UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Green Corridor/Green Infrastructure at UBC

Ayishah Chui, Lisa Ng, Maureen Savage, Anna Thomas

University of British Columbia

LARC 581B Directed Study

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Ayishah Chui, Lisa Ng, Maureen Savage, Anna Thomas

Instructor: Cynthia Girling

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A UBC SEEDS Sustainability Program Project

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I. Introduction

UBC's approach to stormwater management needs to be reviewed. As a growing university, academically and physically, the amount of impervious surface on UBC's campus is expected to increase in order to make room for its new academic facilities (UBC, 2014). An increase in impervious surface implies the increase of runoff, hence, the need to increase the capacity of UBC's runoff mitigation strategy. The increase of impervious surfaces coupled with the increase in extreme annual precipitation due to climate change (City of Vancouver, 2012) enforces the urgent need to address the stormwater infrastructure at UBC. This white paper seeks to provide an alternative to traditional piped stormwater systems by proposing methods that mitigate runoff with green infrastructure. Benefits of green infrastructure such as promoting health and wellness, connecting fragmented wildlife habitats and moderating microclimate would be covered in this paper.

Part 1. Stormwater Management at UBC

II. Existing Stormwater Management at UBC

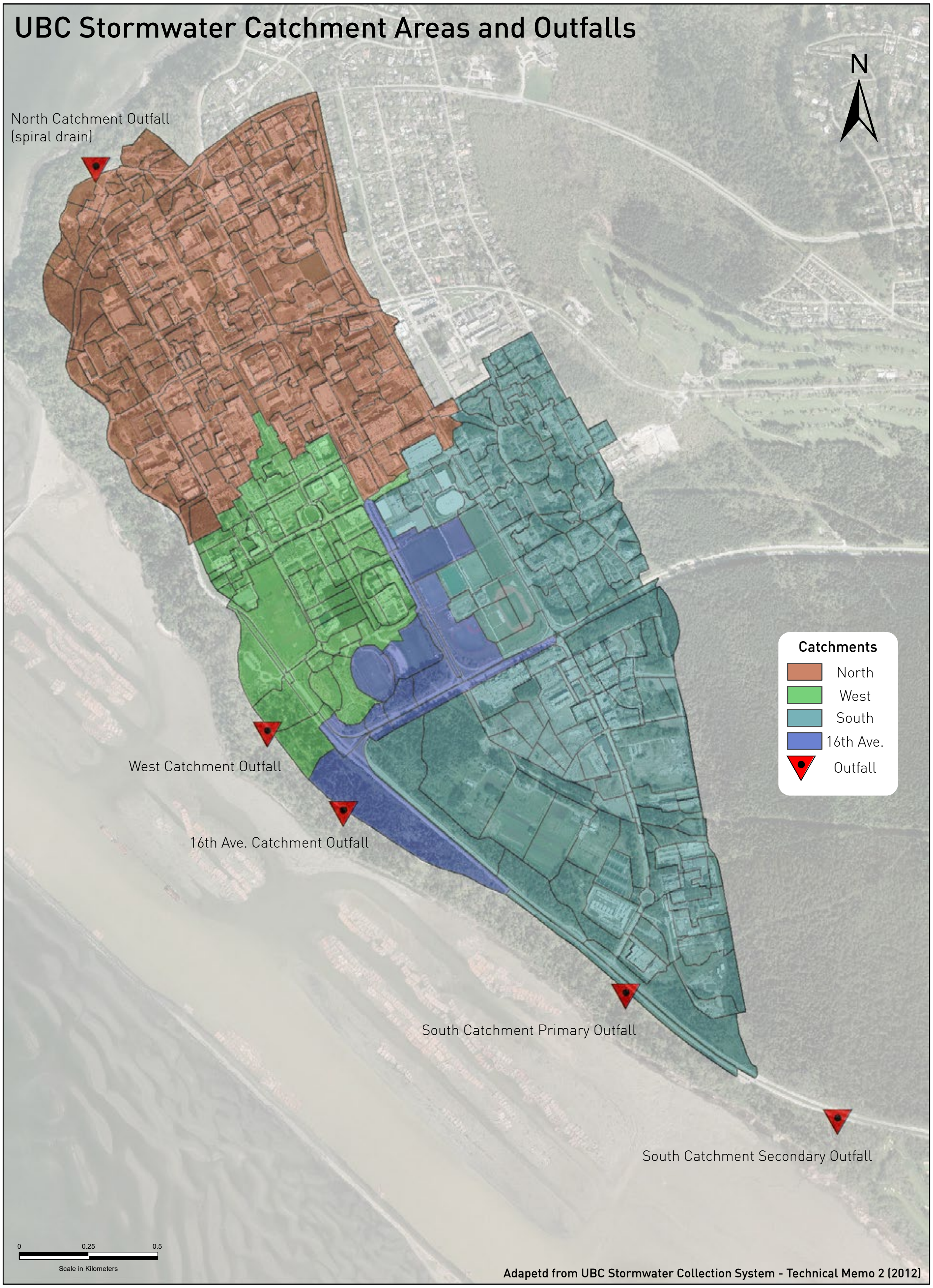
The need to improve UBC's stormwater management strategy is twofold, internal and external.

Internal: Insufficient to Mitigate Campus Stormwater

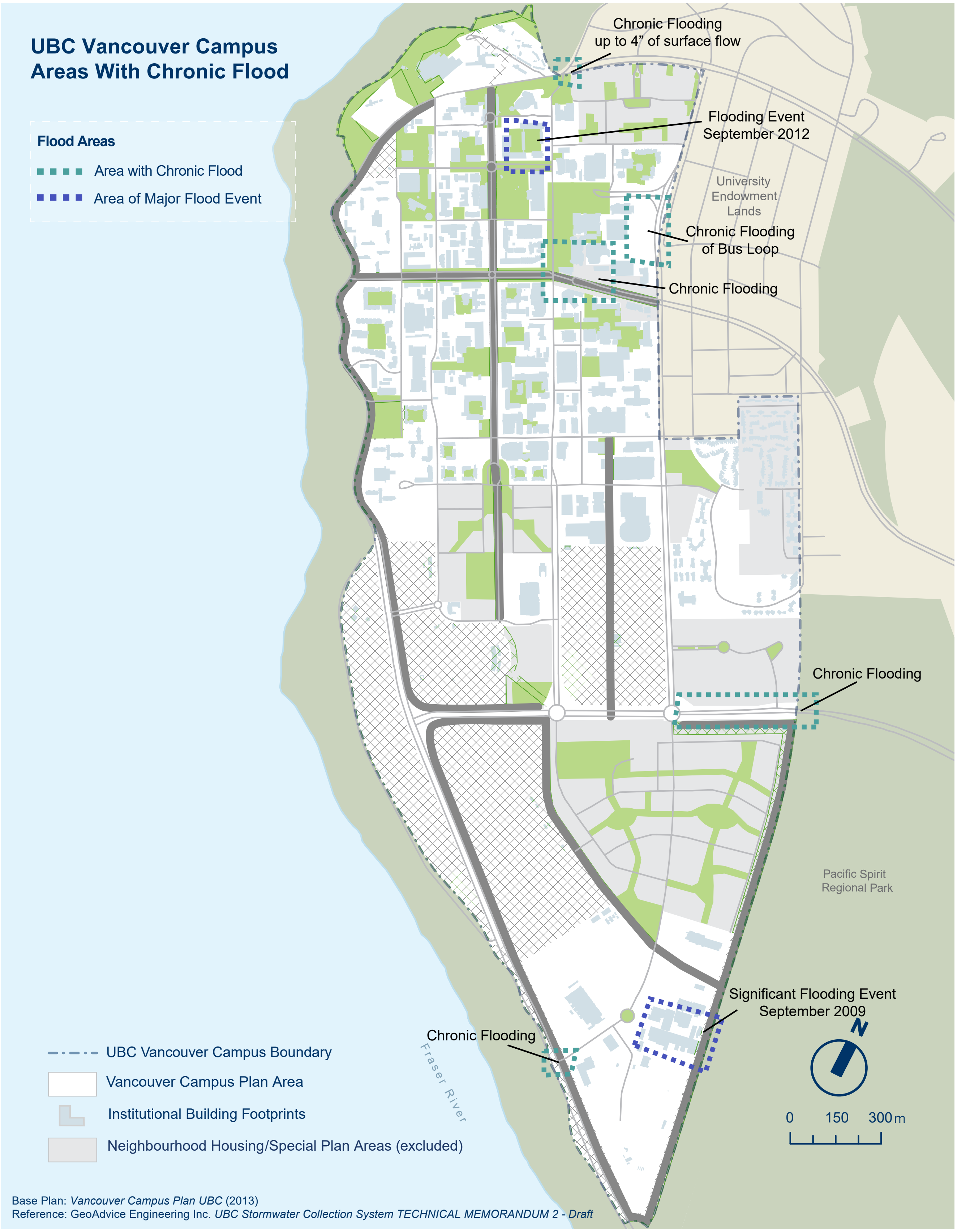
The current stormwater pipe system within UBC is undersized (UBC, 2014). In a 2012 report, multiple locations at UBC are documented to have chronic floods events (GeoAdvice Engineering Inc., 2012). With the plan to increase impervious surface for new buildings in sight, stormwater management on campus needs to be reviewed to ensure that campus infrastructure is sufficient for its current and future needs.

External: Damages Surrounding Environment

Externally, the current outfalls of UBC stromwater are bringing negative impacts to its surroundings. Currently, UBC is divided into 4 stormwater catchments: North Catchment, 16th Ave. Catchment, West or Trial 7 Catchment, and South Catchment (UBC, 2014). Stormwater collected from each catchment is drained by gravity directly to its respective stormwater outfall (UBC, 2016). However, the quality of the stormwater is not always appropriate for discharge (UBC, 2014). Upon discharge, this untreated stromwater pollutes UBC's surrounding water bodies, which in turns put local wildlife at risk. On the other hand, stormwater outfalls of UBC are located beyond UBC's boundaries, within other jurisdictions. Stormwater discharge from these outfalls is causing cliff erosion in the surrounding lands (UBC, 2014). Under the current UBC stormwater management, both physical and biological aspects of UBC's surrounding lands are put at risk. This is especially significant because much of the lands surrounding UBC are sensitive lands of the Pacific Spirit Regional Park.



Figure#01 UBC Stormwater Catchments



Figure#02 UBC Flooding Areas

III. Draft Integrated Stormwater Management Plan

Acknowledging the need to improve UBC's stormwater management strategy, a new draft Intergrated Stormwater Management Plan (draft ISMP) for UBC was written in 2014. In the draft ISMP, "[the] need to shift [UBC's Stormwater Management] away from lands outside UBC's boundaries and refocus on actions within campus that will minimize impact on adjacent lands" is identified (UBC, 2014).

The draft ISMP suggests 3 solutions to address UBC's current stormwater problems:

1) Rebuilding and Reinforcement of Existing Outfalls

This solution tackles the problem of cliff erosion happening at UBC's stormwater outfalls. However, as UBC's stormwater outfalls locates outside of UBC lands, this implies the need to have off-campus constructions (UBC, 2014). This solution is not desirable.

2) Discharge Stormwater to New Wells and Draining Stormwater to a Lower Aquifer

This solution focuses on reducing the quantity of UBC's stormwater discharge. While this solution could reduce the amount of discharge by diverting it to underground, the amount of stormwater this solution is capable to mitigate is not sufficient to solve the existing problems (UBC, 2014). Also, as stormwater runoff is often contaminated and oxygenated, this solution would potentially pollute the aquifier and result in high maintenance required by the well (UBC, 2014). This solution is not desirable.

3) Construction of Underground Stormwater Detention Tanks

This solution focuses on reducing the discharge rate of stormwater at UBC's existing outfalls. Two detention tanks are proposed: including a 1600 cubic meter tank adjacent to SUB near east mall and a 1000 cubic meter tank near the intersection of Chancellor Boulevard and Marine Drive (UBC, 2014). These tanks would provide sufficient temporary storage for UBC's stormwater (UBC, 2014), allowing stormwater to be discharged in a controlled rate and minimize erosion caused by discharge. The draft ISMP states the construction of detention tanks as the preferred solution to the existing stormwater problems in UBC (UBC, 2014).

IV. Problems with Detention Tanks and Hard Infrastructure

While the detention tanks proposed in the draft ISMP could reduce stormwater discharge rates at outfalls, there are problems associated with this solution as discussed below:

Incapable of Reducing Dissolved Pollutants and Fine Particulates in Stormwater

One of the problems of UBC's current stormwater management is the discharge of untreated stormwater, which releases contaminants to surrounding water bodies and damages surrounding wildlife habitats. While primary treatment could be done in a detention system to reduce sediment in stormwater discharge (UBC, 2014), dissolved pollutants and fine particulates could not be filtered out. This incapability to sufficiently reduce discharge contaminants makes the use of detention tank as standalone solutions undesirable.

Incapable of Reducing the Quantity of Stormwater Discharge

While detention tanks could temporarily store stormwater, all the stored stormwater will be discharged eventually. The overall quantity of runoff being discharged through the off-campus outfalls remains the same. This incapability to reduce stormwater discharge quantity limits the usefulness of the construction of detention tanks as a stormwater mitigation solution.

Conflicts with Existing UBC Campus Planning Guidelines/ Design Principles

Under UBC's Campus Planning Plan Policy 39, it is mandated that "stormwater management strategies will incorporate a natural systems approach in managing runoff volume to mitigate downstream impacts" wherever possible (UBC 2010). While UBC is currently using a natural systems approach on building scale, this natural system approach is also applicable to a campus-wide scale. The construction of underground detention tanks is not a natural systems approach.

Not Economically Viable

The construction of detention tanks is not an economically viable solution. In BC Ministry of Environment's Urban Runoff Best Management Practices, it is noted that detention tanks have a "high capital cost compared to surface BMPs (rain gardens, wetlands, swales) and are not normally cost effective" (British Columbia Ministry of Environment, n.d.). This suggests that the construction of detention tanks is an undesirable solution for UBC.

Lacks Environmental Value

Stormwater detention tanks are not a new idea to UBC. In 2013, a study was conducted by Applied Science students on the feasibility of wetland versus detention tank for the UBC farm. In the report, it is mentioned that underground detention tanks are "missing the ability to add much value to the environment" (Zaka, Aassouli, Burton, & Noyes, 2013), despite the fact that above ground space could be used for other purposes. Considering all social, environmental and economic factors, the report concludes that detention tank is not a preferred solution when compared to wetland/wetpond (Zaka, Aassouli, Burton, & Noyes, 2013).

V. Green Infrastructure Approach

While the construction of detention tanks is associated with many problems as a hard infrastructure solution, many of the above problems could be overcame if a green infrastructure approach (e.g. green roofs, green corridor, rain planters, in-street infiltration areas, etc.) is used. Green infrastructure offers multiple ecosystem services to the campus including: stormwater cleansing, reducing stormwater runoff quantities, enhancing sense of place, adding and re-linking habitat, improving stream health, moderate microclimate, reducing GHG. The followings are some benefits of a green infrastructure approach:

Stormwater Cleansing

A green infrastructure approach allows stormwater to be cleansed before being discharged. The manual Evaluation and Management of Highway Runoff Water Quality (1997) published by the Federal Highway Administration of the United States provides a detailed summary of data on stormwater cleansing effectiveness. In the manual, contaminant removal efficiencies of grassed swales are cited as below:

Design	Pollutant Removal Efficiencies (%)							
	Solids	Nutrients		Metals			Other	
	Total Suspended Solid	Total Nitrogen	Total Phosphorous	Zinc	Lead	Copper	Oil & Grease	Chemical Oxygen Demand**
61m swale	83	25*	29	63	67	46	75	25
30m swale	60	*	45	16	15	2	49	25

* some swales, particularly 100-ft systems, showed negligible or negative removal for total nitrogen.
** Data is very limited.
(Barret et al., 1993; Schueler, 1991; Yu, 1993; Yousef, et al., 1985; Horner, 1993, as cited in FHWA, 1996, pg.299)

This table indicates the increasing contaminant removal efficiencies with longer swale (FHWA, 1996). Although contaminant removal capacity of grassed swale is dependent to channel dimensions, longitudinal slope and type of vegetation (FHWA, 1996), in general, grassed swales have been reported for their moderate contaminant removal capacities in terms of suspended solids and metal associated with particulates (FHWA, 1996). These suggest the potential effectiveness of using grassed swale as a mean to cleanse stormwater in a green infrastructure approach.

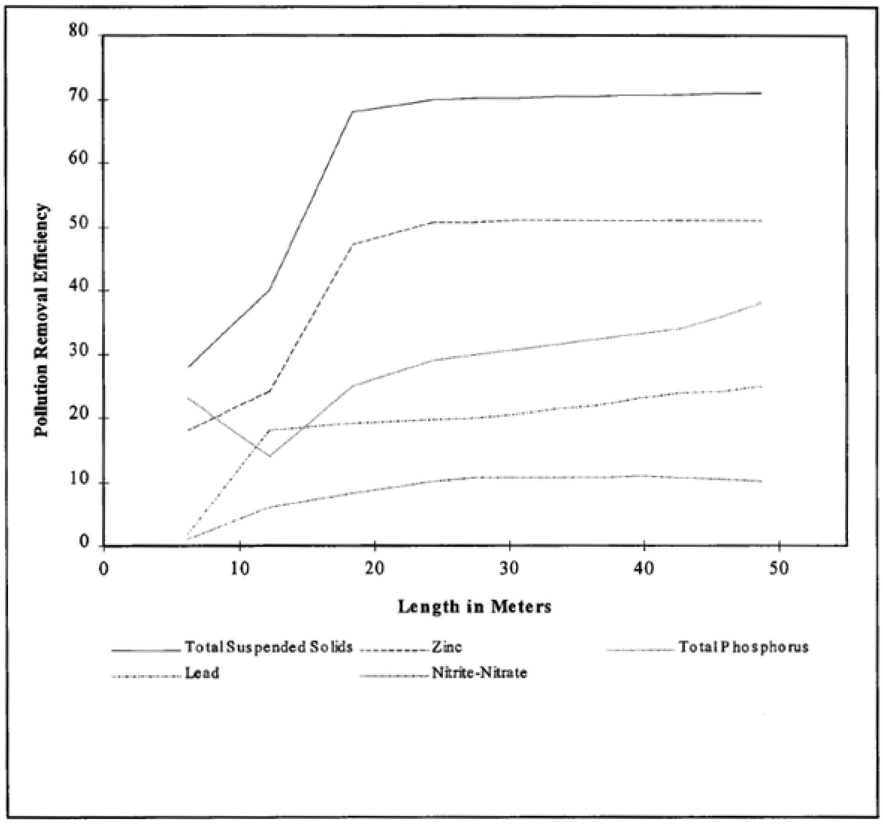
The same manual also cited the contaminant removal efficiencies of filter strips (a.k.a. vegetated buffer strips). Filter strips are similar to grassed swales, but are almost flat with low slopes and are designed only to accept runoff as overland sheet flow (Schueler, 1992, as cited in FHWA, 1996). The followings are the contaminant removal efficiencies of two types of filter strips (Schueler, 1987, as cited in FHWA, 1996, pg.323):

Pollutant Constituent	Grass Filter Strip (6m width)	Forested Filter Strip (30m width)
Suspended Sediment	20 – 40%	60 – 80%
Total Phosphorus	> 20%	40 – 60%
Total Nitrogen	> 20%	40 – 60%
Trace Metals	20 – 40%	> 80%*
Biological/Chemical Oxygen Demand	> 20%	60 – 80%

* Removal rates for trace metals associated with particulates

Part 1. Stormwater Management at UBC

While there are many types of filter strips, this table indicates filter strip's significant efficiencies in contaminant removal regardless type (FHWA, 1996). Filter strip's contaminant removal efficiencies with regard to length are also cited in the manual:



Figure#03 Pollutant removal efficiency versus filter strip length (Yu and Kaighn, 1992, as cited in FHWA, 1996, pg.324)

It is indicated that the optimum length of filter strips is 20-30 m, which further increase in length would only bring relatively minor improvement to the contaminant removal efficiencies (FHWA, 1996). These again suggest the potential effectiveness of using green infrastructure approach to cleanse stormwater, especially when compared to traditional hard infrastructure.

UBC Draft ISMP 2014:

Stormwater runoff at UBC is contaminated and oxygenated (UBC, 2014). This polluted stormwater becomes a source of pollution to its surrounding waterbodies under the current stormwater discharge system. With a green infrastructure approach, this stormwater could be cleansed before being discharged, hence reducing damages to UBC's surrounding environment.

Reduces Quantity of Stormwater Discharge

Green infrastructure could reduce stormwater discharge quantity by encouraging infiltration, dissipating rainfall and bio-retaining rainfall. This reduction of stormwater discharge in turn reduces physical erosion and other environmental damages caused by runoffs, as well as the load on existing hard stormwater infrastructure.

UBC Draft ISMP 2014:

The existing stormwater hard infrastructure at UBC is undersized (UBC, 2014). Introducing green infrastructure to UBC as a stormwater management approach could reduce the demand of this piped system. By allowing rainwater to be infiltrated, dissipated and bio-retained, stormwater discharge quantity could be reduced, hence reducing damages such as cliff erosion caused to UBC's surroundings.

Part 1. Stormwater Management at UBC

Enhances Sense of Place

Green infrastructure approach also help enhance sense of place. Simple interventions such as having trees in urban setting could improve aesthetic and sense of place (Girling, Galdon, Davis, & Kellett, 2009), which could in turn foster a sense of community.

Green infrastructure could help create a sense of place has physical and mental health benefits. While academic institution could be a stressful setting, experimental research has indicated that views to green space in a school setting can reduce mental fatigue and help users to recover from stress (Li & Sullivan, 2016).

UBC Vancouver Campus Plan 2010 and Public Realm Plan 2009:

UBC's sense of place is critical to its public image as a university. In fact, the creation of a sense of place through green infrastructure resonates with UBC's existing campus plan strategies:

Vancouver Campus Plan - Policy 2:
UBC will use its land resource sustainably and develop a denser, compact form through infill and taller buildings to avoid sprawl, improve walkability, strengthen social connections and reserve land for open space and future academic needs. (UBC, 2010-b)

In 2009's UBC Public Realm Plan, it is indicated that UBC has a high demand for better walking and cycling paths because more than 49% of campus users arrive campus by public transit (UBC, 2009). From the same 2009 Plan, it is mentioned that 72% of the public spaces at UBC were assessed as "need improvement" at the time of publication (UBC, 2009). With a green infrastructure approach, the aesthetic quality of campus could be improved while providing other benefits such as stormwater management.

Vancouver Campus Plan - Policy 21:
The open space network for UBC's Vancouver campus will balance the effect of infill in the campus core and host outdoor informal learning spaces, places to nurture the physical and mental health of the campus community, routes for non-motorized transportation and spaces for ecosystem services such as stormwater management. (UBC, 2010-b)

Policy 21 indicates the importance of addressing physical and mental health through campus design (UBC, 2010-b). Studies indicating the association between green spaces and health restorative benefits support the use of green infrastructure approach at UBC.

Relink Fragmented Wildlife Habitat

A green infrastructure approach also provides opportunities for relinking fragmented wildlife habitats in urban settings. While urban development often results in physically fragmenting wildlife habitats into smaller patches, green infrastructures, such as a healthy urban forest, could enhance wildlife habitability in urban setting (Girling, Galdon, Davis, & Kellett, 2009). Other green infrastructures such as green streets and bioswales could provide a linear habitat corridors for wildlife to acquire food, disperse offspring, assure genetic diversity (Austin, 2014). Green corridors can also provide a safe pathway for wildlife to travel between fragmented habitat patches. Studies also suggests an ecosystems of high habitat complexity may intercept and hold more stormwater than ecosystems of low habitat complexity (Ossola, Hahs, & Livesley, 2015). Improvement of habitat value can satisfy multiple objectives.

At UBC:

UBC's campus has fragmented wildlife habitats into patches. The Pacific Spirit Regional Park that surrounds UBC is one of the fragmented habitat. As a habitat for many wildlife species (Sutherland, n.d.), such as Great Blue Herons, a threatened species (IBA Canada, n.d.), there is need to relink the fragmented species of Pacific Spirit Regional Park across UBC's campus.

The redevelopment plan for Block F at UBC is implementing a number of green infrastructure strategies to improve the habitat value, including a new stormwater wetland within Block F (Musqueam Capital Corporation, 2015). With a campus-wide green infrastructure approach, the habitat value of Block F could be further enhanced by increasing its connectivity to other habitat patches in proximity.

Pacific Spirit Regional Park

Pacific Spirit Regional Park (PSRP) is a 763 hectare semi-natural urban forest ecosystem with high recreation, education and biodiversity value (Super, L., Vellend, M., & Bradfiels, G., 2013). The highly diverse types of habitat in PSRP support a large number of wildlife species, including 113 species of birds, 33 mammals, 6 amphibians, and 4 reptiles (Newell, 1983, as cited in Super, L., Vellend, M., & Bradfiels, G., 2013).

Official Community Plan (2005):

While PSRP is not part of UBC's campus, both UBC and two foreshore lots of PSRP are planned under the same official community plan (GVRD, 2005). Coordination and considerations of PSRP is needed in the planning of UBC campus. In particular, it is stated in the OCP that:

"UBC and GVRD (Greater Vancouver Regional District) will need to jointly address slope stability and erosion issues. Full consultation with the public on design, implementation, construction, and maintenance will be required." (GVRD, 2005, pg.22)

This further suggests the need to adapt a design approach at

UBC that could effectively reduce cliff erosion within PSRP. With a green infrastructure approach, not only could cliff erosion be reduced potentially through reduced runoff quantity, quality of runoff releases to PSRP could also be improved, reducing damage caused to the habitat of numerous wildlife species.

Improves Stream Health

Green infrastructure approach could improve stream health in urban catchments. Studies suggest that "improved stream health in urban catchments can only be achieved by reducing the hydraulic efficiency of the stormwater drainage system to decrease the direct connection between impervious surfaces and streams" (Ladson, Walsh, & Fletcher, 2006). With green infrastructure interventions, such as rain planters and in-street infiltration areas, this direct connection between impervious surfaces and streams could be reduced.

UBC Draft ISMP 2014

UBC has developed a large portion of its land into impervious surfaces served by piped stormwater mains with outfalls to adjacent streams (UBC, 2014). Cliff erosion scars are found along these outfall streams (UBC, 2010-a).

As land adjacent to stream is damaged (cliff erosion), the characteristics of stream bed will also be altered, potentially causing excessively high water flow at the streams (CRD, n.d.). This could lead to vegetation removal, hence destroy and degrade habitat along the affected stream (CRD, n.d.).

With green infrastructure approach, health of these adjacent streams could be improved. This is particularly significant at UBC because its outfall streams are located within environmentally sensitive lands.

Improves Air Quality

Green infrastructure approach could also improve air quality. While air pollution is particularly concentrated in high density urban area with tall buildings, vegetation in green infrastructure approach can help to reduce air pollutant (Austin, 2014). A study that simulates the adoption of green wall in urban canyon indicates that green infrastructure could reduce nitrogen oxides by as much as 40% and particulates by as much as 60% (Pugh, MacKenzie, Whyatt, & Hewitt, 2012).

UBC Draft ISMP 2014

As an expanding university, the density of UBC's physical facilities will be increased to make room for its new needs (UBC, 2014). This increase in density, very possibly with taller buildings, anticipates a depletion in campus air quality. With green infrastructure approach, campus air quality could be avoided from depletion or even be improved.

Moderate Microclimate

Green infrastructure could moderate microclimate in urban settings. The form and material used in urban environment often traps heat, causing urban heat island effect (Austin, 2014). This heat island effect could be mitigated with a green infrastructure approach by providing shading surfaces, lower absorption of radiation and transpiration of water (Austin, 2014).

At UBC

UBC is under constant development, which much of its previously softscape area is turned into hardscape. New buildings constructed on campus are often taller than the pervious occupant of its footprint. This increase in hardscaped areas and change in physical form on UBC campus contributes to the urban heat island effect. By implementing a green infrastructure approach, this heat island effect could be mitigated and make the campus' microclimate more comfortable for outdoor activities.

Reduces Greenhouses Gases

Green infrastructure can also help to reduce atmospheric greenhouse gases. By moderating local microclimate on campus with green infrastructure, energy needed for cooling or heating could potentially be reduced, therefore reducing greenhouse gas emissions. As green infrastructure approach also improves the aesthetics and sense of place, people will be more likely to walk, potentially reducing campus vehicular usage, in turn reducing greenhouse gas emissions in campus scale. Green infrastructure could also reduce existing atmospheric greenhouse gas. Plant materials like trees and shrubs in a green infrastructure approach could reduce atmospheric carbon dioxide and sequester carbon. Research suggests that bio-retention cells may also act as a sink for methane, if soils at the surface are aerobic (Cording, 2016). Although the same research also indicates that bio-retention cells may be a small source of nitrous oxide, which is also a greenhouse gas, this emission is not likely to be significant (Cording, 2016).

In UBC

Atmospheric greenhouse gas contributes to the enhanced greenhouse effect, which in turn set off global climate change. By reducing atmospheric greenhouse gas with green infrastructure approach, the anticipated extreme climate events of climate change could potentially be reduced. As a stormwater management approach at UBC, the use of green infrastructure does not only address the future needs, but also reduce potential incidents of extreme rainfall from its root.

Rainwater Harvesting Opportunities

Rainwater harvesting reduces potable water demand and stormwater runoff. This harvested rainwater can be used to substitute freshwater in non-potable uses such as toilet flushing and irrigation (Girling, Galdon, Davis, & Kellett, 2009).

In UBC

Rainwater harvesting is one of the 5 priorities in UBC's Water Action Plan. With a green infrastructure stormwater approach at UBC, rainwater could be harvested to reduce campus freshwater consumption. In fact, 15% of potable water consumed by UBC is for irrigation use (UBC, n.d.-c). This could make a significant reduction of water demand at UBC if rainwater is harvested for campus irrigation wherever possible. Rainwater harvesting also allow rainwater to be utilized on campus land, which also reduces cliff erosion at UBC's stormwater outfalls.

Part 1. Stormwater Management at UBC

VI. Part 1 Summary

The proposed detention tanks at UBC have been found by this paper to be a very one-dimensional solution to stormwater management. While detention tanks have the advantage of requiring no above ground space in order to function, they do not address a number of issues, including filtration of pollutants in stormwater, degradation of habitat on the UBC campus, and they do not align with numerous UBC planning and design principles and policies. The alternative that we are suggesting, a green corridor, would address these issues. There are numerous successful instances of green infrastructure being used to manage stormwater and simultaneously enhance the landscape, two of which we have included in this paper, Heritage Park in Minneapolis, and the UniverCity development at SFU. These instances show that institutions are beginning to responsibly manage the rainwater that falls onto their lands. UBC has an exciting opportunity to implement green infrastructure on a campus-wide scale. A green corridor on campus would not only address the above mentioned issues, it would bring the following additional benefits: increasing the sense of place on campus and provide an environment that reduces mental fatigue and stress of students, staff, and faculty; maintain ecosystem services such as air and water quality; and relink the fragmented habitat zones on UBC campus.

Part 2. A Demonstration of Green Infrastructure Approach

I. Introduction

To demonstrate the benefits of green infrastructure, this section will use green corridor as an example to show how green infrastructure approach could be used in the context of UBC.

This proposed green corridor spans east-west across UBC campus with most parts located along Agronomy Road (see Figure#04). This green corridor system uses an integrated green infrastructure approach, which includes in-street infiltration area, green roofs, bio-swale, and underground stormwater harvesting tanks.

While stormwater management is an important aspect of green infrastructure approach, the ability of such approach to enhance biodiversity should not be overlooked. The concept of ecosystem services are the material and immaterial goods, services and benefits people receives from the functioning ecosystems (Mooney, 2014). Due to the interrelated relationship between ecosystem services and wildlife habitats, design considerations given to enhance and maintain ecosystem service on site could result in enhanced habitat value and resiliency on UBC campus.

The followings are some benefits of green infrastructure approach, their relevant ecosystem service category, and the relevant green infrastructural interventions to bring these benefits:

Stormwater Cleansing

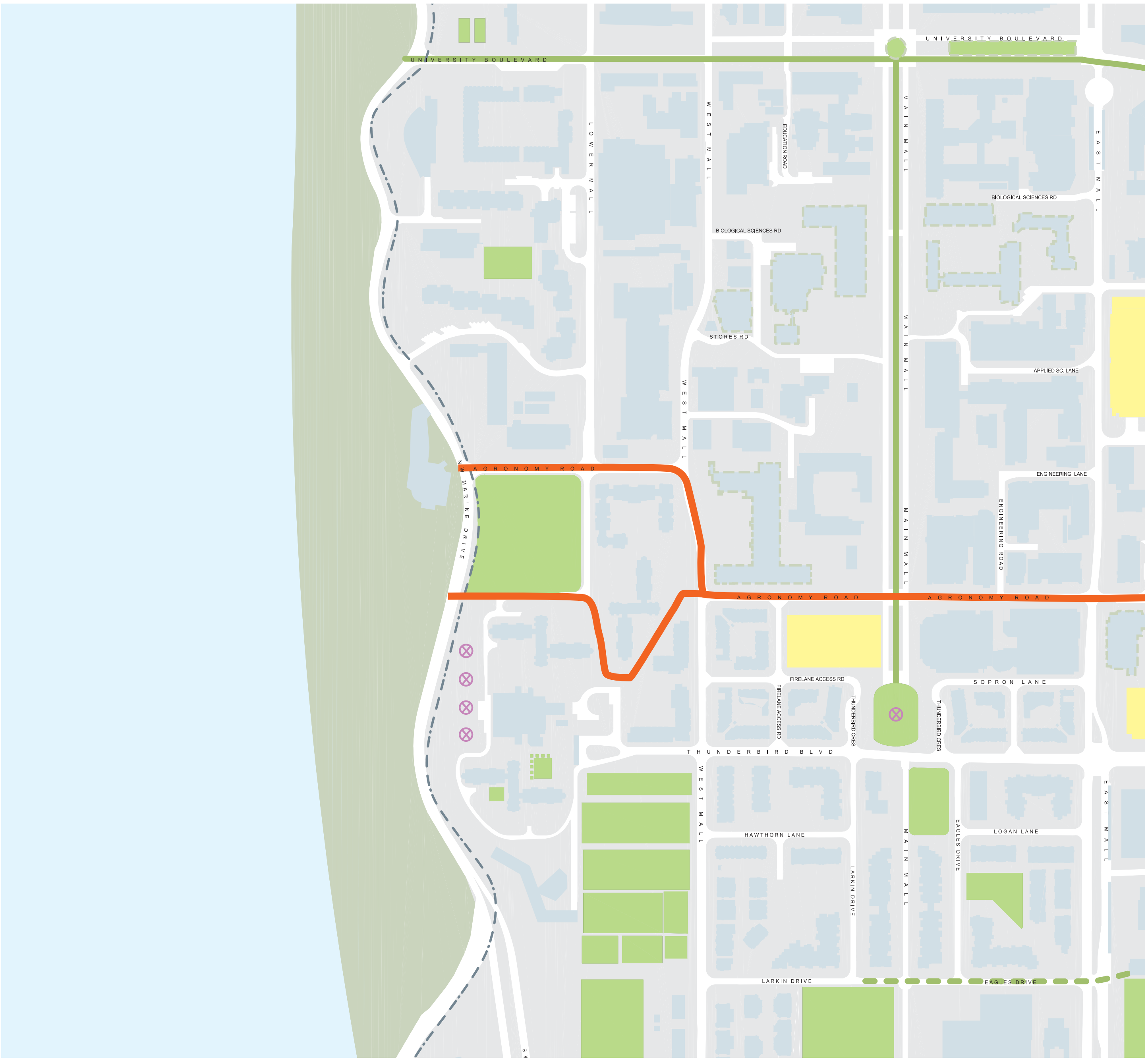
Stormwater Cleansing is a regulating ecosystem service (TEEB, n.d.) that could be done with intervention such as bio-swale. Bio-swale cleanse stormwater using soil plants and microbes (Girling, Galdon, Davis, & Kellett, 2009). Pollutants in stormwater could be removed by processes such as settling, infiltration and plant uptake in a bio-swale (Girling, Galdon, Davis, & Kellett, 2009).

Reduces Quantity of Stromwater Discharge

Quantity of stormwater discharge could be reduced with intervention such as in-street infiltration area, constructed wetland, and underground stromwater harvesting tanks. In-street infiltration area and constructed wetland could reduce stormwater discharge quantity by providing pervious surfaces for run-off to be infiltrated, hence reducing stormwater entering the piped stormwater drainage system. Underground stormwater harvesting tanks could reduce stormwater discharge by capturing and storing runoff that would otherwise be discharged through the existing piped drainage system. The harvested (stored) rainwater would then be used as an alternative water source on campus instead of discharged through outfalls.

Enhance Sense of Place

The enhancement of sense of place is a cultural ecosystem service (TEEB, n.d.). The sense of place of UBC could be improved with intervention such as a vegetated bike or walking paths. In UBC's 2010 Vancouver Campus Plan, "Improve the design cohesiveness of buildings and landscapes" (UBC, 2010-b) is mentioned as one of the major approach in campus planning.The UBC campus plan indicates reinforcing the campus grid as one of the guidelines for improving design cohesiveness on Campus (UBC, 2010-b). A vegetated bike or walking path with vegetation planted on either one or both sides could help reinforce the campus grid, as well creating a distinctive and ecologi-

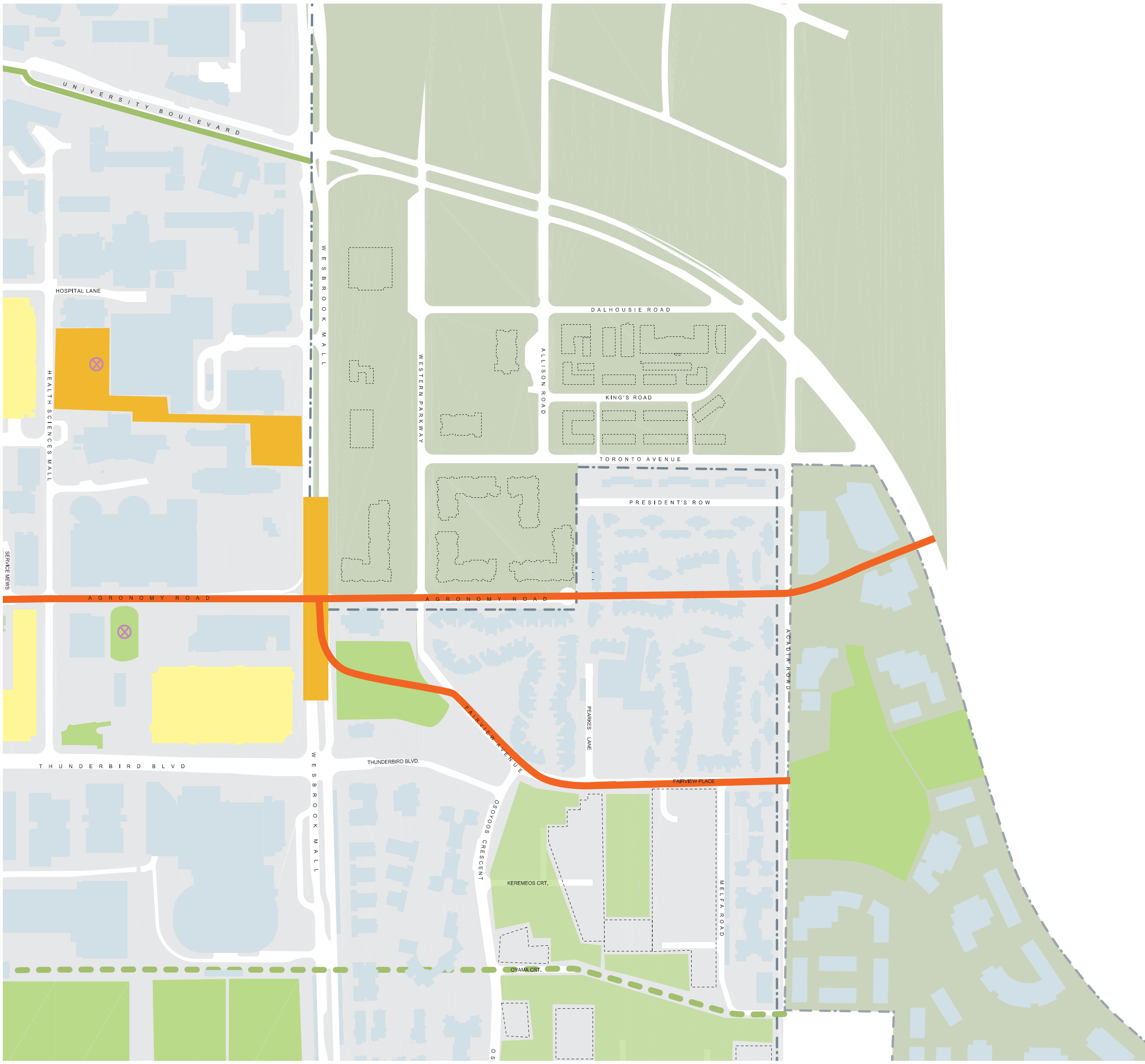


Figure#04 Proposed Green Infrastructure System

Upon completing the design charrette with UBC's Campus and Community Planning members, we established our primary green corridor intervention along Agronomy Road. We also identified other potential sites suitable for intervention, including green roofs, cisterns, Patient Park, and an alternate green corridor.

LEGEND

- EXISTING STORMWATER TREATMENT SYSTEM
- EXISTING GREEN CORRIDOR
- CISTERN LOCATION
- PRIMARY INTERVENTION
- ALTERNATIVE SITES
- MINOR INTERVENTIONS
- POTENTIAL GREEN CORRIDOR
- POTENTIAL BUILT
- POTENTIAL GREEN SPACE



cal gridline for wildlife.

Relink Fragmented Wildlife Habitat

Relinking fragmented wildlife habitat is an ecosystem service that falls under wildlife habitat and supporting service (TEEB, n.d.). Fragmented wildlife habitat could be relinked with interventions such as green roofs or allée with continuous street tree canopies. Greenroofs could serve as wildlife habitat on its own, as well as enhancing biodiversity of its urban context (City of Toronto, 2013), while continuous street tree canopies could also be served as a linear wildlife habitat. These interventions across campus could help relink the fragmented wildlife habitat adjacent to UBC campus.

Improves Stream Health

Erosion prevention is a regulating ecosystem service (TEEB, n.d.), which in turn ensure stream health. Stream health could be improved with an intervention such as in-street infiltration area. These infiltration areas help reduce the hydraulic efficiency of the stormwater drainage system at UBC, reducing erosion, hence improving stream health (Ladson, Walsh, & Fletcher, 2006).

Improve Air Quality

Air quality regulation is an ecosystem service that falls under regulating service (TEEB, n.d.). The use of vegetation could help improve campus air quality (Austin, 2014). Vegetation could come in different forms including street trees, ornamental planting borders, or a mix of tree and shrubs along pedestrian walkways.

Moderate Microclimate

Regulation of microclimate is an ecosystem service that falls under regulating service (TEEB, n.d.). Microclimate on campus could be moderated with interventions such as street trees and constructed wetland. Street trees could provide canopy for shade along pedestrian walkways, as well as moderate climate through transpiration. Constructed wetland could moderate climate by providing a body of water, which could be served as heat buffer.

Reduces Greenhouses Gases

Carbon sequestration and storage is a regulating ecosystem service (TEEB, n.d.), which by sequestering carbon, atmospheric green house gases could be reduced. This greenhouse gas reduction could be done with interventions such as bio-retention swales and vegetation. Planting mediums could be used as a sink for greenhouse gases (Cording, 2016), while vegetation could reduce carbon dioxide when it photosynthesizes.

Rainwater Harvesting Opportunities

Rainwater could be harvested on campus with interventions such as underground stormwater harvesting tanks. While underground harvesting tanks could seem to be similar to stormwater detention tank, the most critical difference between the two interventions are the output of the stored water. Unlike stormwater detention tank, stormwater harvesting tank releases water as an alternate water source.

Part 2. A Demonstration of Green Infrastructure Approach

II. Three Optional Approaches

With all the interventions and the relevant ecosystem services they could generate in mind, we came up with three options for incorporating green infrastructure at UBC:

Option 1: Low Impact Approach

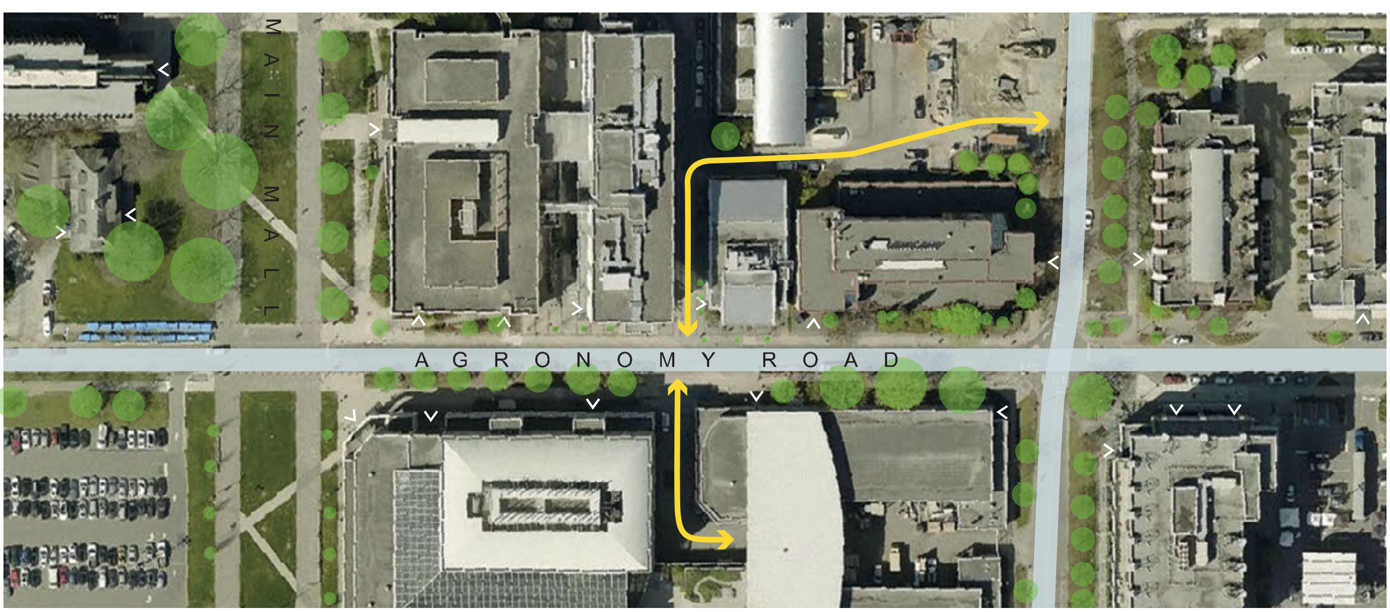
- An approach that requires the least amount changes made to the current condition, particular in terms of traffic conditions.

Option 2: Woonerf Approach

- An approach inspired by the Dutch living street system. This approach uses an asymmetrical design to both liven up building edge as well as slow down traffic.

Option 3: Greenway Approach

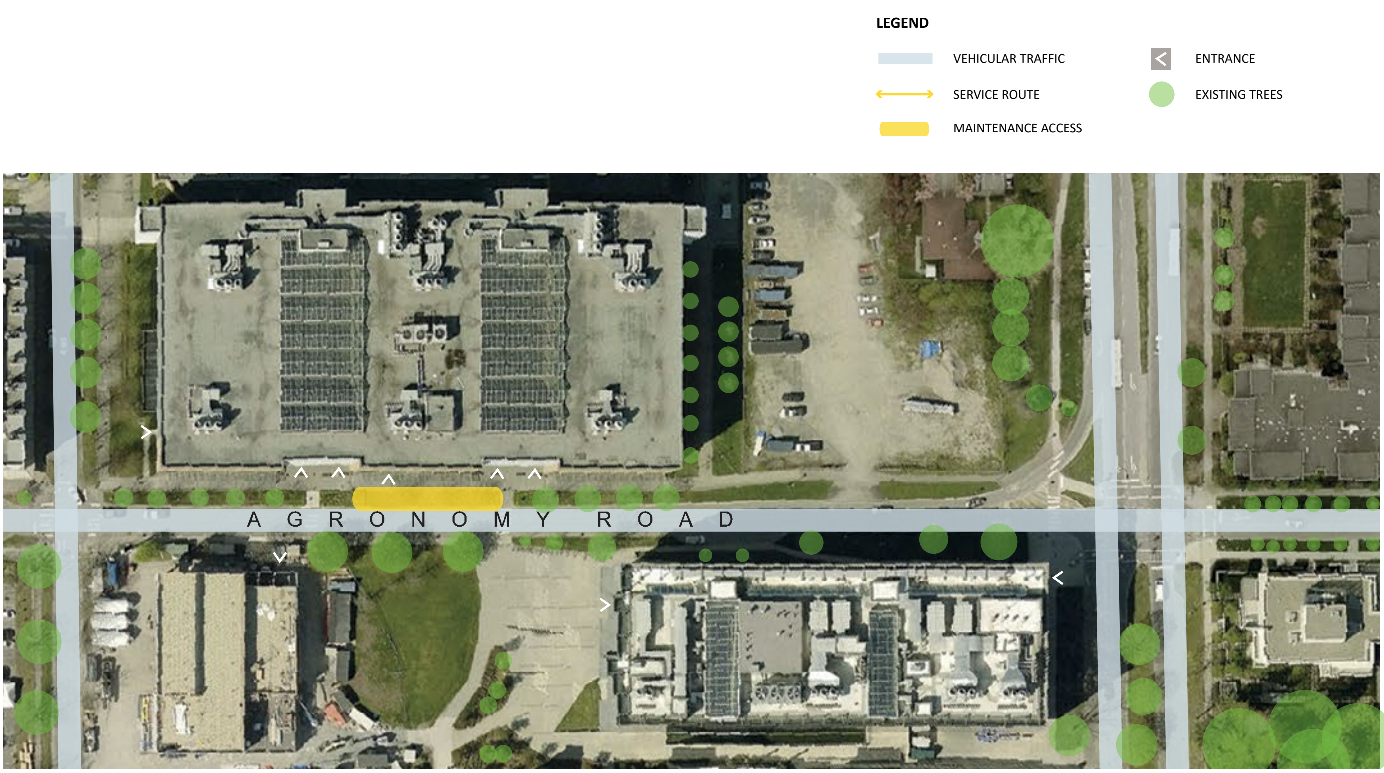
- An approach that demand for the greatest amount of change among the three options, where the greatest amount of ecosystem services would be produced out of the three approaches.



Figure#05 Existing Site Condition

The three optional approaches are further developed with respect to a potential demonstration site. The selected site for demonstration is a section of Agornomy Road as shown in Figure#05.

Proposed interventions for the three options will be located primarily along existing pedestrian paths, roads, and planters on Agronomy Road. The existing buildings will not be modified. With consultation with UBC’s Campus and Community Planning members, it is decided that existing trees along Agronomy Road are to be retained for this demonstration. For all three options, service roads are also kept accessible. Maintenance/service access for Life Sciences Building are also retained along Agronomy Road.

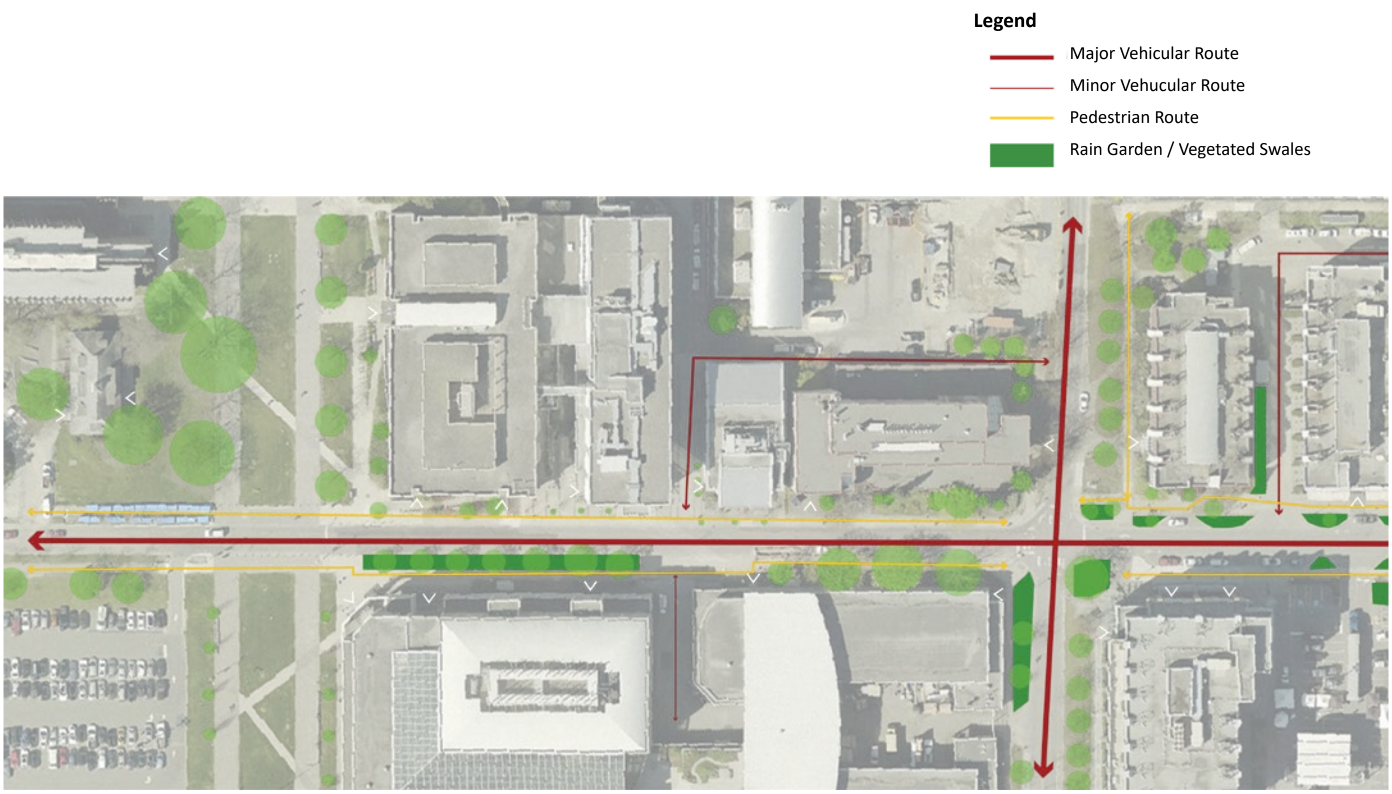


Part 2. A Demonstration of Green Infrastructure Approach

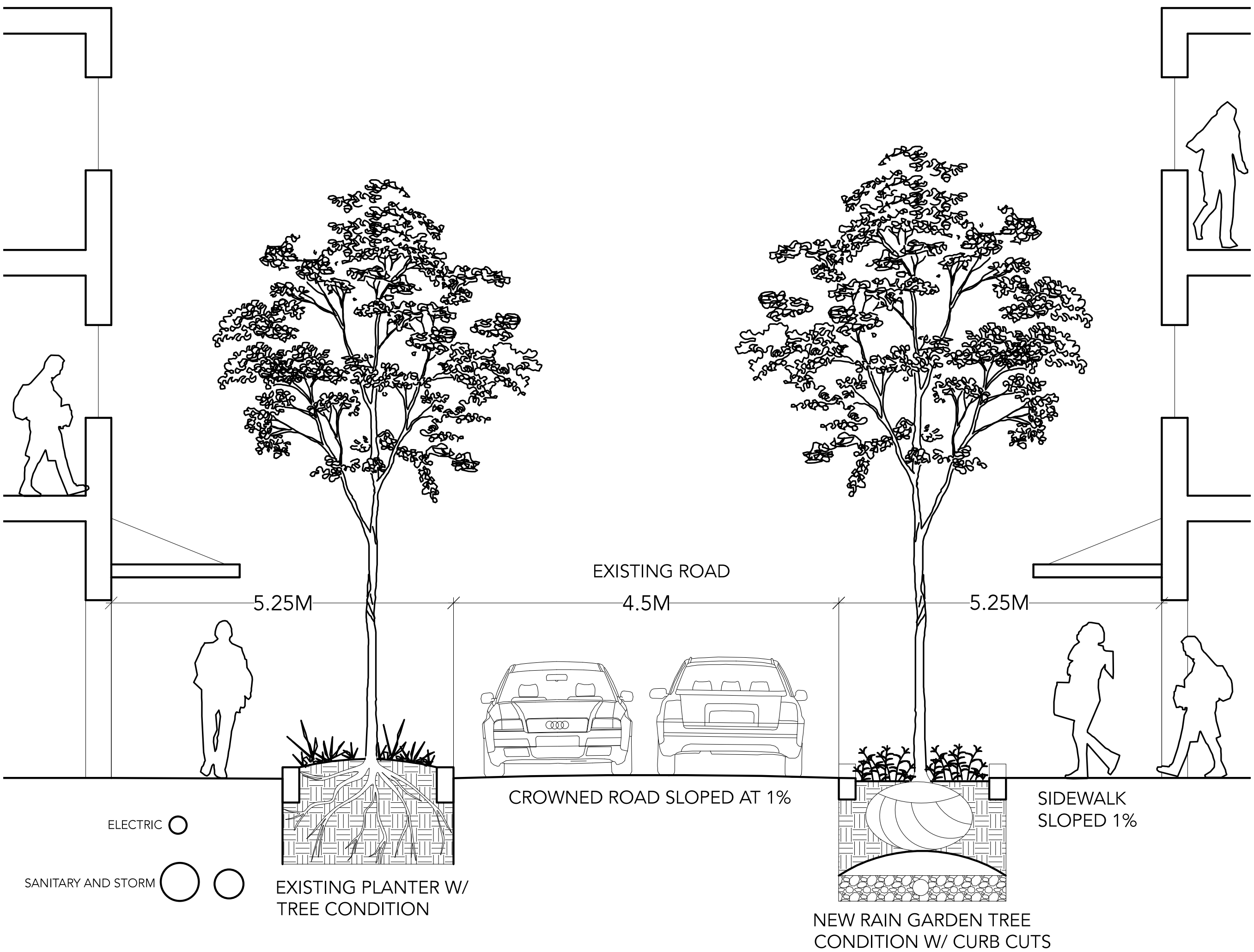
Option 1: Low Impact Approach Demonstration

The Low Impact option suggests minor changes that would greatly reduce the amount of stormwater flowing into the sewer system. On the plan, we highlight existing planters that would be suitable for revised vegetation and modifications of the curbs, such as curb cuts. These existing planters could be renovated to have lower soil levels and plants suited to rain gardens to allow water to flow in through curb cuts and be absorbed and infiltrated.

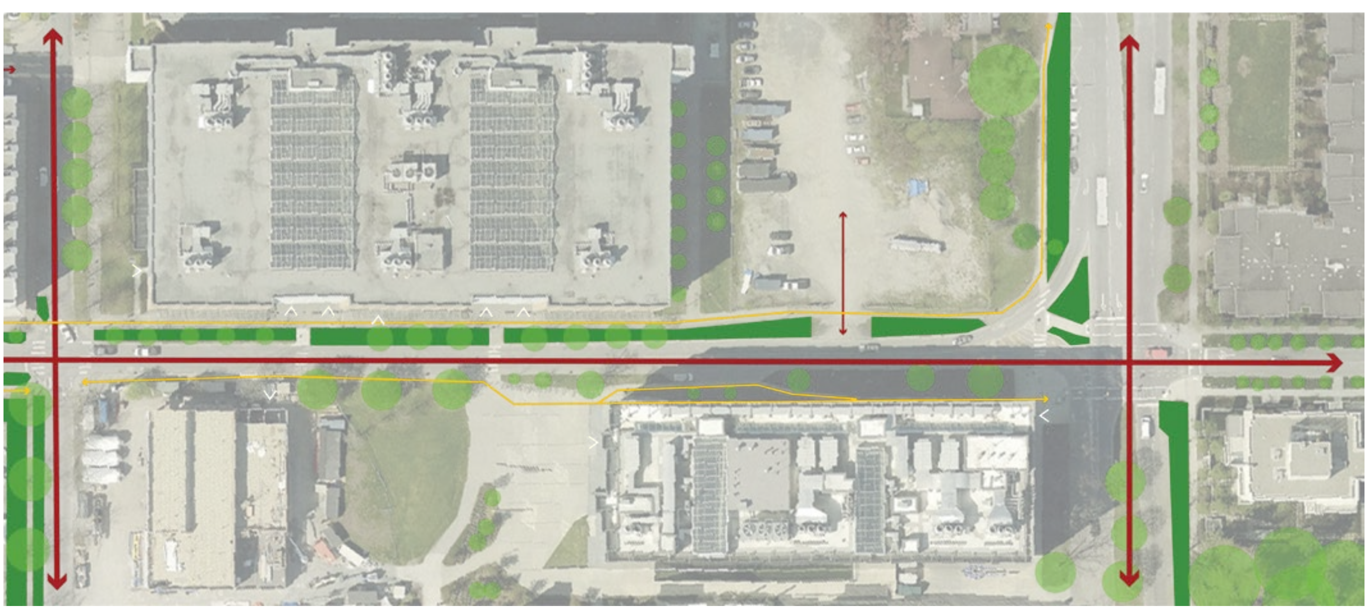
Minor adjustments such as curb cuts, and modifying the existing planters along Agronomy allow for these areas to take runoff from the road and infiltrate it into the soil. The transition can be made very easily, without much adjustment to the status quo. The vehicular access on Agronomy would remain unchanged.



Figure#06 Low Impact Approach Demonstration Plan



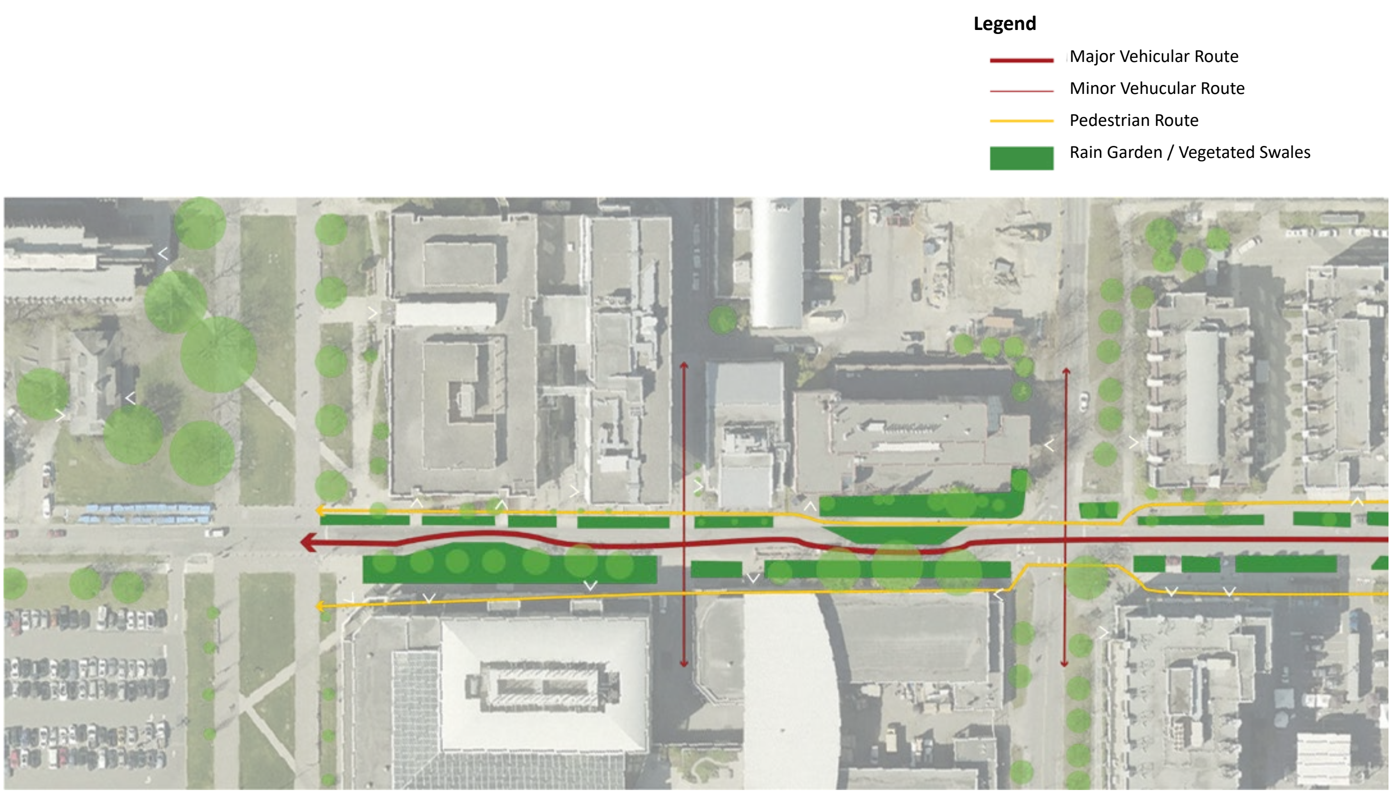
Figure#07 Low Impact Approach Demonstration Section



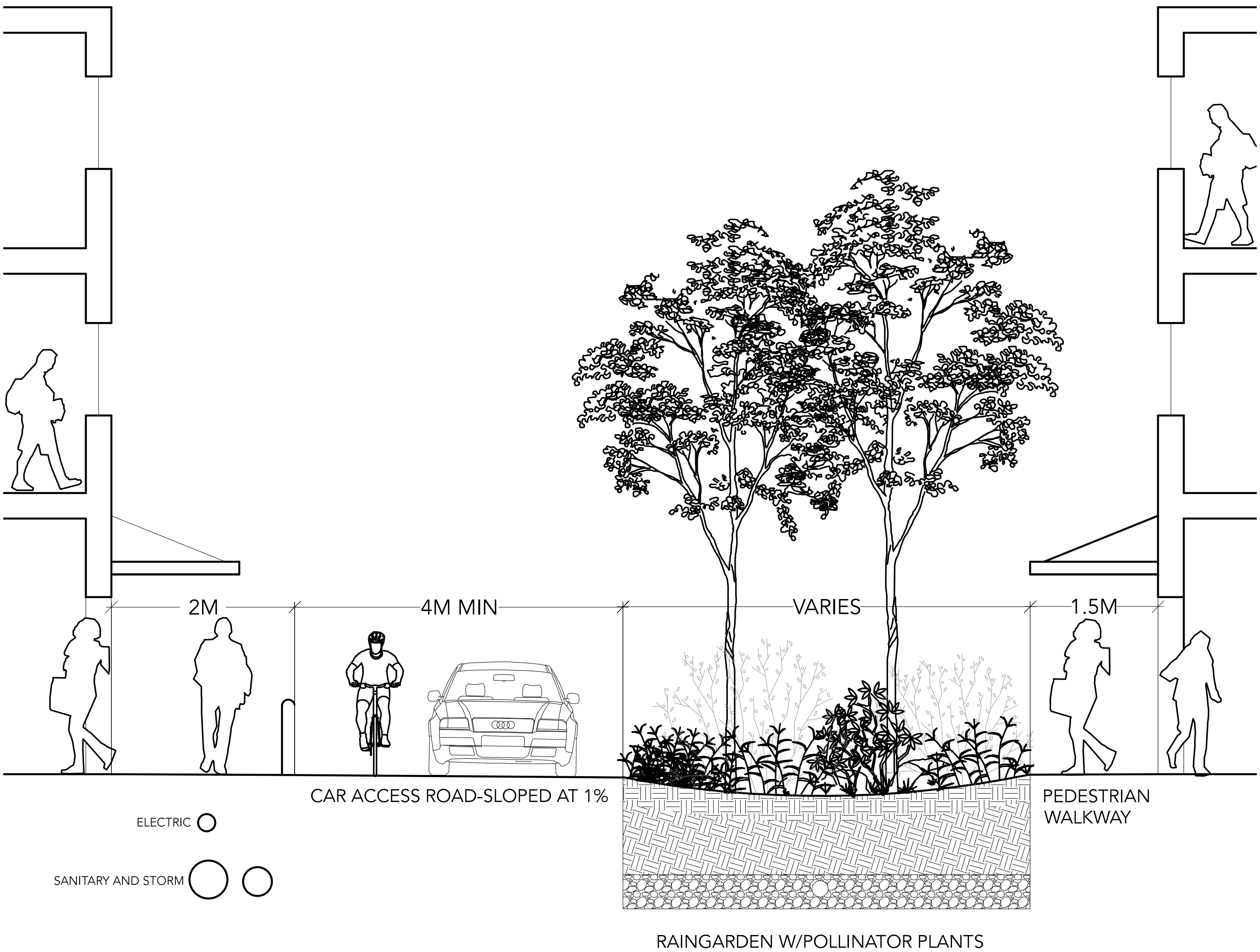
Part 2. A Demonstration of Green Infrastructure Approach

Option 2: Woonerf Approach Demonstration

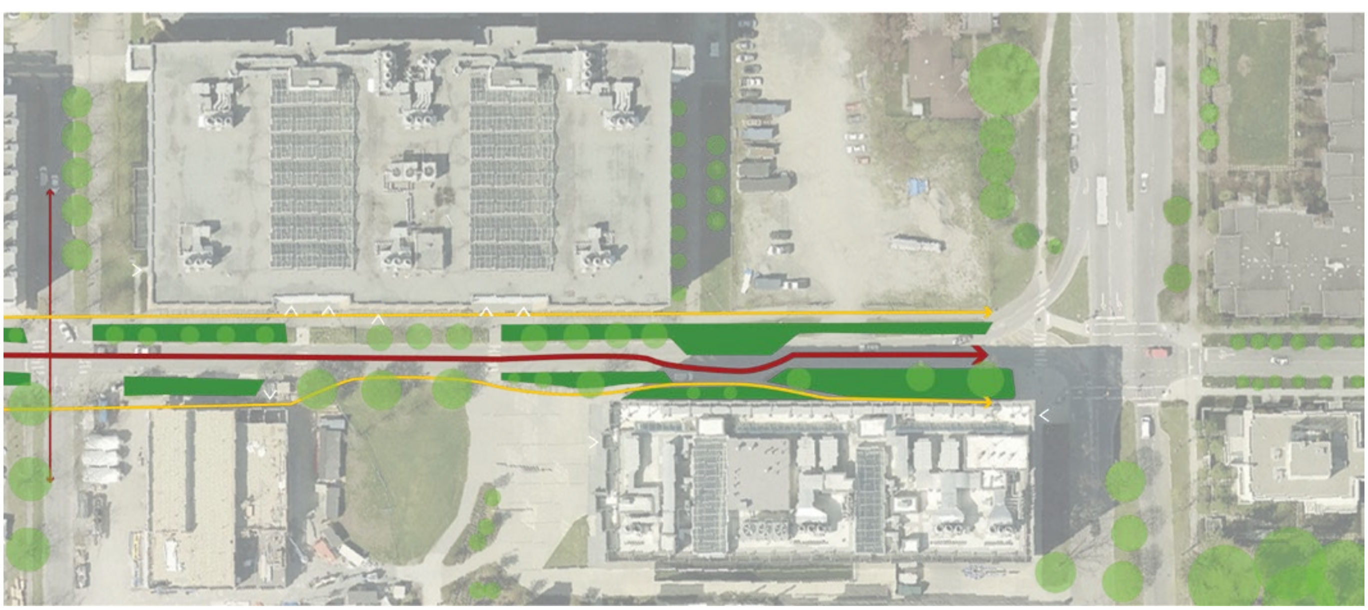
The main goal with this design option is to create a “living street.” Agronomy Rd. would become a mainly pedestrian and cyclist zone that would maintain vehicle access. Large planted areas, continuous paving, and no curbs create an environment that calms traffic and allows people to inhabit the street, giving programming from the building the opportunity to spill out onto the woonerf street. The larger planted areas allow for greater biodiversity of planted materials, which allows for plants that support pollinators and songbirds on campus. These planters would also function as an LID system that will filter runoff from the street, reducing the impact on the conventional greywater system.



Figure#08 Woonerf Approach Demonstration Plan



Figure#09 Woonerf Approach Demonstration Section



Part 2. A Demonstration of Green Infrastructure Approach

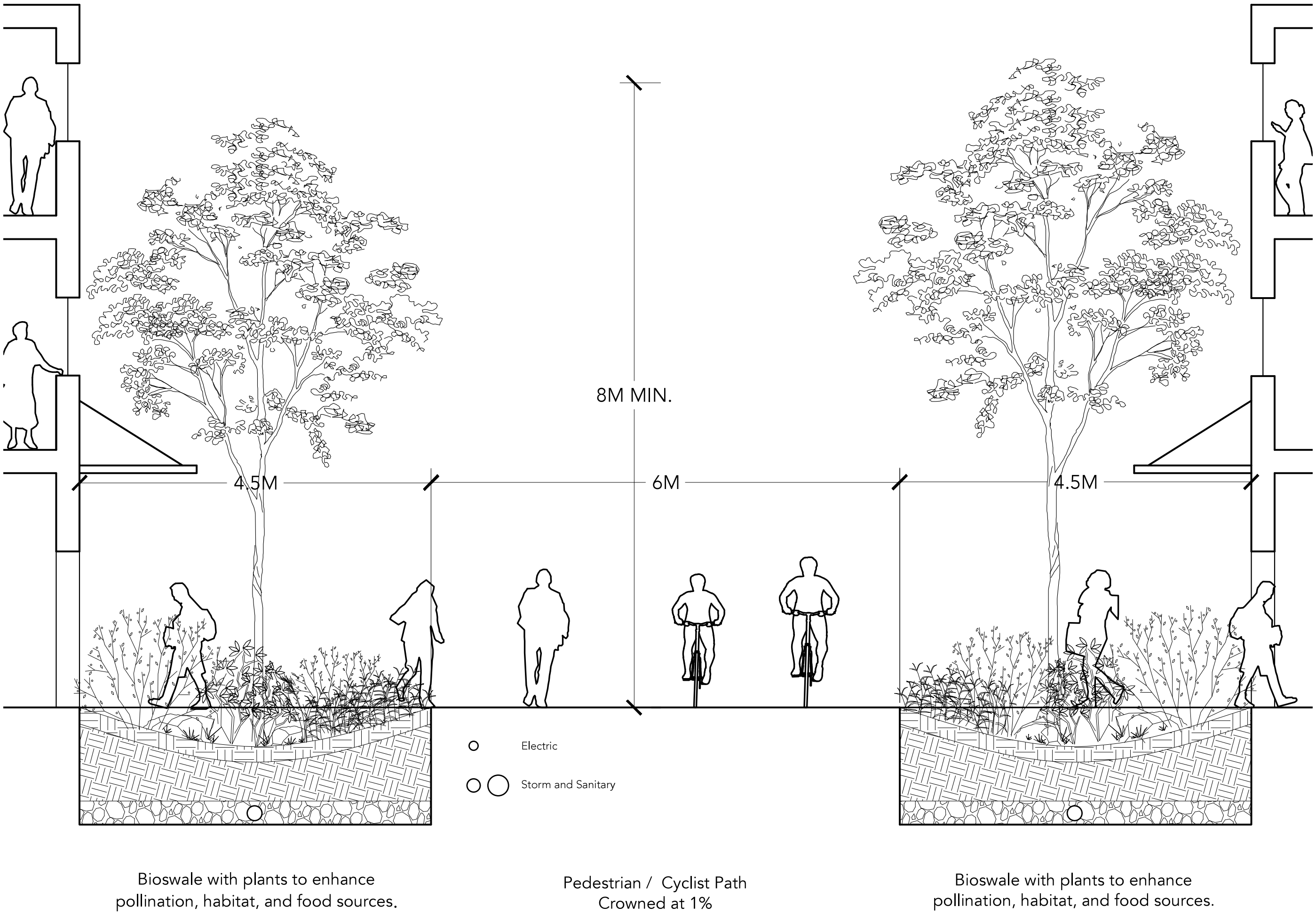
Option 3: Greenway Approach Demonstration

In the this option, Agronomy Rd would transition to pedestrian and cyclist use with larger planted bioswales on either side. It would be closed to all vehicular traffic, except for emergency or service vehicles. However, cars would still be able to cross Agronomy Rd at East Mall and Health Sciences Mall to allow for continued access to the parkades and other areas of campus. The flow of people would be redirected to the middle of the greenway with sidewalks that would feed directly into entrances of buildings. This allows the bioswales to extend to the buildings which creates the opportunity to direct water from the roofs and the crowned pathway into the swales to be infiltrated rather than going to the storm drains. The bioswales would significantly reduce impervious surface while increasing infiltration. The enhanced bioswales will also provide an opportunity for more diverse plantings with increased vertical stratification and food sources, which can create more habitat opportunities for urban wildlifes. This Greenway will significantly increase biodiversity of the campus while creating a safer, more enjoyable, and more efficient means of traveling by foot or bike through campus.

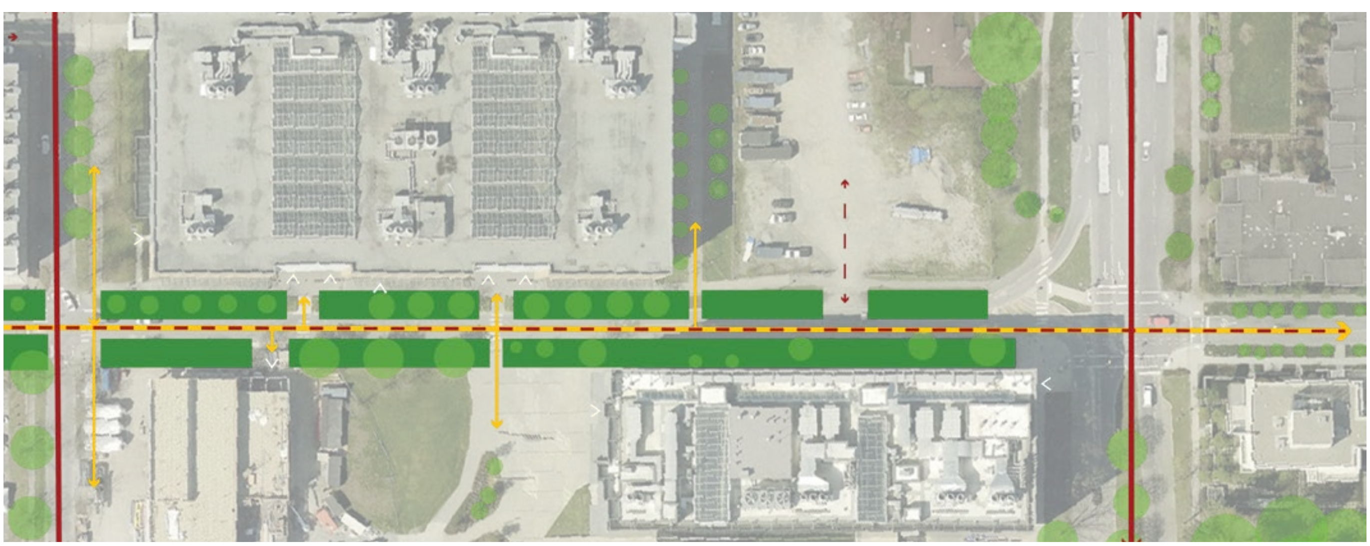
Legend

Major Vehicular Route
Service /Emergency Route
Pedestrian /Cyclist Route
Bioswales

Figure#10 Greenway Approach Demonstration Plan



Figure#11 Greenway Approach Demonstration Section

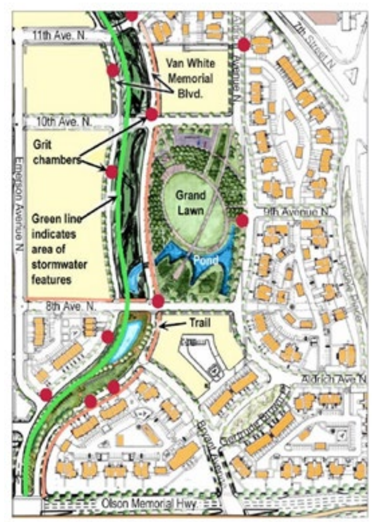


Part 3. Green Infrastructure Precedents

While benefits of green infrastructure approach mentioned in the previous sections are only anticipated scenarios, there are many precedents that are designed using the green infrastructure approach. These are some built examples of using green infrastructure approach on stormwater management that are instructive to UBC:

1) Heritage Park, Minneapolis, USA

Setting	: Urban
Drainage Area	: ~ 400 acres
Project Area	: 145 acres
Project Timeline	: 2001 - 2007
Cost	: $75 million infrastructure + $150 million housing
	(Minnesota Pollution Control Agency, 2016)



Figure#12 Heritage Park Plan (Barr Engineering Company, 2013)

Heritage Park is an urban community redevelopment project with a rainwater treatment system at the core of its park and open space (Minnesota Pollution Control Agency, 2016). Stormwater on site was discharged directly to the Mississippi River prior to the redevelopment (Minnesota Pollution Control Agency, 2016), similar to UBC's current situation. This new redevelopment combines engineered and natural approaches in its stormwater management.

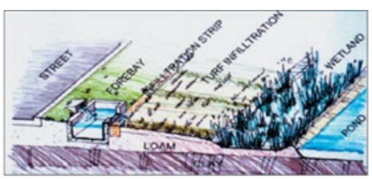
Precedent Highlights:

- Detains, cleanses and infiltrates runoff from 400 acres of urban area with a linear stormwater park of 145 acre (Minnesota Pollution Control Agency, 2016; Girling & Kellett, 2005).

- Reduced 70% of suspended solids as well as total phosphorus and metal through biofiltration before the rainwater reaches Crystal Lake (Barr Engineering Company 2013).

Figure#13 Heritage Park Annotated Perspective (Barr Engineering Company, 2013)

Figure#14 Heritage Park Annotated Perspective (Barr Engineering Company, 2013)



Figure#15 Heritage Park Schematic Filtration Diagram (Minnesota Pollution Control Agency, 2016)

- The design not only improves water quality, but also reduces impervious surfaces, reduces flood hazards, and enhances public space (Barr Engineering Company, 2013).

- Cleaning Components used in the Design include:

    - Grit chambers: large, below-ground concrete structures which removes large solids in stormwater, must be cleaned periodically by vacuum truck (Barr Engineering Company, 2013)

    - Trench forebays: Linear, above-ground planted cleaning devices that reduces sediments in stormwater, maintained by having sediment scooped out by a machine every 5 years (Barr Engineering Company, 2013)

    - Filtration basins: shallow planted areas which removes pollutants such as phosphorus; plant materials and clay soil also slow down rainwater velocity in the system and encourage infiltration on site (Barr Engineering Company, 2013)

Lessons Learned for UBC:

- Effectiveness of Combined Stormwater Management System (Mix of Engineered and Natural techniques)

    - At Heritage Park, 1 acre of land treats rainwater for 2.8 acres of land on average (calculated from data cited above)

- Linear Stormwater Management System facilitates step by step rainwater cleansing processes

    - significant reduction of phosphorus, heavy metals, and suspended particle levels in discharges is practical in such a system

- Sense of place could be enhanced with a combined stormwater management system

Part 3. Green Infrastructure Precedents

2) Green Street, Portland, USA

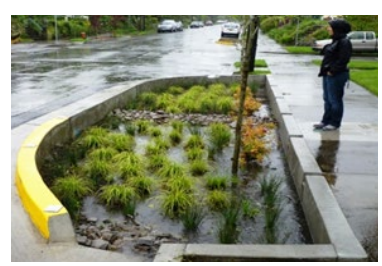
Setting	: urban
Drainage Area	: ~ 64 acres in total
Project Area	: ~ 4 acres in total
Project Timeline	: ~ ongoing
	Data as of year 2009 of 700 facility units (City of Portland, 2010)

Portland Green Street is part of the City of Portland's Grey to Green Initiative (City of Portland, 2010). Contrary to having a centralized treatment system, Green Streets manage stormwater in situ at where the rain falls (City of Portland, 2010). Some examples include using vegetated curb extensions, street side planters, or infiltration basins (rain gardens) that collect stormwater runoff from streets, reducing the amount of stormwater needed to be discharged to the city's sewage system (City of Portland, 2010).

Precedent Highlights:

- 90% of stormwater runoff is reduced in locations with the installation of Green Streets interventions (City of Portland, 2010)
- In 2009, 700 Green Street facilities cumulatively manage approx. 48 million gallons of stormwater runoff (City of Portland, 2010)
- Average green facility size is approximately 23.2 meter square, planted with a mixture of trees, shrubs, and grass vegetation (City of Portland, 2010)
- On average, each facility drains 4,000 sq ft of impervious surface (City of Portland, 2010)
- Green streets provides wildlife habitat, neighborhood green spaces, and refresh groundwater supplies (City of Portland, 2010).
- Greenness associated with both physical and mental health (City of Portland, 2010)

Figure#16 Green Street near Portland State University campus (http://flickr.com/photos/sitephocus/2629874914/)



Figure#17 Green Street during rain (http://media.bizj.us/view/img/1766781/portland-green-streets-rain-700*750.png)

Figure#18 Green Street close up view (http://flickr.com/ pho tos/26074955@ N02/2447323637/)]

Figure#19 Street runoff enters planter (Photo by Kevin Perry, Bureau of Environmental Services, City of Portland)

- Green Streets provide significant shade benefits (City of Portland, 2010)
- Other benefits of green streets includes:
  - PM10 removal - 0.04 lbs / facility / year (City of Portland, 2010)
  - Energy saving with reduced need of sewage pumping - 155+ kWh/ facility (City of Portland, 2010)
  - GHG reduction - 0.3 metric tonnes / facility / year (City of Portland, 2010)

Lessons Learned for UBC:

- Multiple in situ stormwater management facilities could effectively manage and reduce storm water
  - In Portland, 1 acre of land could manage stormwater for 16 acres of impervious surface on average (calculated from data cited above)
- Potential energy savings with rainwater management systems
- Planting area with multiple layers - mix of trees, shrubs and grass could effectively reduce stormwater needed to be discharged to sewage system
- Increasing greenness of urban environments is associated with positive physical and mental health benefits
- Neighbourhood-scaled green space could be used to provide wildlife habitat

Part 3. Green Infrastructure Precedents

3) "Growing Vine Street", Seattle, Washington

Setting	: urban
Project Area	: Beckoning Cistern 700 sq ft, Cistern Steps 1,200 sq ft
Project Built	: 2003
	(Echols & Pennypacker, 2015)

Residents of the Belltown neighborhood were interested in improving the quality of urban water discharged into Elliott Bay. The idea arose to convert eight blocks of Vine Street into an urban watershed through a series of artistic interventions that would both reduce local CSOs (combined sewer overflow) and improve water quality of runoff entering Elliott Bay, then Puget Sound (Echols & Pennypacker, 2015).

Precedent Highlights:

- Created a prototype Green Street that is pedestrian friendly and ecologically sustainable
- Two blocks of Vine Street are enlivened by two separate artistic systems (Public Art) that manage roof runoff from some adjacent buildings
- Capture, convey, cleanse, and reuse for irrigation, infiltration, or detain and discharge into city sewer system
- Beckoning Cistern is a 15-foot-tall, 6-foot-diameter galvanized aluminum cylinder that captures rainwater from the roof of the adjacent 81 Vine building; roof runoff is first filtered in rooftop planters, then falls via downspout to the cistern, where a flow splitter sends some runoff into the container while the rest drops into the first of three round planters, set in a bed of native plants, which cascades down the hill; a concrete scupper extends from each planter to spill rainwater overflow to the next planter (Echols & Pennypacker, 2015).

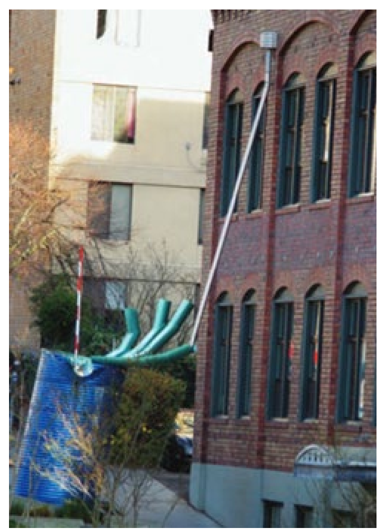


Figure #20 Beckoning Cistern, captures filtered roof runoff that has been filtered by rooftop planters before sending it to biofiltration planters (Echols & Pennypacker, 2015)

Figure #21 Tiered infiltration basins step down the slope, with any overflow at the bottom directed to the city sewer system (Echols & Pennypacker, 2015)

Figure #22 Roof runoff at 81 Vine is directed to these candelabra downspouts, whose playful forms evapotranspire some rainwater and oxygenate the rest (Echols & Pennypacker, 2015)

- All runoff in the Beckoning Cistern system is retained either in the cistern or in the planters, with none discharged; in the Cistern Steps system, a great deal of the water is retained in the planters, and some discharges to the city system (Echols & Pennypacker, 2015).
- Follows the “always slow it down, spread it out, soak it in” mantra through dispersal of the rainwater in a number of basins and planters. The “safety backup” is that overflow from both systems can discharge to the city system (Echols & Pennypacker, 2015).
- The Beckoning Cistern holds 300 gallons of roof runoff, harvested to irrigate plantings in front of 81 Vine. All the rest of the runoff in these systems, irrigates the planters of the stormwater management system, one of the effective symbioses possible in green infrastructure (Echols & Pennypacker, 2015)

Lessons Learned for UBC:

- The incorporation of public art in stormwater management could increase education and community engagement opportunities for UBC Campus.
- The roofs of buildings can be used as the first step of water filtration, either as a green roof or planters, before sending it to the ground for further biofiltration.
- There are creative ways to store water for irrigation purposes, rather than infiltration or piping elsewhere. This can be done in coordination with Building/ Landscape Operations.
- Use of topography to create tiered biofiltration planters.
- Capturing roof runoff provides numerous opportunities for creative interventions because of the theatrical “show” of transporting water from roof to ground.

Part 3. Green Infrastructure Precedents

4) Southwest Recreation Center, University of Florida, Florida, USA

Setting	: University Campus
Drainage Area	: 0.57 acre
Project Area	: 1.19 acre
Project Built	: 2010
	(Echols & Pennypacker, 2015)

The expansion project of the Southwest Recreation Center at University of Florida proposed in 2008 adds around 0.57 acres of impervious surface to the campus. To to ensure that stormwater discharge after the expansion would not exceed its pre-construction rate, an artistic system with rain gardens, rainwater runnels, and sculptures was designed on the land around the expansion. This does not only treat the increased runoff, but also helps promote the environmental value of the university.

Precedent Highlights:

- Focus on “Capture”, “Convey”, “Cleanse”, “Detain” and “Discharge” as design concepts (Echols & Pennypacker, 2015)
- Runoff from the building’s roof is conveyed through six runnels, which flow from the front of the building to a bioswale parallel to the building (Echols & Pennypacker, 2015)
- Runnels are pebble-filled and carry rain past sidewalks to reach the bioswale (Echols & Pennypacker, 2015)
- Bioswales filter rainwater through a tiered system that slows, spreads, and detains rainwater (Echols & Pennypacker, 2015)The designed system is sized to hold and convey a 100-year storm (Echols & Pennypacker, 2015)
- Design of legible rainwater trails and six differently coloured runnels tells the hydrologic story to users in an effective way (Echols & Pennypacker, 2015)

Figure#23 Southwest Recreation Centre Water Trails (Echols & Pennypacker, 2015)

Figure#24 Southwest Recreation Centre Water Runnels (Echols & Pennypacker, 2015)

Figure#25 Southwest Recreation Centre Bioswales (http://sites.clas.ufl.edu/africa-mdp/files/sw-rec.jpg)]

Figure#26 Southwest Recreation Centre Night Lighting (http://www.recmanagement.com/images/201205/201205_aw_1g_06.jpg)]

- Sculptural and lighting component of design also help making the "roof-to-river" message apparent to users (Echols & Pennypacker, 2015)
- Native plantings in bioswales provide habitat for local wildlife (Echols & Pennypacker, 2015)
- The design allows the University to make its environmental value clear to users (Echols & Pennypacker, 2015)

Lessons Learned for UBC:

- The process of moving rainwater from place of reception to treatment provides an opportunity for artistic and educational interventions.
- The environmental value and the image of UBC could be demonstrated through its campus design and a rainwater management design that is noticeable to users.
- Bioswales with native plantings could enhance the habitat value of the site in addition to managing stormwater.
- Use of eye-catching repeated pattern (i.e. the six distinctly coloured runnels at University of Florida) could make stormwater management design more noticeable, this encourages users to be more aware of stormwater management issues.

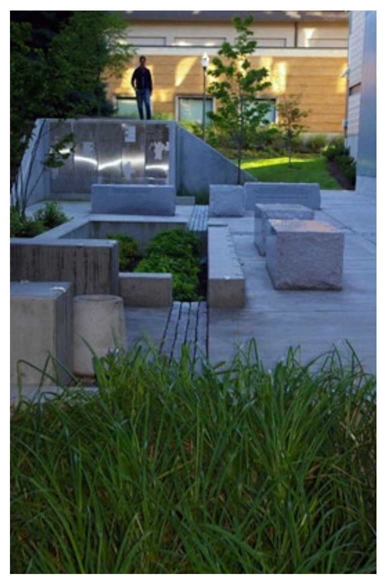
5) Stephen Epler Hall at Portland State University, Portland, Oregon

Setting	: University Campus
Project Area	: 20 000 sq ft
Project Built	: 2003
	(Echols & Pennypacker, 2015)

Portland State University is an urban university of 28,000 students. As it has grown, it has become more and more committed to green environmental strategies and education. Stephen Epler Hall was intended from its conception to be a space that showcases sustainable strategies, and the university's commitment to responsible rainwater management. At the time of construction, Portland was facing problems with CSO (combined sewer outflows) discharged into the Willamette River. The need to reduce storm flows into the sewer system allowed green infrastructure to be prioritized in the design of Stephen Epler Hall. The resulting design is a unique and fun jigsaw puzzle-like "bio-alley" that showcases rainwater in an urban environment (Echols & Pennypacker, 2015).

Precedent Highlights:

- The rainwater management concept is to capture, convey, cleanse, reuse (irrigation or toilet flushing) or detain and discharge (Echols & Pennypacker, 2015).
- Roof runoff falls via four downspouts into river-pebble filled splash boxes. The water is then conveyed through the boxes by scuppers to runnels that convey runoff across the courtyard to sunken flow through filter planters or "biopaddies" (Echols & Pennypacker, 2015).
- Once the runoff is bio-filtered by the paddies to remove sediment and other contaminants, secondary treatment is provided by ultraviolet lights in the cistern to kill bacteria. The water can



Figure#27 Bio Alley (https://artfulrainwaterdesign.psu.edu/project/stephen-epler-hall-portland-state-university)

Figure#28 Bio Alley (https://artfulrainwaterdesign.psu.edu/project/stephen-epler-hall-portland-state-universit)

Figure#29 Bio Alley https://artfulrainwaterdesign.psu.edu/project/stephen-epler-hall-portland-state-university

now be used for irrigation and toilet flushing for the adjacent residence. (Echols & Pennypacker, 2015). One of the main goals was to reduce off site impacts, especially on sewer systems. The adsorption, evapotranspiration and retention in the biopaddies, in addition to the detention and reuse associated with the cistern, has diverted 26-52% (depending on season) of runoff from the city's storm system (Echols & Pennypacker, 2015).

- The system sends 111,000 gallons of water annually to the 10,000 gallon cistern (Echols & Pennypacker, 2015).
- Covered seating located strategically across from the downspouts provides opportunities for people to observe the system in action.
- Rectilinear design of the biopaddies, granite set runnels and splash boxes allow the infrastructure to integrate seamlessly into the university's urban fabric (Echols & Pennypacker, 2015).
- Sunken bio-paddies are the only planted areas in the system, making maintenance clear and simple, a must for a university with large grounds to maintain (Echols & Pennypacker, 2015).

Lessons Learned for UBC:

- Significant interventions can be made in relatively small campus spaces that showcase responsible rainwater management. There are many smaller scale spaces at UBC that could become "bio-alleys".
- Integrating rainwater management infrastructure throughout a small space can increase the experiential qualities of a space, while sparking awareness about rainwater management.
- Green infrastructure can be used in combination with below-ground cisterns to maximize capture of rainwater and reduce negative downstream effects.
- Utilizing green infrastructure and responsible rainwater manage-

ment strategies on campus is an effective way to define UBC as a sustainable and progressive place of learning.

Conclusion

Stormwater Management at UBC

UBC's stormwater management needs to be improved. While the proposed traditional hard infrastructural approach could provide a solution to prevent flooding during storm events, its benefits is very limited. There are also problems with the proposed hard infrastructure, including incapability in reducing dissolved pollutants and fine particulates in stormwater, incapability in reducing quantity of stormwater discharge, conflict to existing UBC campus planning guidelines/design principles, non-economically viable, and lacking environmental value.

As a better alternative, green infrastructure could also provide benefits available with traditional hard infrastructure, while having other benefits. These benefits includes: stormwater cleansing, reduces quantity of stormwater discharge, enhances sense of place, relink fragmented wildlife habitat, link to Pacific Spirit Regional Park, improves stream health, improves air quality, moderate microclimate, reduces greenhouses gases, and providing rainwater harvesting opportunities. These suggests the appropriateness in using green infrastructure at UBC as a mean of stormwater management.

A Demonstration of Green Infrastructure Approach

We have proposed three options for a Green Corridor on Agronomy Rd. from Main Mall to Wesbrook Mall; Low Impact, Greenway, and the Woonerf Street. The Low Impact option suggests minor enhancements such as curb cuts and modifying existing planters to allow for more infiltration of stormwater on site. The Greenway modifies and

Conclusion

expands planters to become bioswales which greatly enhance biodiversity by introducing new and more complex plant communities that will provide habitat and food sources for wildlife on campus. The bioswales also clean and infiltrate a larger amount of stormwater. The Greenway closes Agronomy Rd. to vehicular traffic, except for emergency and service vehicles, and redirects pedestrians and cyclists to the middle of the street. Lastly, the Woonerf option would create a "living street" which prioritizes pedestrians and cyclists but still remains open to car traffic. Some planters would be enhanced and extended out into the road, calming and discouraging cars to utilize it. The Woonerf option enhances biodiversity with larger and more robust planted areas and provides numerous placemaking opportunities while encouraging programming from within the buildings to spill out into the street.

Green Infrastructure Precedents

While the options demonstrate a possibility of using green infrastructure at UBC for stormwater management in a form of green corridor system, it is also worthwhile studying existing green infrastructures to better understand the opportunities in actual implementations. By looking at five different case studies, lessons from actual design details to ways to enhance habitat value with green infrastructure is learnt.

Future Research or Student Project Topics

- How would sun and shadow condition at differnt locations affect the design of the green corridor?

- How could the multiple benefits of green corridor be expressed to its users? Could and should we put a monetary value to the proposed green infrsatructure?

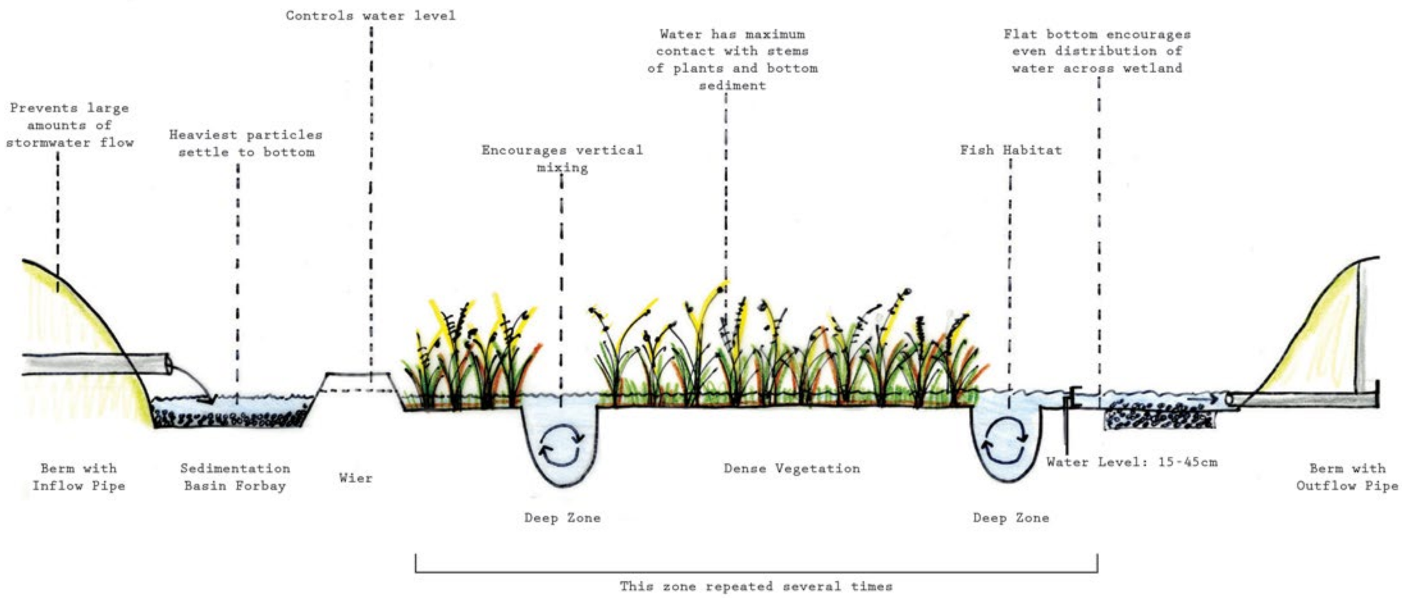
- What is the potential of rainwater harvesting at UBC? Is it possible for UBC to harvest enough water to meet its residence's survival needs, given that there is potential demand in case of seismic disaster?

- To what extent would social and environmental benefits be able to balance out the initial building cost and running cost of the proposed green infrastructure ?

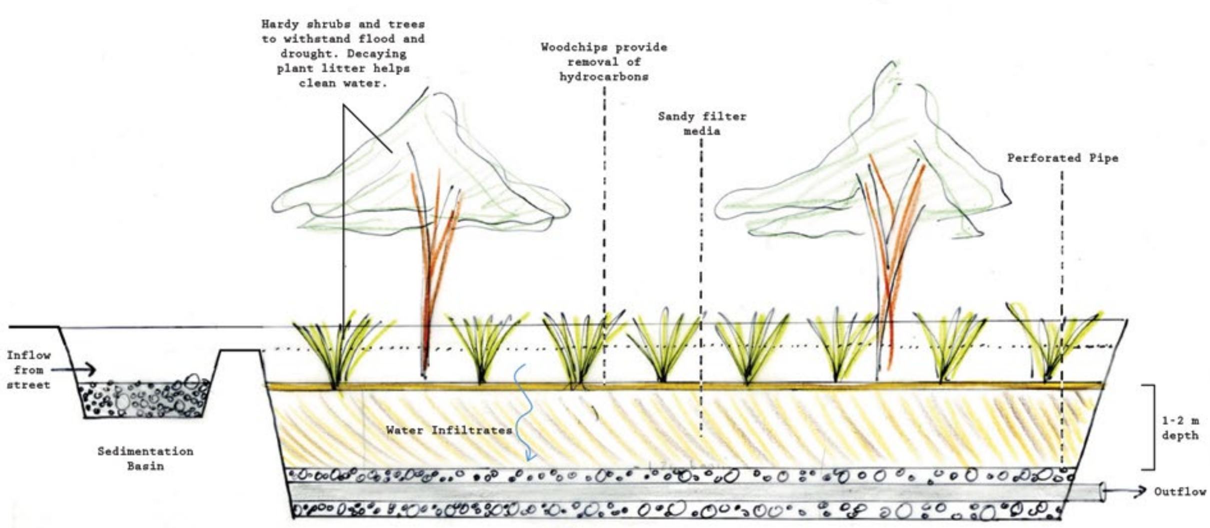
- How could a green corridor at UBC be designed in a way that it could also ensure users' security, such that some more vulnerable users could still feel safe walking alone at night?

Appendix

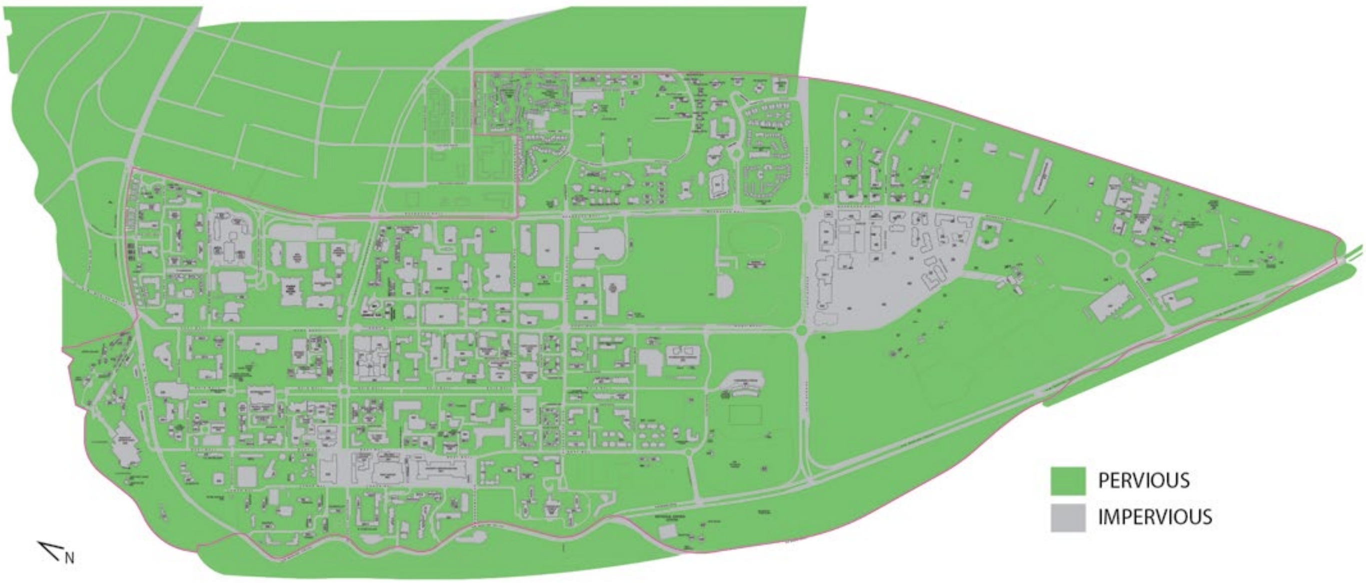
Urban Wetland Design



Biofiltration Basin for Non-Infiltration Zone



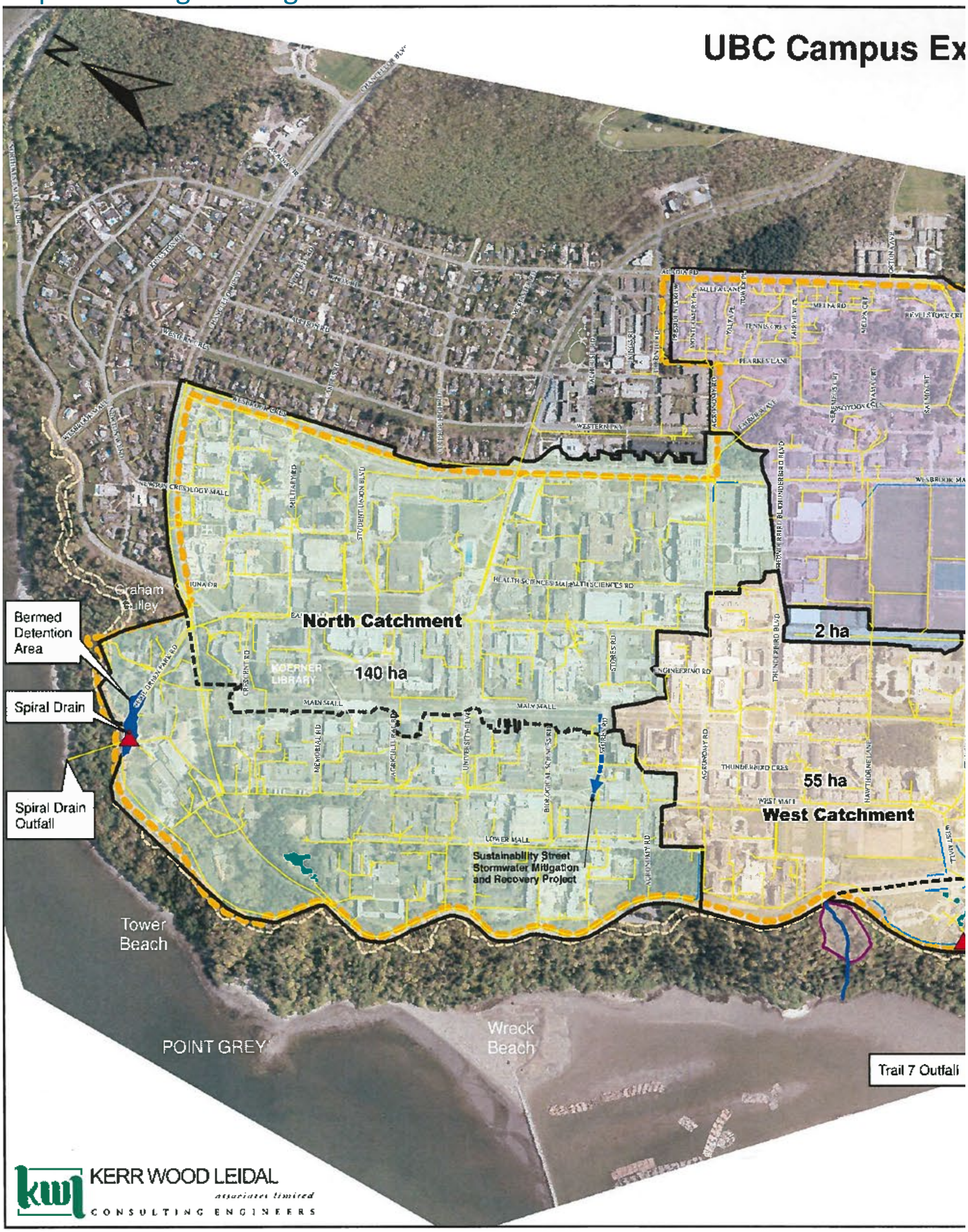
Pervious and Impervious Surface Distribution at UBC

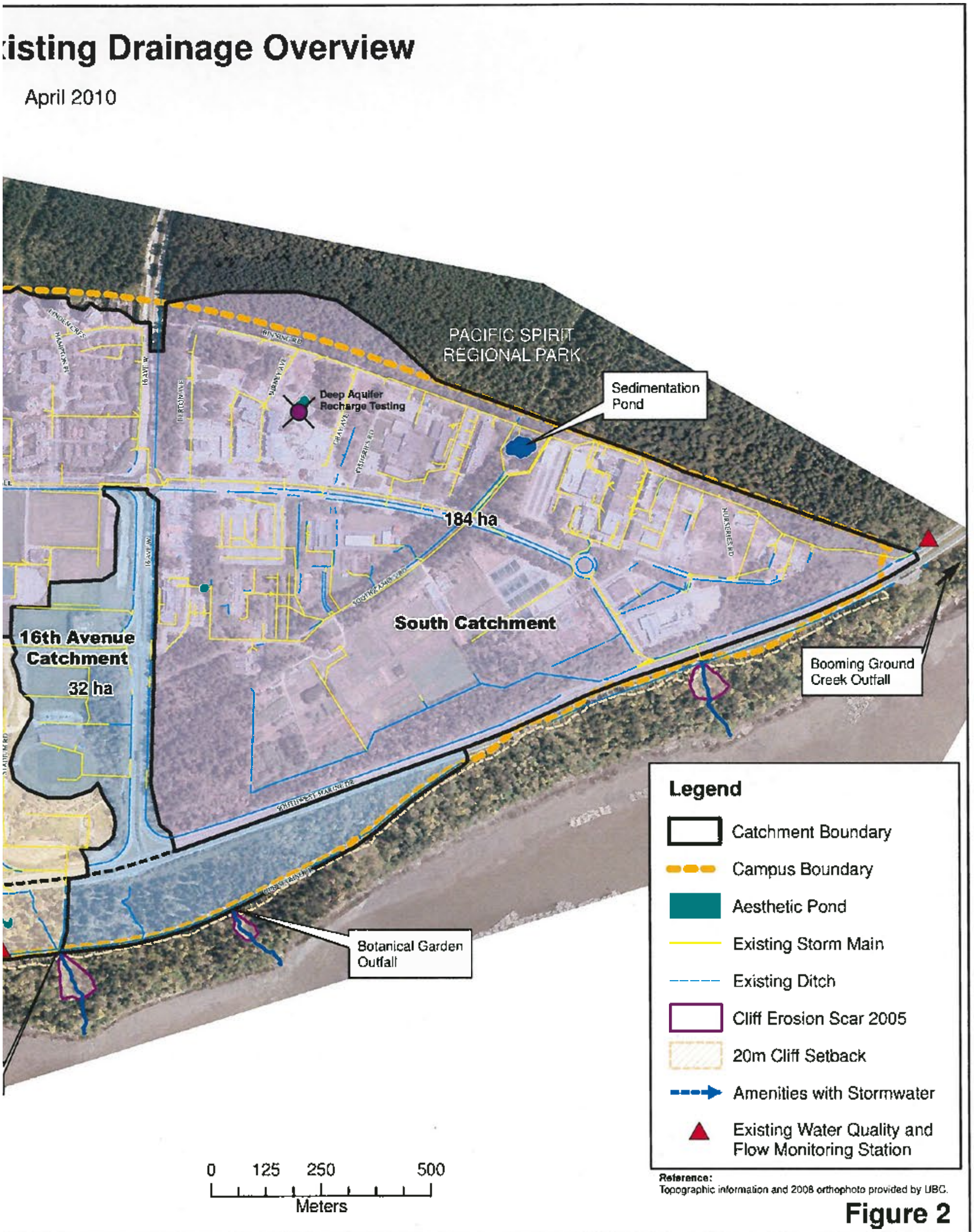


Non-Infiltration Zone at UBC with Contours

Appendix

UBC Campus Existing Drainage Overview

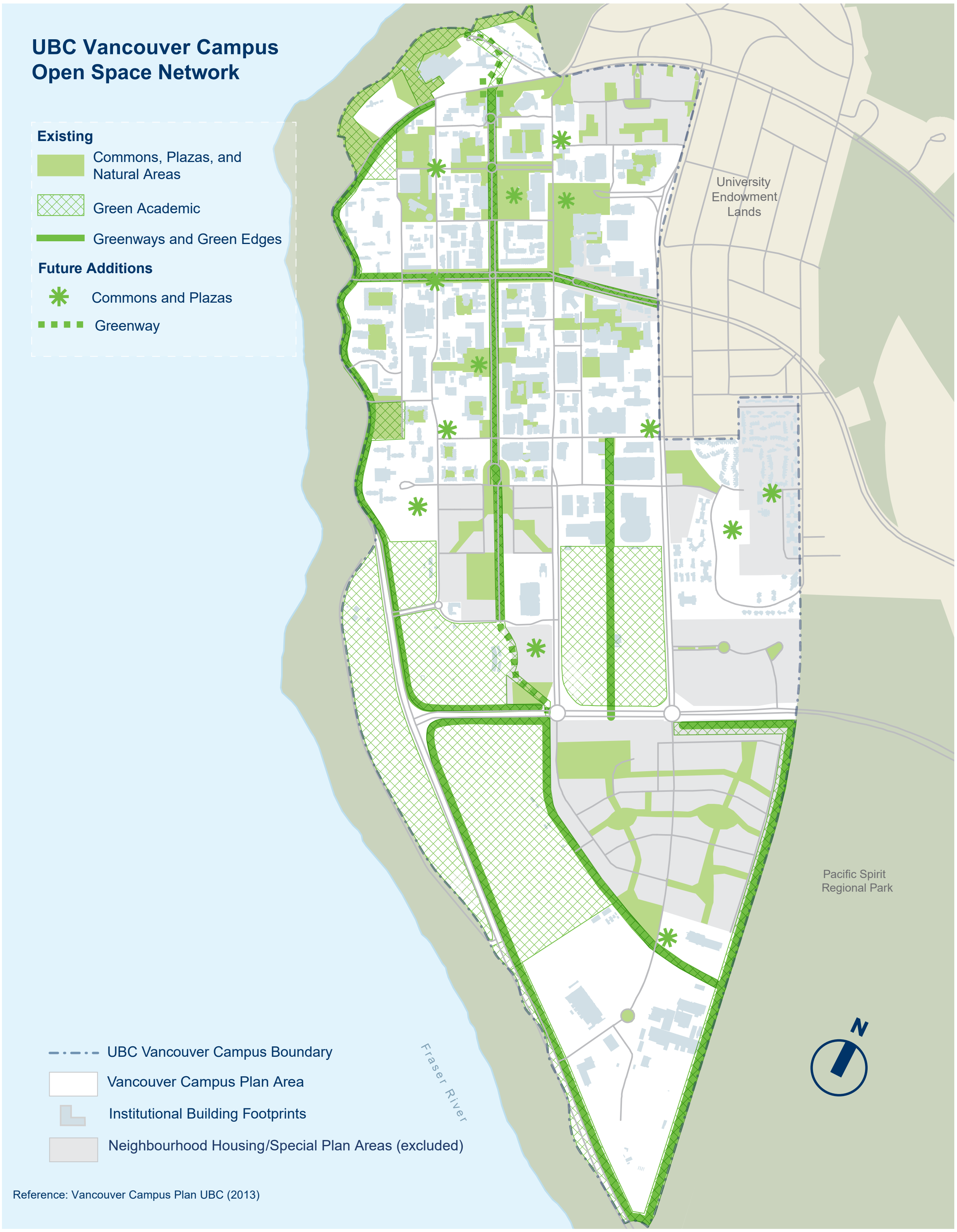




xisting Drainage Overview
April 2010
PACIFIC SPIRIT REGIONAL PARK
Sedimentation Pond
Deep Aquifer Recharge Testing
184 ha
South Catchment
16th Avenue Catchment
32 ha
Booming Ground Creek Outfall
Botanical Garden Outfall
Legend
Catchment Boundary
Campus Boundary
Aesthetic Pond
Existing Storm Main
Existing Ditch
Cliff Erosion Scar 2005
20m Cliff Setback
Amenities with Stormwater
Existing Water Quality and Flow Monitoring Station
0 125 250 500
Meters
Reference:
Topographic information and 2008 orthophoto provided by UBC.
Figure 2

Appendix

UBC Campus Open Space Network



Habitat Classification of UBC Campus and Surrouding Areas

(Caylee Dyck, Mapping the Biodiversity Potential on UBC Campus, UBC SEEDS, 2016)

Appendix

Existing Green Infrastructure on UBC Campus

University Boulevard Water Feature
- Central Water Feature

Image Source: https://www.flickr.com/photos/vangruvie

University Boulevard Water Feature
- Storm Water Feature

Image Source: http://planning.ubc.ca

Memorial Road Rain Garden

Image Source: http//planning.ubc.ca

Existing Green Infrastructure on UBC Campus

Beaty Biodiversity Center and Aquatic Ecosystems Research Laboratory Courtyard

Image Source: http://www.archdaily.com/100682/beaty-biodiversity-center-and-aquatic-ecosystems-research-laboratory-pat kau-architects

Beaty Biodiversity Center and Aquatic Ecosystems Research Laboratory Rain Garden

Image Source: http://www.archdaily.com/100682/beaty-biodiversity-center-and-aquatic-ecosystems-research-laboratory-pat kau-architects

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