering	$450,000.00
Consultation	$300,000.00
Construction	$2,550,000.00
Monitoring	$300,000.00
Total task budget*	$3,032,200.50
Grand Total	**$6,632,700.50**

*Task budget found in Appendix C.

4.9. Schedule

This is a relatively large-scale restoration project that started in August 2017 and if approved, will continue under the current plan set out in this document into 2019, with monitoring and maintenance up to 10 years post-restoration. On the ground fieldwork should take place in the summer and fall of 2018. Water channel construction, weir removal and fish collection, can occur as early as mid-winter 2019 depending on construction permits and approvals. The leading restorative amendment is the installment of the water channel, which will need to be done overnight at low tide during off-peak hours of traffic. A tentative restoration project schedule (Gantt chart) was developed (Figure 15).

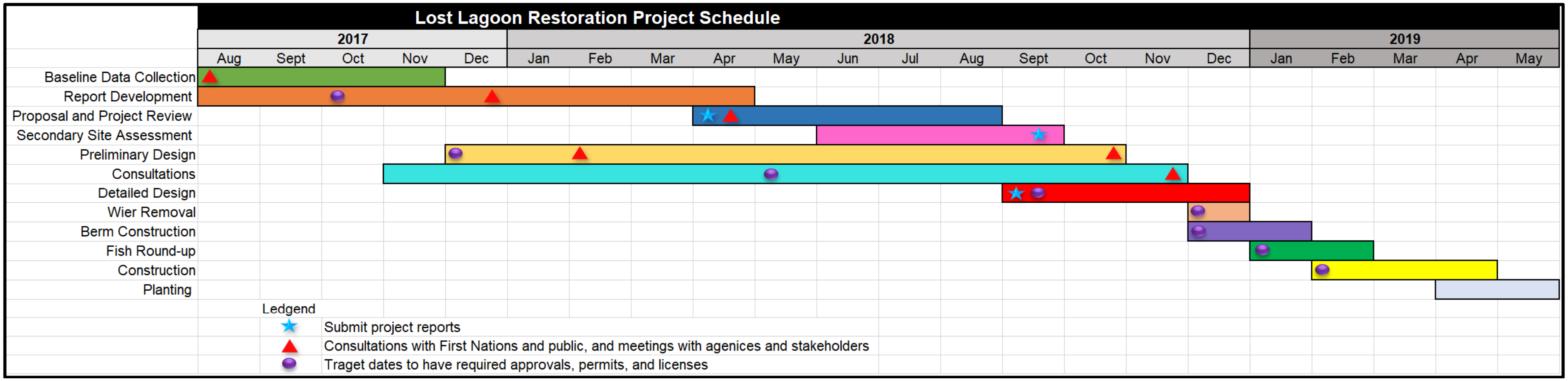

Figure 15. Preliminary work schedule for the Lost Lagoon restoration project 2017-2019.

Chapter 5. Conclusions and Future Considerations

Scientific evidence shows that in the absence of restoration, Lost Lagoon poses hazardous risks to humans and wildlife and will continue to do so into the future. This study describes the current and projected ecological risks and strongly suggests that they can best be averted by returning Lost Lagoon to an improved version of its historical coastal saltmarsh conditions. In turn, providing an intertidal habitat that will improve the structural complexity for native coastal land and water-based species, as well as human society. This research also builds on approaches for coastal restoration and demonstrates alternative ways information can be delivered to the public within the emerging field of ecological restoration.

Although a shifted baseline is associated with Lost Lagoon, motivating the public to think optimistically about the necessity of ecological change, restoration efforts will garner more support, and ultimately increase their chances of success. To harness the most suitable remedial strategies for Lost Lagoon, and to gain public support, communicating the past, present and projected future conditions will prove successful in attaining an understanding that restoration is needed for Lost Lagoon's long-term survival. This proposed restoration plan and its anticipated restorative success can be utilized to establish best practices for other ecological restoration projects and could serve as a blueprint for other at-risk aquatic ecosystems.

As a whole, saltmarsh restoration will improve the quality of B.C.'s coastal landscape and marine ecosystems, which ultimately connect to the rest of the world. While more than 40% of the world's population lives along coastal boundaries, coastal marshes comprise of solely 4% of the land surface (Gedan et al. 2009). Oversights from past anthropogenic activities have rendered many of these ecosystems to severely altered states and are expected to continue as time progresses. By endorsing the practice of aquatic restoration, ecological risks can be curtailed and ecosystem services for the land, animals and humans can be recovered.

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Appendix A: Detailed Flora and Fauna Inventory and Water Quality Parameters from Data Collection

Table 1. Vegetation community in Lost Lagoon, Vancouver, B.C. (Compiled from personal observation, Worcester 2010, Worcester and Johnstone 2007, iNaturalist and Stanley Park Bioblitz 2017)

Vegetation	Native	Introduced/ non-native	Invasive
Aquatic plants	Bulrushes (*Typha sp.*) Cattail (*Typha latifolia*) Marine algae (*Enteromorpha sp.*) Reeds (*Scirpus robustus*) Soft rush (*Juncus effusus*) Water-cress (*Radicula nasturtium aquaticum*)	Fringed willowherb (*Epilobium ciliatum*) Western yellow pond-lily (*Nuphar polysepala*) Waterweed (*Myriophyllum sp.*)	Purple loosestrife (*Lythrum salicaria*)
Terrestrial plants	Dogwood (*Swida sanguinea*) Pacific water parsley (*Oenanthe sarmentosa*) Purple-leaved Willowherb *Epilobium ciliatum ssp.*	Avens (*Geum sp.*) Barberries (*Berberis sp.*) Common yarrow (*Achillea millefolium*) Common bracken (*Pteridium aquilinum*) Common Cat's-ear (*Hypochaeris radicata*) Common Ivy (*Hedera helix*) Evergreen Huckleberry (*Vaccinium ovatum*) Greater plantain (*Plantago major*) Nootka rose (*Rosa nutkana*) Ocean spray (*Holodiscus discolor*) Rose spiraea (*Spiraea douglasii*) Snowberries (*Symphoricarpos sp.*) Salmonberry (*Rubus spectabilis)* Salal (*Gaultheria shallon*) Vetchs (*Vicia sp.*) Western Sword Fern (*Polystichum munitum*)	American black nightshade (*Solanum americanum*) Bittersweet nightshade (*Solanum dulcamara)* Cutleaf blackberry (*Rubus laciniatus*) English ivy (*Hedera helix*) Horsetails (*Equisetum sp.*) Himalayan blackberry (Rubus armeniacus) Trailing blackberry (*Rubus ursinus*) Yellow flag iris (*Iris pseudacorus*)
Trees	Willow (*Salix sp.*)	Red Alder (*Alnus rubra*) Rockey Mountian Maple (*Acer glabrum*)	Pacific Crab Apple (*Malus fusca*)
Mosses, liverworts, hornworts		(*Bryophyta sp.*) (*Barbula vinealis*) (*Schistidium sp.*) (*Tortula princeps*)	

Table 2. The migratory, resident and transient bird species that have been observed at the Lost Lagoon in Vancouver, B.C. (compiled from P. Woods 2017, personal communication, Worcester and Johnstone 2007).

Resident, Transient and Migratory Birds in Lost Lagoon		
Introduced	**Native**	**Species of Concern**
American Robin (*Turdus migratorius*)	Barrow's goldeneye (*Bucephala islandica*)	Barn swallow (*Hirundo rustica*)
American wigeon (*Anas americana*)		Caspian Tern (*Hydroprogne caspia*)
Black-capped Chickadee (*Poecile atricapillus*)		Double-crested Cormorant (*Phalacrocorax auritus*)
Black-capped Chickadee (*Poecile atricapillus*)		Forster’s Tern (*Sterna forsteri*)*
Brown Creeper (*Certhia americana*)		Great blue heron (*Ardea herodias fannini*)
Black swans (*Cygnus atratus*)*		Long-tailed Duck (*Clangula hyemalis*)
Common yellowthroat (*Geothlypis trichas*)		Short-billed Dowitcher (*Limnodromus griseus*)
Common merganser (*Mergus merganser*)		Surf Scoter (*Melanitta perspicillata*)*
Canada goose (*Branta canadensis*)		Red-necked Phalarope (*Phalaropus lobatus*)
California Gull (*Larus californicus*)		Western Grebe (*Aechmophorus occidentalis*)*
Dunlin (*Calidris alpine*)		Wandering Tattler (*Heteroscelus incanus*)
Glaucous-winged Gull (*Larus glaucescens*)		
Hooded merganser (*Lophodytes cucullatus*)		
Mute swan (*Cygnus olor*)*		
Mallard (*Anas platyrhynchos*)		
Merlin (*Falco columbarius*)		
Northern flicker (*Colaptes auratus*)		
Northwestern Crow (*Corvus caurinus*)		
Northern Rough-winged Swallow (*Stelgidopteryx serripennis*)		
Pacific-slope Flycatcher (*Empidonax difficilis*)		
Pied-billed grebe (*Podilymbus podiceps*)		
Purple Finch (*Haemorhous purpureus*)		
Sandpiper (*Calidris sp.*)		
Song sparrow (*Melospiza melodia*)		
Spotted Towhee (*Pipilo maculatus*)		
Spotted Towhee (*Pipilo maculatus*)		
Townsend’s Warbler (*Setophaga townsendi*)		
Warbling Vireo (*Vireo gilvus*)		
Wilson’s Warbler (*Cardellina pusilla*)		
Wood duck (*Aix sponsa*)		

Note: *Species that may no longer occupy area.

Table 3. Key fish, herptil, invertebrate, and small mammal species that have resided in Lost Lagoon, Vancouver, B.C. (compiled from personal observation, Worcester and Johnstone 2007).

Fish species		
Introduced	**Native**	**Invasive**
Brown catfish/brown bullhead (*Ameiurus nebulosus*)* Cutthroat trout (*O. clarkii*)* Prickly sculpin (*Cottus asper*)	Flatfish (*Pleuronectidae sp.*)* Threespined stickleback (*Gasterosteus aculeatus*) Rainbow trout (O*ncorhynchus mykiss*)*	Common carp (*Cyprinus carpio*)
Herptile species		
Northern Green frog (*Lithobates clamitans melanota*) Western painted turtle (*Chrysemys picta*)		American bullfrogs (*Rana catesbeiana*) Red-eared sliders (*Trachemys scripta*)
Mammals		
American mink (*Neovison vison*) Common raccoon (*Procyon lotor*) Coyote (*Canis latrans*) Little brown bat *(Myotis lucifugus)* North American Beaver (*Castor canadensis*) Striped skunk (*Mephitis mephitis*) Yuma Myotis (*Myotis yumanensis)*	The North American river otter (*Lontra canadensis)*	

Invertebrate species	
Introduced	**Of concern**
Bees (*Apidae sp.*) Black Slug (*Arion ater*) Blue-eyed Darner (*Rhionaeschna multicolor*) Bird Hover Fly (*Eupeodes volucris*) Common eastern bumblebee (*Bombus impatiens*) Eight-spotted Skimmer (*Libellula forensis*) Gastropods (*Gastropoda sp.*) Hover Flies (*Syrphidae sp.*) Honey Bee (*Apis mellifera*) Leopard Slug (*Limax maximus*) Moth Flies (*Psychodinae sp.*) Midges *Chironomidae sp* Magnificent Bryozoan (*Pectinatella magnifica*) Pacific Banana Slug (*Ariolimax columbianus*) Woodland Skipper (*Ochlodes sylvanoides*) Yellow-faced Bumblebee (*Bombus vosnesenskii*)	Blue dasher dragonfly (*Pachydiplax longipennis*) Johnson's hairstreak butterfly (*Callophrys johnsoni*)

Note: *species may no longer be present on site.

Table 4. Main fish and bird species found occupying Coal Harbour, B.C.

Fish	
Native	**Introduced**
Bay pipefish (*Syngnathus leptorhynchus*) Coho (*O. kisutch*) Chum (*O. keta*) Chinook (*O. tshawytscha*) Cutthroat trout (*O. clarkii*) English sole (*Parophrys vetulus*) Pink salmon (*O. gorbuscha*) Pacific herring (*Clupea pallasii*) Pacific staghorn sculpin (*Leptocottus armatus*) Pacific sand lance (*Ammodytes hexapterus*) Shiner perch (*Cymatogaster aggregata*) Starry flounder (*Platichthys stellatus*) Sockeye (*O. nerka*) Steelhead (*O. mykiss*) Sunflower star (*Pycnopodia helianthoides*) Tidepool sculpin (*Oligocottus maculosus*)	
Bird species	
American pipit (*Anthus rubenscens*) American widgeon (*Anas americana*) Barrow's goldeneye (*Bucephala islandica*) Belted kingfisher (*Megaceryle alcyon*) Bufflehead (*Bucephala albeola*) Common loon (*Gavia immer*) Glaucous-winged gull (*Larus glaucescens*) Great blue heron (*Ardea Herodias*) Killdeer (*Charadrius vociferus*) Mallard (*Anas platyrhynchos*) Mew gull (*Larus canus*) Northwestern crow (*Corvus caurinus*) Ring-billed gull (*Larus delawarensis*) Red-throated loon (*Gavia stellate*)	Canada goose (*Branta canadensis*)
Invertebrate species	
64 listed *sp.*	

Table 5. Water chemistry averages over three months (August-October) in 2017 for Lost Lagoon, Vancouver, B.C.

Site	DO%	DO mg/L	pH	Salinity	Temp
1	56	4.71	6.99	0.93	24
2	60.5	5.13	7.19	0.94	24.1
3	65.1	5.45	7.26	0.93	24.4
4	77.4	6.29	7.28	0.93	24.4
5	62.9	5.28	7.17	0.92	24
6	73.7	6.01	7.28	0.92	24.4
7	55.3	5.05	7.17	0.92	23.3
8	64.2	5.62	7.14	0.93	23.3
9	n/a	n/a	n/a	n/a	n/a
10	81.4	6.49	7.23	0.93	26.3
11	86.2	7.88	7.68	0.92	26
12	88.9	6.8	7.69	0.94	26.5
13	82.9	6.96	7.69	0.94	26.2
14	80.1	6.78	7.44	0.05	22.6

Table 6. Total heavy metal concentrations found in sediment samples in August 2017 in Lost Lagoon, B.C. in 2017.

Heavy Metals	Site BW	Site OB	Site IC	Site CH
Antimony (Sb)	30.4	1.21	1.26	0.87
Arsenic (As)	5.12	7.50	6.71	4.80
Barium (Ba)	152	85.8	88.4	53.8
Beryllium (Be)	0.30	0.34	0.34	0.19
Cadmium (Cd)	2.54	1.1 9	2.45	1.04
Chromium (Cr)	95.0	27.9	22.8	20.2
Cobalt (Co)	10.2	10.5	10.3	7.90
Copper (Cu)	519	99.2	123	68.8
Lead (Pb)	83.0	58.8	105	57.3
Mercury (Hg)	0.092	0.093	0.228	0.077
Molybdenum (Mo)	12.1	1.72	1.55	0.92
Nickel (Ni)	30.1	24.7	25.7	16.5
Selenium (Se)	1.00	0.57	0.85	0.32
Silver (Ag)	0.48	0.19	0.36	<0.10
Thallium (Tl)	0.090	0.165	0.236	0.191
Tin (Sn)	46.1	4.1	13.0	2.9
Uranium (U)	0.629	2.04	3.37	0.965
Vanadium (V)	57.2	63.7	40.2	33.6
Zinc (Zn)	691	152	231	147

Appendix B. Restoration Strategies for Fish Collection

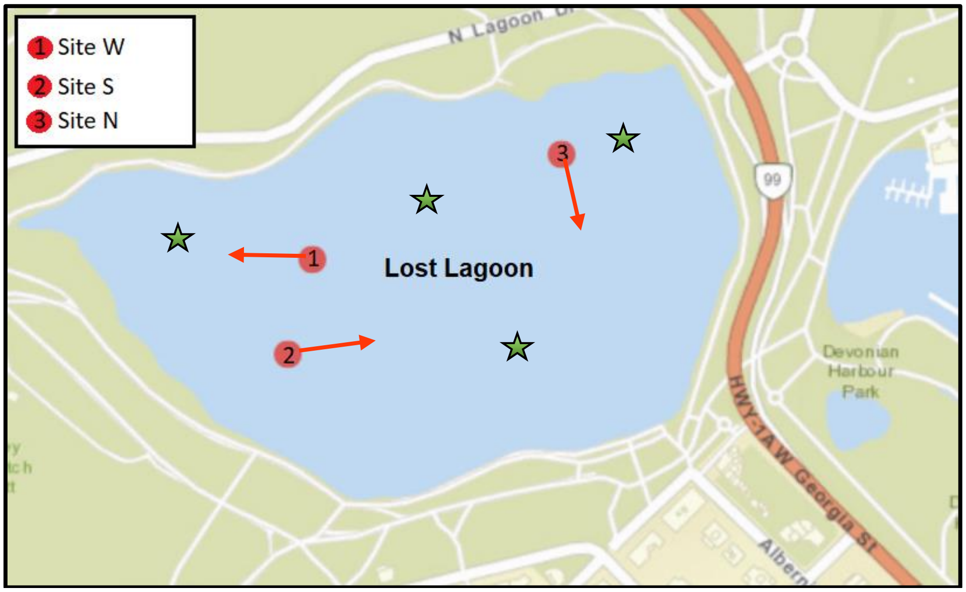

Figure 1. Site locations for gillnets and bottom trap nets in Lost Lagoon, Vancouver, B.C. The red arrows indicate the direction to set them in and the star symbols indicate the bottom trap net locations.

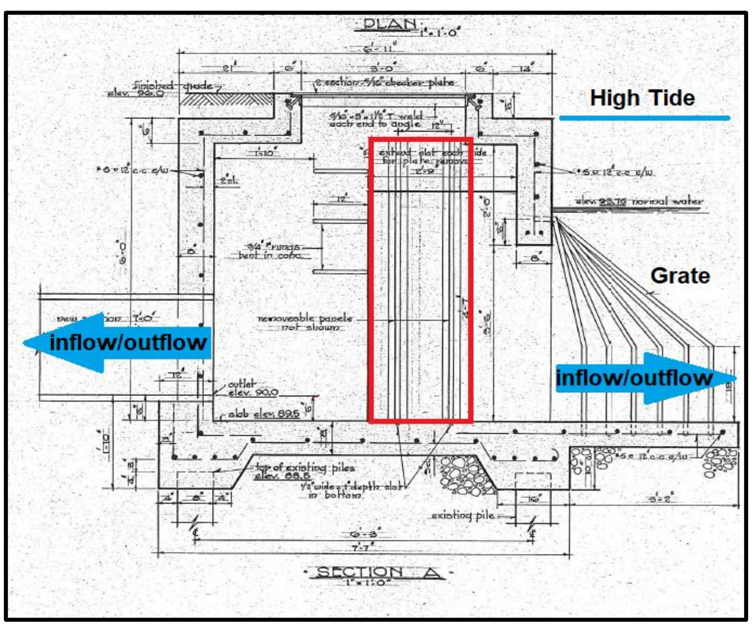

Figure 2. Suggested weir removal on the existing flap-gate control valve that connects Lost Lagoon to Coal

Harbour in Vancouver, B.C. to introduce hydraulic flushing (photo provided by N. Page).

Appendix C. Project Budget and Schedule

Table 1. Forecasted project budget for the restoration of Lost Lagoon in Stanley Park, Vancouver, B.C.

Category	Description	Units	Rate	Quantity	Cost
	General field tools				
Field notes	Write in the Rain field book	item	$38.46	3	$115.38
Camera	Polaroid iOS48 waterproof camera	item	$64.99	1	$64.99
GPS	handheld Garmin eTrex 20 x 2.2" GPS	item	$169.99	1	$169.99
Safety Gear	gloves, hard hats, vests, glasses	item	$3.98-10.97	10	$263.90
				Total cost	**$614.26**
	Task 1. Fish Collection				
Equipment	custom made gillnets to target carp	item	$322.00	3	$966.00
	Bottom trap nets	Item	$250.00	2	$500.00
	chest waders	item	$89.99	3	$269.97
	GPS Garmin sonar device	item	$109.97	1	$109.97
Workers	fishery technician staff 8 hrs/3days	hour	$50.00	3	$1,200.00
Licenses	Fishing Permit	fee	$35.00	1	$35.00
Services	fish carcass pick-up and compost	fee	$2,000.00		$2,000.00
				Total cost	**$5,080.94**
	Task 2. Weir Removal				
Machinery	truck to remove weir from site	day	$100.00		$100.00
Workers	engineer/ labourers for 8 hrs	hour	$50.00	3	$1,200.00
Licenses	water diversion approval	fee	$250.00		$250.00
				Total cost	**$1,550.00**
	Task 3. Excavator				
Machinery	excavator used to construct berms	hour	$1,000.00	1	$1,000.00
Workers	labour worker for 8 hrs	hour	$100.00	1	$800.00
				Total cost	**$1,800.00**
	Task 4. Water channel Installation				
Contraction	Machinery, infrastructure				$2,550,000.00
Workers	hydraulic engineers	hour			$450,000.00
Signs	warn public for construction on HWY1A	sign	$1,000.00		$1,000.00
				Total cost	**$3,001,000.00**
	Task 5. Planting Plan				
Plants	plugs from local nursery	plants	$1.00	11,075	$11,075.00
Soil	local delivery of soil mix (10 yards)	delivery	$1,000.00		$1,000.00
Workers	labourers/managers for 8hrs/3days	hour	$45.00	5	$5,400.00

Equipment	planting shovels	item	$64.99	5	$324.95
				Total cost	**$17,799.95**
		Task 6. Geese Exclosures			
Equipment	PVC pipe	item	$10.47	50	$523.50
	wooden poles	item	$12.00	100	$1,200.00
	215 m of 1/2"/50' biodegradable rope	item	$36.00	7	$252.00
	hammer	item	$27.99	3	$83.97
	steel post pounder	item	$79.80	2	$159.60
	staples	item	$15.29	3	$45.87
	staple gun and staples	item	$42.99	2	$85.98
	flagger	item	$4.99	20	$99.80
	1" x 36" x 50'chicken wire	item	$47.99	10	$479.90
	1/2" x 200' measuring tape	item	$38.99	1	$38.99
Workers	construction labour for 8 hrs	hour	$50.00	5	$2,000.00
				Total Cost	**$4,469.61**
				Grand total	**$3,032,200.50**