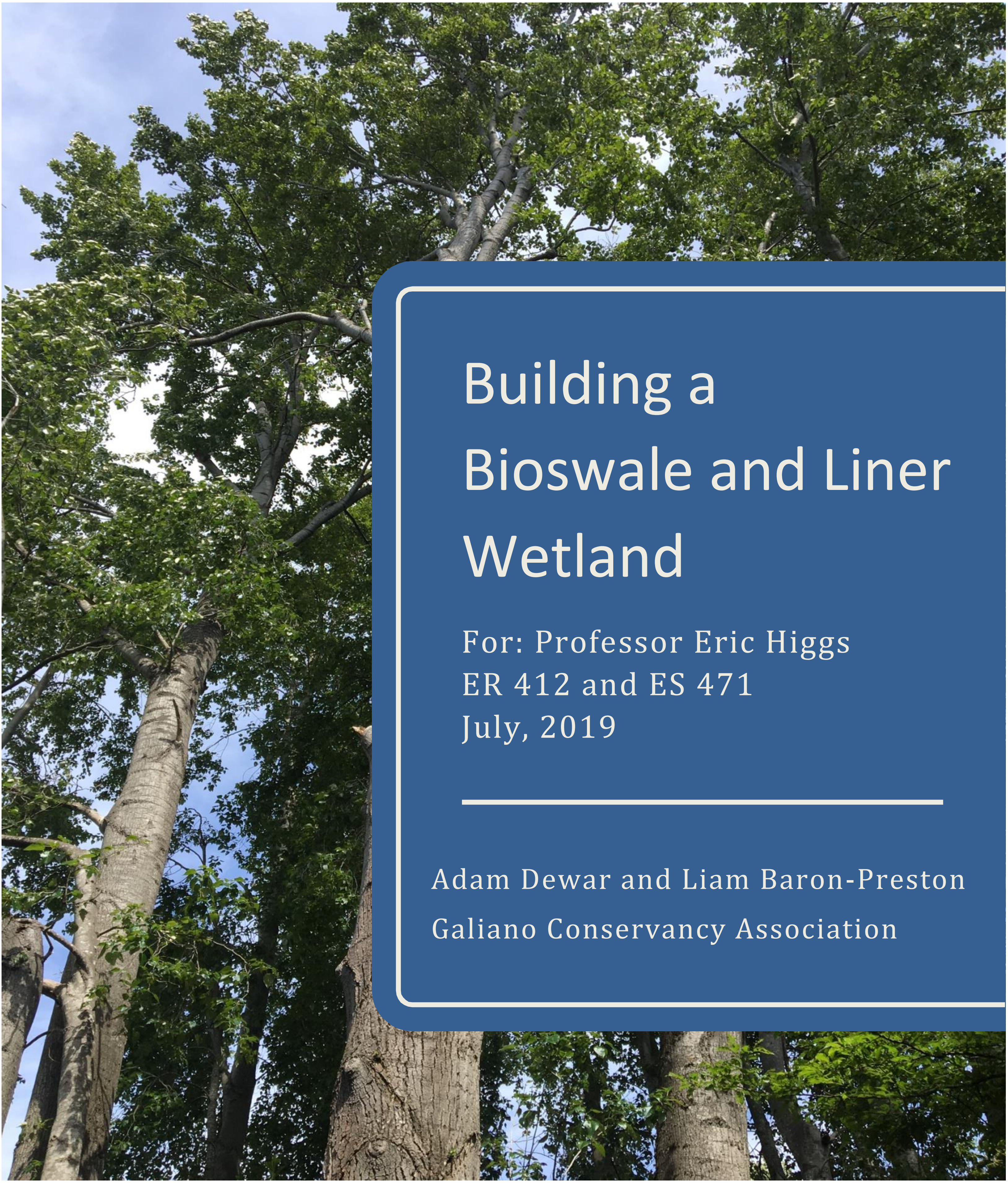

Building a Bioswale and Liner Wetland

For: Professor Eric Higgs
ER 412 and ES 471
July, 2019

Adam Dewar and Liam Baron-Preston
Galiano Conservancy Association

Table of Contents

1. Introduction

The project undertaken is to design a bioswale for the Millard Learning Centre on Galiano Island. This bioswale will feed into a liner wetland that will serve as a year-round pond. The project site is where the learning centre's "head office", the Program Centre, is currently being constructed. The water inflows for the bioswale and the pond are certain to contain pollutants and contaminants of varying types. For example, the water off the parking lot may be contaminated with heavy metals from vehicles and suspended solids from sediment flow as the lot is dirt and gravel. The bioswale's purpose is to slow and filter the water (CRD, 2019) to ensure the water entering the wetland is as clean as possible in hopes of creating a stable, self-sustaining habitat. The bioswale and wetland will be created through site excavation to ensure proper flow and depth characteristics, and by the planting of native plants. Plant communities will be designed to have similar composition and successional characteristics to other wetland sites on the Millard Learning Centre property. The plan is to only use native plants that are already existent on Galiano Island specifically, to avoid the effects of non-native species on the island's ecosystems. This design proposal will cover the ecology, function, and habitat value of this bioswale and wetland. It will also delve into specific design plans, both in the physical building of features, and in the plant composition of the designed system. It will also touch on future projects that could be associated with this project as establishment moves forward.

2. Bioswales

"Bioswales are vegetated open channels specifically designed to attenuate and treat stormwater runoff for a defined water volume. Like open ditches, they convey large stormwater volumes from a source to a discharge point, but unlike ditches, they intentionally promote slowing, cleansing, and infiltration along the way." Capital Regional District definition (CRD, 2019).

2.1 Bioswale ecology

As stated above, the primary goal of a bioswale is to slow and filter the water that it receives from its inputs. Ecologically, bioswales host a team of important players, namely healthy vegetation and soil. The above ground parts of the plants are integral in the slowing of the water flow, along with the slope of the swale, as mentioned below. This slowing of the water allows for sediments containing pollutants to settle. These sediments and pollutants are then incorporated into the soil already in the swale. In this process the pollutants may either be immobilized and sequestered or physically broken down. The breakdown process is facilitated by the bacteria that are present in healthy soils (CRD,2019). The key to an effectively constructed bioswale is thick vegetation and proper substrate selection within the channel itself. A secondary benefit to bioswales is the increase in biodiversity in and around the implementation site provided that the plants selected to vegetate the swale are not introduced and naturally occurring in that area.

2.2 Bioswale function

The primary functions of a bioswale are slowing and filtration of its source water. The slowing function of a bioswale is generally created by its sloped base (CRD, 2019). According to the CRD, bioswales should have a longitudinal slope of only 1-2%. If the natural slope of the land exceeds this threshold, then the swale should be "dished" at regular intervals to achieve its desired water slowing characteristics. This essentially equates to building catchment basins along the length of the swale to ensure the water moves slowly enough and spends enough time in the swale to be filtered. A secondary, and site-specific benefit for water collection and slowing is the prevention of erosion. Collection of the water from the dirt parking lot will mitigate erosion effects that are currently being observed on the road down to the learning centre, and the slowing of the water will help prevent erosion within the bioswale itself.

In terms of filtration, bioswales provide promising filtration properties with regards to both suspended solids (Purvis et al., 2018), which are generally associated with erosion and sediment transport, and dissolved heavy metals associated with automotive wear and fluid leaks (Evans et al., 2019). In figure 1 we see a heatmap of dissolved heavy metal concentrations as water flows through a bioswale that was built on the campus of Pomona University in Southern California. Evans and colleagues (2019) found that there was a statistically significant decrease in the concentrations of the heavy metals lead, zinc, cobalt, and manganese and a remarkable decrease in copper (first 5 boxes in figure 1). These metals are all directly attributed to automotive sources, be it engine, bearing and brake wear or fluid leaks. This is a critical benefit of bioswale implementation, especially since the main water catchment for this proposed project is itself a parking lot that is likely to experience these very pollutants. Studies show that if these pollutants make it further into the watershed, and in our case, a standing wetland, acute toxicity can be experienced by aquatic organisms and there can be great negative impact on invertebrate communities. This impact can greatly disrupt the health of the aquatic habitat as a whole, and bioswales are an excellent low impact design feature that can help maintain watershed and associated wetland health (Anderson et al., 2016). Full data results from the study performed by Anderson and his colleagues can be found in appendix 1.

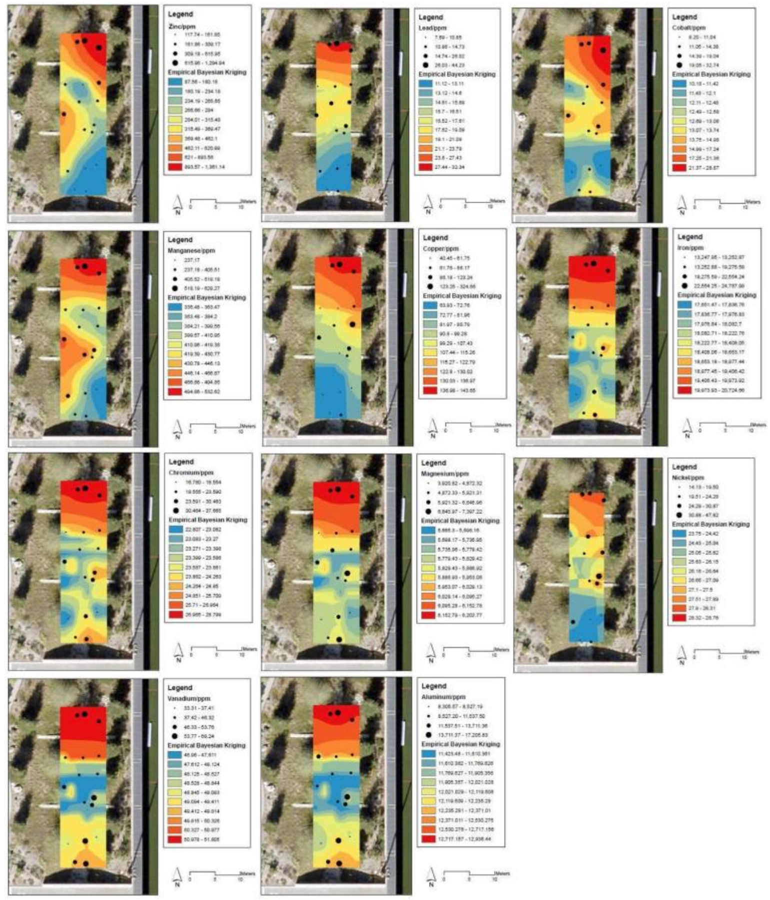

Figure 1: Heatmaps showing dissolved heavy metal concentration as water flows through a bioswale. The first five panels correspond to metals that are relevant to the Millard Learning Centre project. https://ars-els-cdn-com.ezproxy.library.uvic.ca/content/image/1-s2.0-S004896971833417X-gr2_lrg.jpg

3. Wetland function and ecology

Wetlands are valuable habitats for many species of both flora and fauna. However, wetlands provide more than just habitat, they carry a host of other ecosystem services with them. For example, wetlands provide services such as pollutant removal, stormwater storage and regulation, and microclimate regulation (McLaughlin and Cohen, 2013). McLaughlin and Cohen (2013) stipulate that the ecosystem services that wetlands provide are inextricably tied to their healthy ecological functions.

Wetlands comprise about 6% of the total land of British Columbia and have seen a 15% decline since 1800 (CRD, 2019). With this decline in mind, wetland creation and restoration is critical moving forward. Directly or indirectly, nearly all wildlife will depend on wetlands at some point in their life cycle. Wildlife that shallow water wetlands in BC support through most of their life cycles include but are not limited to frogs, newts, salamanders and toads. Many of these species happen to be species that are at risk in British Columbia. Many bird species such as Great Blue Heron, swallows, warblers, wrens and chickadees also rely heavily on wetlands seasonally for both nesting and feeding purposes (CRD, 2019).

One primary issue currently observed in wetlands that are constructed specifically for stormwater treatment are the deleterious effects of pollutants in the source water. While stormwater wetlands are effective at treating these pollutants, it's possible that the impacts on the habitat occur more quickly than pollutant removal (Sievers et al., 2018). However, the Sievers study only looked at wetlands in an urban context. For this project, we hope that the water treatment provided by the bioswale prior to water entering the wetland can be sufficient to allow the wetland habitat to function in a healthy manner. We believe this to be possible because the pollutant concentration will be vastly less than what is seen in a fully urbanized context. This does, however, underscore the importance of water quality testing as part of a management plan moving forward after implementation of this project.

4. The Project

4.1 Project goals

1. Prevent and mitigate further erosion of the dirt and gravel parking lot and road on the Millard Learning Centre property
2. Reduce pollutants present in the stormwater runoff from the parking lot and upper road as well as part of the roof of the new Program Centre
3. Reduce pollutants and contamination present in the greywater discharge from the new Program Centre
4. Manage peak water flow by attenuating and slowing water from inputs

5. Demonstrate the creation of green infrastructure that can aid in education and in the implementation of similar projects
6. Create a self-sustaining ecosystem that will in turn provide valuable plant and animal habitat

4.2 Project objectives

1. Design a functioning bioswale using only local, native plants and proper substrate to facilitate the filtration, sequestration and removal of harmful pollutants from the watershed
2. Design a self-sustaining wetland that the bioswale feeds into to manage flooding during peak flows, store and further filter stormwater, and provide valuable wetland habitat to native flora and fauna of Galiano Island

5. Site description

5.1 Overview

The site for this project is on the upper level of the Millard Learning Centre property. The site sits adjacent to the parking lot on its Southwestern side. The site has a pronounced slope from the parking lot down to where it meets the road, this slope has a Southwest facing

View looking down the hill. The Program Centre is on the left and the channel to be used as the course of the bioswale is visible between the side of the building and the road. The bioswale will follow the curvature of the road, hugging its left side. Photo: Adam Dewar aspect. This aspect combined with the slope provides ideal sun conditions and yields great sun exposure. The whole project site is about 735m2 (Yip, 2018) with the bioswale and wetland portion of the project covering an estimated 100-200m2 of that. The site as we know it right now, is very degraded. This is mainly due to the fact that it's an active construction site where the new Program Centre is being built. The whole upper half or so of the site has been excavated and a building that will serve as the new Program Centre is being erected. There are two large piles of detritus consisting of excavated vegetation and coarse woody debris. In between these debris piles and the road to the west of the Program Centre is a vegetated slope, with a combination of both native and non-native plants. While it is likely that this whole area will as well be excavated as part of the implementation of the bioswale, wetland and separate nursery annex project, the current plant communities can still give us valuable information about the site and should be paid attention to. For example, on the northern border of the site, and the northwestern corner there is lots of common rush (*juncus effusus*) and Bolander's rush (*juncus bolanderi*) present, this suggests soil with good moisture content and high water table, thus making this site a good choice for a wetland.

5.2 Vegetation

As mentioned above, the site is currently a construction zone so determining the natural vegetation communities present on the site proves difficult. However, on the less disturbed vegetated slope we observed the presence of several different rush and sedge species, bracken fern (*pteridium aquilinum)* also had a pronounced population. Trailing blackberry (*rubus ursinus)* is

Transition area, this is where the bioswale will begin to meet the wetland. Just on the left side of the road as it flattens out there is a shallow depression in the ground that will be used as the base of the year-round wetland. This photo also shows vegetation and site degradation from the ongoing construction. Photo: Adam Dewar frequently found among the tangles of several grass species and then there are a number of invasive species present as well such as bull thistle (*cirsium vulgare)* and common foxglove (*digitalis purprea)*. Fern Yip (2018) performed a vegetative assessment prior to the commencement of the building project and excavation. The pre-construction site boasted many of the same dominant plants that can be found there now, however there were several non-dominant plants found in the area that were not observed this time around. These plants included more berry species, such as tall Oregon-grape (*mahonia aquifolium)* and salmonberry (*rubus spectabilis)* along with yerba buena *(clinopodium douglasii)* and several other plants and saplings. A full list of these non-dominant plants found on site in 2018 can be found in appendix 2.

5.3 Water catchment

The critical aspect of the site for this project is the water catchment area. Site and project hydrology specifics (channels, catchment basins, culverts etc.) will be covered in greater detail in section 6.1 below. Purely in terms of water catchment, the bioswale will receive its inputs from the parking lot, the roadside half of the Program Centre's roof and the Program Centre's underground grey water discharge. The primary water source is the parking lot, which is just over 400m2 in area and its ground is highly compacted dirt and gravel with some sections containing larger rocks. There will be some water infiltration because the surface isn't paved, however due to its compact nature, it can be treated as semi-impervious. The secondary water source is the roof of the Program Centre, this roof was calculated to have an area of about 75m2. It is a metal sheeting roof and is therefore completely impermeable, so all the water that falls on "our" half of the roof will end up in the bioswale. The tertiary water source is something of a wildcard. The Program Centre is not yet completed or operational, so it's anyone's guess as to how much grey water will be discharged from the building once things are up and running. There is also a forested area along the southern border of the parking lot, this area is sloped toward the parking lot with a northern aspect. Since this island is within the Coastal Douglas-fir (CDF) forest biogeoclimatic zone (UBC Forestry, 2019) we are most likely dealing with a brunisolic soil type (Nuszdorfer et al., 1991). However, it would be prudent to have a soil profile and assessment taken on site to be sure. The soil type on the site will go a long way in determining how much water infiltration can be expected and therefore how much runoff we will see entering our bioswale system from that part of the "mini-watershed" that we are collecting from.

6. The Design

6.1 Hydrology

This proposed system will have three main flow inputs and two flow outputs (Figure 2). The three water inputs are parking lot runoff, rain catchment from half of the roof, and grey water from the office building that will be released underground in the garden.

As seen in Figure 1, The first input, parking lot runoff, will be collected by allowing impermeable barriers to conduct water to a collection point and to the head of the bioswale, from which it will flow down the bioswale to the wetland. The collection point will be connected to the bioswale by a pipe/culvert to allow bus access to the building.

The second input is the rain catchment from half of the roof where water will be collected by a gutter system and conducted to the bioswale. At the head of the bioswale there will be a collection pool to gather water from these two inputs and slow the water flow. There will be three more equidistant collection pools in the bioswale for the purpose of slowing the extra downhill flow generated from the grade of the slope. The system should be designed to accommodate the theoretical peak flow, which is calculated by the following formula:

$$Q=CIA \qquad \text{(PDH, 2012)}$$

Where Q= peak runoff flow (cubic ft/s)

C= runoff coefficient (based on impermeability of surface, table in appendix 3)

I= average rainfall intensity (inches/hour)

A= drainage area (acres)

Parking lot: Q= 0.75*0.51*0.1

Q= 0.038 ft3/s = 1.08 l/sec

Roof: Q= 1*0.51*0.02

Q= 0.0102 ft3/s = 0.3 l/sec

Total Peak Flow = 1.08+0.3 = 1.38 litres per second

These calculations were based on the largest day of rainfall ever recorded on Galiano Island and assumed that all of that rain fell in the span of 5 hours. It is unlikely that this type of peak flow will ever be dealt with on this site, however, when slowing water is the most important factor for bioswale function, overengineering is a must. Channels, catchment basins and culverts that are not able to handle high peak flows are susceptible to damage, erosion, unnatural sediment flow and decreased filtration ability.

The third input into the system will be water coming from the grey water system of the new building. This grey water will be filtered by a native plant garden (Yip, 2018) and some water may flow downhill into the wetland. We do not know how much of this water will flow into the wetland and how much will be successfully infiltrated deeper into the ground.

The two outputs for this system will both be located by the wetland. The first is a culvert that already exists and will drain groundwater from beneath the pond liner of the wetland. If extra room is found in the budget, a perforated pipe could be used to direct groundwater from below the deepest point of the wetland to this culvert for drainage. The second output is the main output for water in the wetland, an overspill pipe. The overspill will also set the maximum water level of the wetland and should be as large as possible for high flow events and to avoid blockage by winter freezing. It would be simplest to have the overspill pipe run under the road, but other ways to move the water, such as an impermeable sunken trench and metal grate or a cattle guard, should also be considered.

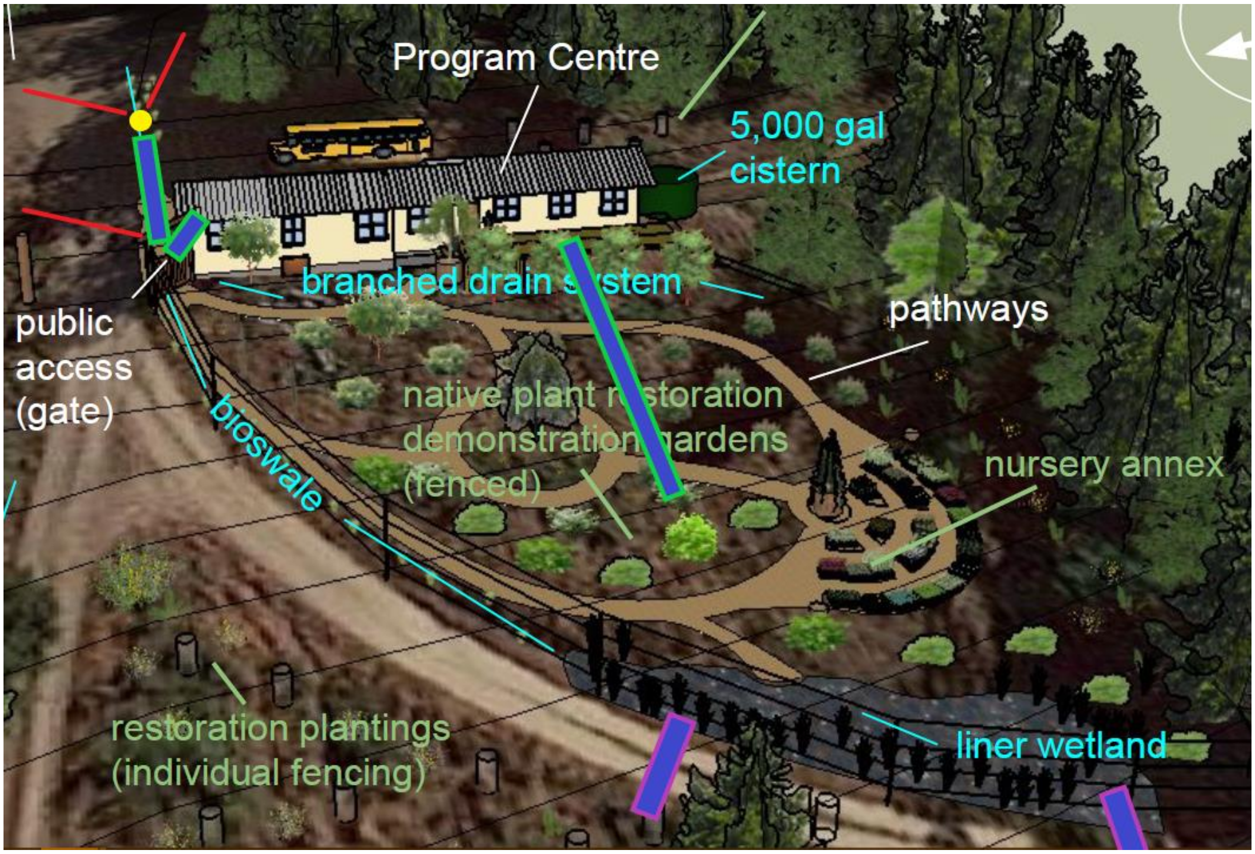

Figure 2. Hydrological inputs and outputs to the designed bioswale and wetland system. Blue bars represent pipes and the edge colour represents the direction of flow, with green representing flow inputs and purple representing flow outputs. There are three input pipes: a pipe directing parking lot runoff (left), a pipe directing roof runoff from the roadside half of the roof (middle), and the grey water pipe terminating underground in the garden (right). The red lines in the parking lot represent impermeable barriers sunk into the lot to direct runoff to a catchment point (yellow) and the top of the bioswale adjacent to the gate. There are two output pipes: a culvert (left) and an overspill pipe (right).

6.2 The Bioswale

The bioswale will stretch from the corner of the office building, alongside the road, to the wetland. Given the depth restriction imposed by a pipe crossing the site approximately 0.61m underground, we recommend that the swale have a depth of 0.5m and a width of 1.75m. This depth would allow for 30cm of substrate with 20cm of space for plant growth and surface flow. We do not know if these dimensions will accommodate the peak flow calculated above, but there are formulae for the calculation of swale dimensions found in water design manuals. The most widely cited manual we found was that of King County in Washington state. King County contains the city of Seattle and we believe that their Surface Water Design Manual (King County, 2016) would be a useful resource for this project given the similar average annual precipitation of Seattle and Galiano Island (Pelmorex Inc., 2019, Lam, 2016). Due to limited site time, we do not have the necessary measurements to use the standard formulae found in section 6.3 of the King County manual. We are not hydrologists and as such we recommend that the GCA conduct a land survey to determine the necessary measurements and consult with a hydrologist or surface water engineer to ensure that the bioswale and wetland function as intended.

In the current design we also recommend four small water collection pools spaced at even distances down the length of the bioswale, with the first located at the head of the bioswale where water from the parking lot pipe and roof runoff enter the system. These pools will help slow the water and prevent erosion due to the steep slope. These pools would also provide an opportunity for a water quality monitoring project to measure the efficacy of the bioswale.

The bioswale vegetation will consist of three sections with different species compositions, referred to as communities (Figure 3). These communities are to mimic the successional change in species composition in the areas approaching the other wetlands found nearby. Each community will be planted with plant species native to Galiano Island to avoid the introduction of non-native species to the island. While we recommend the species composition of each section, this recommended composition is only for the initial establishment of the bioswale and it is expected that the composition will change as volunteer plants move in and some planted species become more dominant. As the boundaries between communities are conceptual, we do not have exact measurements for where these boundaries will lie, but the third community should be the section of swale where water pools in the winter, but is still dry in the summer. The boundary between the first and second community can be located halfway from the head of the bioswale to the third community.

The first vegetative community (outlined in red in Figure 2) is recommended to consist of four species: 3 rush species (*Luzula subsessilis, Juncus effusus, Juncus bolanderi*) and 1 sedge species (*Carex obnupta*). The second vegetative community (outlined in yellow) is also recommended to consist of four species: 1 rush species (*Juncus bolanderi*) and 3 sedge species (*Carex obnupta, Carex hendersonii, Scirpus microcarpus*). All of these species may be planted in equal proportions in their respective sections such that community 1 is 75% rush and 25% sedge and community 2 is 25% rush and 75% sedge. The reasoning behind this is to simulate a gradient from rush to sedge found around nearby wetlands and allow competition between different species to end up with the native species best suited for the swale environment. The third vegetative community (outlined in blue) will consist of two species: Panicled Bulrush (*Scirpus microcarpus*) and Swamp Lantern (*Lysichiton americanus*) because both of these species can easily tolerate seasonal standing water.

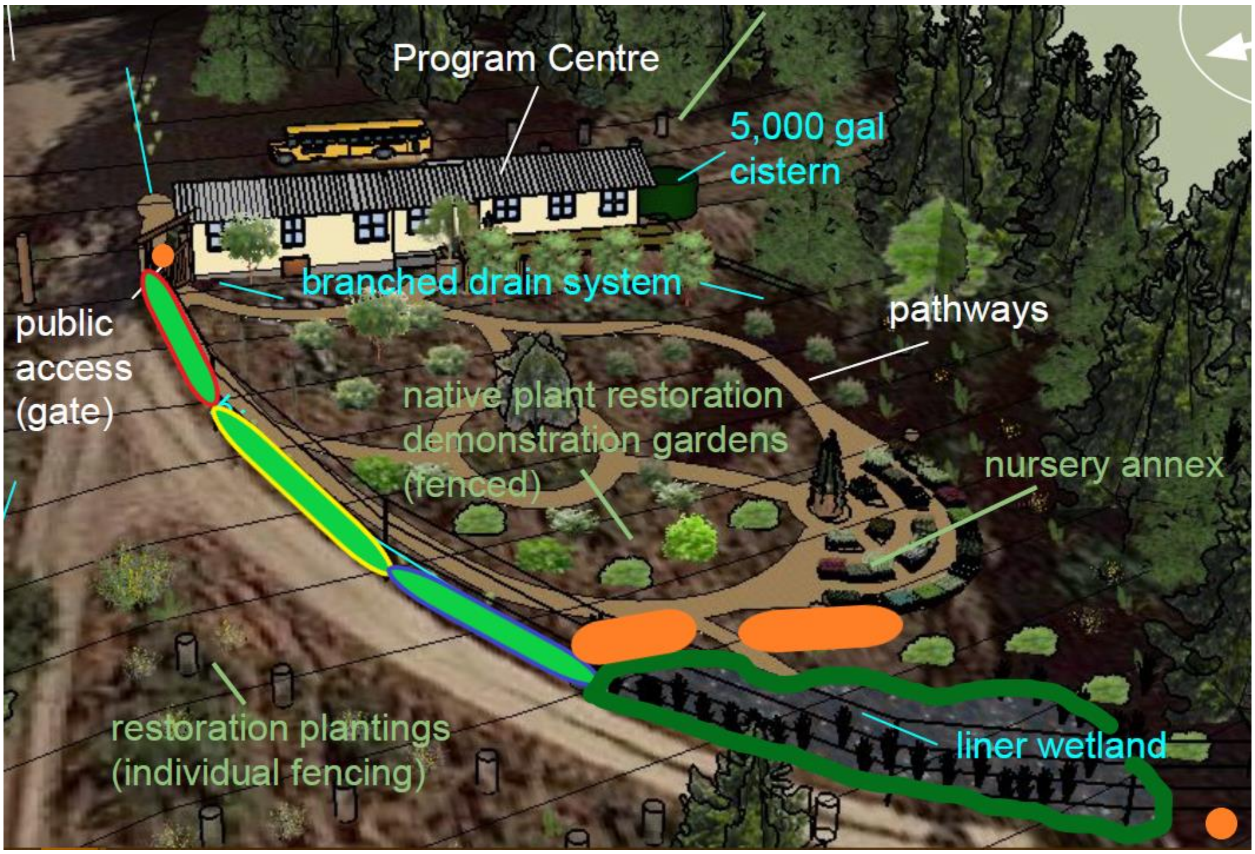

Figure 3. Vegetative communities of the designed bioswale and wetland system. Light green represents the bioswale communities, dark green represents the wetland community, and orange represents auxiliary plants. There are three bioswale communities differentiated by edge colour. The first and second bioswale communities (red and yellow respectively) will both be made up of rush species (*Luzula subsessilis, Juncus effusus, Juncus bolanderi*) and sedge species (*Carex obnupta, Carex hendersonii, Scirpus microcarpus*) with the first (red) being more rush dominant and the second (yellow) being more sedge dominant. The third community will be made up of Panicled Bulrush (*Scirpus microcarpus*) and Swamp Lantern (*Lysichiton americanus*). The wetland community will be made up of Panicled Bulrush (*Scirpus microcarpus*), Broadleaf Cattail (*Typha latifolia*) and Scouler's Willow (*Salix scouleriana*). The orange dot beside the office represents an Oceanspray bush (*Holodiscus discolor*). The orange bars between the wetland and the garden represent Salmonberry bushes (*Rubus spectabilis*). The orange dot on the bottom right represents a Bigleaf Maple tree (*Acer macrophyllum*).

6.3 The Wetland

The wetland will receive water from the bioswale and the surrounding hillside. The exact size of the wetland is still largely undefined, but it will utilize 200m2 pond liner and must have a center area deeper than three feet to allow for open water, so the wetland will likely be 100m2 - 150m2. We recommend that a survey of the area be conducted to determine the size of the wetland. We also recommend a berm be built between the wetland and the road to allow for the necessary depth, and the size of this berm should be determined by the survey.

The wetland vegetation (Figure 2) will largely consist of three species: Panicled Bulrush (*Scirpus microcarpus*), Broadleaf Cattail (*Typha latifolia*) and Scouler's Willow (*Salix scouleriana*). Panicled Bulrush and Broadleaf Cattail are both dominant in nearby wetlands and are large plants that will provide structure for the edge of the wetland. Scouler's Willow is the most commonly noted willow species on Galiano Island (iNaturalist, 2019) and of all the native willow species, it can survive in the most xeric conditions (E-Flora BC), making it easier to care for during establishment of the wetland. We recommend that Scouler's Willow be planted along the road-side of the wetland to shade the wetland, hopefully preventing algal blooms, and aesthetically separate the wetland from the road and fence. Like the bioswale, it is expected that other native species will 'volunteer' and establish themselves in the wetland. Some expected volunteers include Bracken Fern (*Pteridium aquilinum*), Giant Horsetail (*Equisetum telmateia*), and Soft Rush (*Juncus effusus*).

We recommend that woody debris be implemented in the wetland to increase structural diversity. A log extending into the water would be useful habitat for birds and amphibians and one or two stumps in the pond would act as biotic islands and attract greater species abundance. It is also recommended that substrate samples from another wetland on the property (taken from a comparable depth) be introduced to the wetland in order to jumpstart micro-biotic processes.

6.4 Auxiliary Flora

Our design includes three auxiliary plantings as seen in orange in Figure 2. The Oceanspray bush (*Holodiscus discolor*) to be planted near the head of the bioswale is there for aesthetics and to draw the eye from the gutter that will be draining water from the roof to the bioswale. We still want the water inputs visible for possible education tours, but for everyday purposes that area should be aesthetically pleasing.

The Salmonberry bushes (*Rubus spectabilis*), in addition to growing berries, will provide a conceptual barrier between the garden and the wetland. Salmonberry also has extensive root systems that will secure the soil immediately upland of the wetland to help prevent erosion and slow/infiltrate groundwater flow coming downhill.

The Bigleaf Maple (*Acer macrophyllum*) is to further shade the wetland. Currently the area gets a lot of sun and by planting the maple and willow species we can help prevent future algae blooms that could harm the wetland ecosystem.

6.5 Next Steps

The recommended next steps for the project should be to conduct a land survey of the site to obtain the numbers needed to calculate the proper bioswale dimensions and recommend the height of the berm and size of the wetland. Then a hydrologist should be consulted, and their recommendations taken into account.

7. Future Assessment

7.1 Water Quality Testing

As mentioned above in the hydrology section, this bioswale will require water collection features to help slow the water flow due to the relatively steep slope of the site. These catchment basins can be doubly beneficial if they are also used as water quality testing stations. Having little pockets of deeper water along the bioswale will allow for easier collection for testing purposes. The distance between each basin will be a known value and if suspended solids and dissolved heavy metals can be measured at each basin, then the efficiency and effectiveness of the bioswale's natural filtration can be tested and demonstrated. These testing stations can be used moving forward in educational programs and green infrastructure demonstrations as well, outlined below in section 7.3.

7.2 Repeat Photography

There is an existing and ongoing project on the property of the Millard Learning Centre that seeks to select an implement yearly repeat photography of specific sites on the property. Adam Huggins and Keith Erickson have interest in expanding this project to include more sites where monitoring via repeat photography would be beneficial. There are currently 9 permanent repeat photography sites on the Learning Centre property and we believe this project would be an ideal candidate for at least one permanent photo site, possibly two. It would be fascinating to see changes to the bioswale as well as the wetland over time.

7.3 Educational Programs

Like most restoration projects, there is always an educational aspect that can be presented to the public. Implementations such as interpretive signage explaining the ecosystems, plant communities and functions of the bioswale and wetland all lead to greater understanding of the purpose of such a restoration project. This project is also an excellent candidate to be used as a model for similar projects that could be implemented on the properties of landowners on the island. If interpretive signage were to be built in the area of the project, signs presenting the steps taken to design, plan and build it could be included as well. This is a prime example of green infrastructure that provides both practical ecological and aesthetic benefits.

In the future, workshops, activities and demonstrations could be implemented as well. Workshops to “design your own bioswale” and to give the public hands on training on how to create such a project themselves could be created. Also, in conjunction with the water quality testing mentioned in section 7.1, school groups could take part in activities or demonstrations where water is tested at each water collection zone to see just how effective and efficient the bioswale is at filtering out harmful pollutants.

One of the four main tenets of contemporary restoration is that projects must “benefit and engage society” (Suding et al., 2015) and this is a project that presents an excellent opportunity to do just that.

References

Anderson, B. S., Phillips, B. M., Voorhees, J. P., Siegler, K., & Tjeerdema, R. (2016). Bioswales reduce contaminants associated with toxicity in urban storm water. Environmental toxicology and chemistry, 35(12), 3124-3134.

CRD. (2019). Green Stormwater Infrastructure: Bioswlaes. Retrieved July 6, 2019, from https://www.crd.bc.ca/education/green-stormwater-infrastructure/bioswales

E-Flora BC Atlas Page. (n.d.). Retrieved July 15, 2019, from http://linnet.geog.ubc.ca/Atlas/Atlas.aspx?sciname=Salix%20scouleriana&redblue=Both&lifeform=2

Evans, Z. C., Ryswyk, H. V., Huertos, M. L., & Srebotnjak, T. (2019). Robust spatial analysis of sequestered metals in a Southern California Bioswale. Science of The Total Environment,650, 155-162. doi:10.1016/j.scitotenv.2018.08.441

iNaturalist.org. (n.d.). Retrieved July 14, 2019, from INaturalist.org website: https://www.inaturalist.org/observations?place_id=94935&view=species

King County. (2016). Surface Water Design Manual. Retrieved from https://www.kingcounty.gov/services/environment/water-and-land/stormwater/documents/surface-water-design-manual.aspx

Lam, L. (2016). Seattle's Rainy Reputation Is Well-Deserved. (n.d.). Retrieved July 14, 2019, from The Weather Channel website: https://weather.com/science/weather-explainers/news/seattle-rainy-reputation

McLaughlin, D. L., & Cohen, M. J. (2013). Realizing ecosystem services: wetland hydrologic function along a gradient of ecosystem condition. Ecological Applications, 23(7), 1619-1631.

Nuzsdorfer, F C, et al. Ecosystems of British Columbia . BC Ministry of Forests, 1991.

PDH. (2012). Stormwater Drainage Design for Parking Lots. PDH Online Courses. Retrieved July 8, 2019, from https://pdhonline.com/courses/c201/c201content.pdf.

Pelmorex Inc. (n.d.). Statistics: Galiano Island 9, British Columbia - The Weather Network. Retrieved July 14, 2019, from Legacyweb.theweathernetwork.com website: https://www.theweathernetwork.com/ca/api/sitewrapper/index?b=%2Fstatistics%2F&p=%2Ffor

ecasts%2Fstatistics%2Findex&url=%2Fstatistics%2Fcabc2500%2Fgaliano-island-9%2F%2F%2F%3F

Purvis, R., Winston, R., Hunt, W., Lipscomb, B., Narayanaswamy, K., McDaniel, A., ... & Libes, S. (2018). Evaluating the water quality benefits of a bioswale in Brunswick County, North Carolina (NC), USA. Water, 10(2), 134.

Sievers, M., Parris, K. M., Swearer, S. E., & Hale, R. (2018). Stormwater wetlands can function as ecological traps for urban frogs. Ecological applications, 28(4), 1106-1115.

Suding, K., Higgs, E., Palmer, M., Callicott, J. B., Anderson, C. B., Baker, M., ... & Randall, A. (2015). Committing to ecological restoration. Science, 348(6235), 638-640.

UBC Forestry. (2019). About BEC and BGC Units. Retrieved July 10, 2019, from https://cfcg.forestry.ubc.ca/resources/cataloguing-in-situ-genetic-resources/about-bec-and-bgc-units/

Yip, Fern. Imagining Restoration of the Galiano Conservancy Association's Project Centre Site. Galiano Conservancy Association, Aug. 2018.

Appendix 1

Results of the study on bioswale pollutant removal (Anderson et al., 2016)

						TSS	Bifenthrin	Cyfluthrin	Cypermethrin	(Es)Fenvalerate	Fenpropathrin	L-Cyhalothrin	Permethrin	Fipronil	Fipronil Desulfinyl	Fipronil Sulfide	Fipronil Sulfone	Imidacloprid	Cadmium	Copper	Lead	Nickel	Zinc	Total PAHs
Storm 1		*Hyalella*	*Ceriodaphnia*	*Pimephales*																				
		% Surv.	% Survival	% Survival		mg/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Khol's	Inflow	34	96	95		86	**0.5**	ND	ND	ND	ND	ND	ND	**0.8**	ND	ND	ND	NA	**0.05**	9.6	1	3	48	0.06
	Outflow	**94**	100	93		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	ND	5.3	0.94	2.1	5.7	0.01
Chili's	Inflow	20	100	98		43	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	0.13	12	1.9	5.5	62	0.10
	Outflow	**100**	100	88		5	ND	ND	ND	ND	ND	ND	ND	**1**	2.2	ND	2.9	NA	**0.06**	6.5	0.76	2.6	12	0.03
Tresor	Inflow	4	96	95		12	**1.2**	ND	ND	ND	ND	ND	ND	**1.5**	10	ND	9.8	NA	**0.05**	9.7	0.72	3.1	37	0.06
	Outflow	**82**	96	100		3	**0.8**	ND	ND	ND	ND	ND	ND	**1.3**	12	ND	12	NA	ND	5.3	0.75	1.7	18	0.05
Storm 2		*Hyalella*	*Ceriodaphnia*	*Chironomus*	Dry Wt.																			
		% Surv.	% Survival	% Survival	(mg)	mg/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Khol's	Inflow	66	100	81	0.39	136	5.6	1.2	3.1	**0.7**	3.6	1.3	15	**0.8**	**0.6**	ND	**0.6**	ND	0.52	78	11	32	590	0.47
	Outflow	**98**	100	71	**0.77**	38	**0.4**	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1	ND	**0.07**	5.9	1	2.8	15	ND
Chili's	Inflow	72	100	83	0.50	140	7	1	1.6	**1**	4.2	1.1	ND	1	ND	ND	ND	ND	0.22	32	4.2	20	220	0.37
	Outflow	**98**	100	90	**0.87**	12	ND	12	ND	ND	ND	ND	ND	**1.1**	ND	ND	2.3	ND	ND	7.3	1	3.3	18	0.01
Tresor	Inflow	14	100	48	0.17	93	16	1.1	6.2	**0.9**	13	2.1	130	3.3	5.6	ND	9.5	ND	0.2	28	7.4	16	220	0.47
	Outflow	**84**	100	81	**0.96**	20	1.7	ND	**0.4**	ND	1.5	**0.2**	22	2.5	3.6	ND	5.1	ND	ND	5.1	1.2	2.3	34	ND
Storm 3		*Hyalella*	*Ceriodaphnia*	*Chironomus*	Dry Wt.																			
		% Surv.	% Survival	% Survival	(mg)	mg/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Khol's	Inflow	76	92	92	0.78	14	ND	ND	ND	ND	ND	ND	ND	7.8	ND	ND	ND	ND	0.13	15	1.9	6.5	99	0.07
	Outflow	**98**	100	96	**0.87**	10	ND	ND	ND	ND	ND	ND	ND	**1.2**	ND	ND	**1.5**	ND	**0.06**	6.1	1.1	4.2	11	0.01
Chili's	Inflow	100	100	100	0.85	102	ND	ND	ND	ND	ND	ND	ND	5.3	ND	ND	ND	ND	0.14	26	2.3	7.6	160	0.46
	Outflow	96	88	96	0.94	ND	ND	ND	ND	ND	ND	ND	ND	12	ND	ND	**1.8**	ND	ND	3.8	0.68	1.3	20	0.01
Tresor	Inflow	24	96	73	0.81	81	6	ND	6.7	ND	ND	ND	73	24	**4.8**	**2.8**	12	ND	0.22	42	5.3	15	240	0.53
	Outflow	**98**	100	81	1.01	5	ND	ND	ND	ND	ND	ND	ND	32	5.4	2.5	17	ND	ND	4.6	0.34	1.5	13	0.01

Appendix 2

Non-dominant species found during a 2018 site assessment by Fern Yip

Latin name	**Common name**	**Coordinates**	**Description**
Satureja douglasii	Yerba buena	0465707, 5419736	Small patch
Mahonia aquifolium	Tall oregon-grape	0465711, 5419735	1 individual
Gnaphalium thermale	Slender cudweed	0465727, 5419766	1 individual
Rubus spectabilis, R. ursinus, R. discolor	Salmonberry, trailing blackberry, himalayan blackberry	0465723, 5419759	Patch of Rubus spp. growing on an old stump
Pseudotsuga menziesii	Douglas-fir	0465705, 5419742	6 saplings (<0.5m height)
Pseudotsuga menziesii	Douglas-fir	0465735, 5419743	2 saplings (1-1.5m height)
Thuja plicata	Western redcedar	0465711, 5419741	7 saplings (<0.5m height)

Appendix 3

Runoff coefficient table from HEC-22 “Urban Drainage Design Manual”, 2001

Type of Drainage Area		Runoff Coefficient, C
Business	Downtown areas	0.70 - 0.95
	Neighborhood areas	0.50 - 0.70
Residential	Single-family areas	0.30 - 0.50
	Apartment dwelling areas	0.50 - 0.70
Lawn	Sandy soil, flat, <2%	0.05 - 0.10
	Heavy soil, flat, <2%	0.13 - 0.17
	Heavy soil, steep, >7%	0.25 - 0.35
Streets	Asphalt	0.70 - 0.95
	Concrete	0.80 - 0.95
	Brick	0.70 - 0.85
Others	Drives and walks	0.75 - 0.85
	Roofs	0.75 - 0.95