UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Stormwater Management

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University of British Columbia

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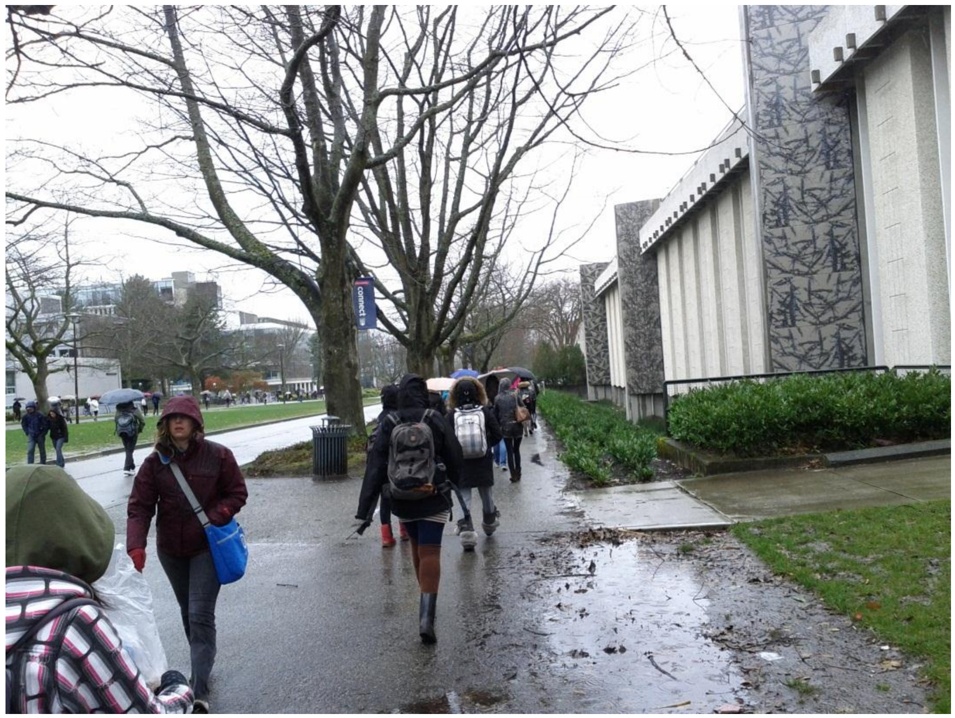
STORMWATER MANAGEMENT



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SYNTHESIS REPORT

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EXECUTIVE SUMMARY

This report tries to propose sustainable stormwater solutions for UBC and tests their commitments to overarching sustainability goals of the institution. The final evaluation of our four main concepts reveals that for each sustainability category (environmental, economic and social), there is not one concept that prevails in all three categories. Before factoring in the risk analysis, it seems like the wet swales option has the best results. The risk analysis shows that the water harvesting option (using open and closed cisterns) has the smallest probability for the cost of construction being more than estimated, and also the least impact on community and environment if something were to go wrong during operation. It is up to Utilities staff to decide the importance of risk in selecting a viable option.

This pocket wetland option scored well in the social and environmental sustainability categories, yet was tied for weakest in the economic and risk. The environmental benefits are clearly positive since it stores the most water out of all the options and ultimately reduces water use on the farm by 50% annually, however can cost between \$145,000 - \$410,000.

The wet swale option scored well in the social, environmental and economic categories. Out of all the options it has the lowest projected cost at \$31,000 - \$74,000, contributes to its surrounding environment by incorporating native vegetation and will be able to hold a sizable amount of water annually. Yet it is also the weakest option in the risk analysis, tied with pocket wetlands. This is because the swale is an open channel, deals with contaminated runoff and may require reworking existing (uncharted) piping in the area.

The water square is ranked third or fourth in most of the categories which suggests it is not a strong option. This is because of the large construction costs (\$200,000+). However it is able to store a significant amount of water (2nd best from the group). The fact that it does not rank well does not mean it is a weak option – UBC is in the beginning stages of building a skatepark on campus and the two designs have a fair bit of overlap and so there is a potential to benefit from a co-design process.

The water harvesting option ranks higher in the social and economic aspects but appears to rank as the weakest option in terms of the environmental impact relative to the other options since it only provides the Plant Ops Nursery with 16% of its irrigation needs. This option is the least risk-prone option according to our evaluation of risk indicators. It does not store as much water as others, but is well suited to provide water for irrigating the Nursery during peak times. This option can be considered a potential low risk pilot project.

We suggest further research with a specialist on the wet swales and the water harvesting options to provide a more accurate evaluation for UBC.

1.0 INTRODUCTION

UBC serves as an innovative platform for sustainability experimentation. The University wields a significant influence if it succeeds at providing an efficient and sustainable approach to conserving and reusing water – it will lead by example, for a global audience of academic, operational and civic workers.

Currently, UBC's stormwater management system consists of a network of gravity inlets, pipes, overland flow routes and open channels (ditches) to outfalls at the Georgia straight and mouth of the Fraser River. In addition, UBC has four catchment areas which serve to direct stormwater flow from concentrated areas to low elevation areas.

The University currently uses irrigation – which is the artificial application of water to agriculture and landscaping. The water currently comes from the Metro Vancouver water supply. UBC spent $2,900,004 in 2011 for water, and 11% of that was used for irrigation. By accumulating stormwater, the University prevents soil erosion as well as reducing the chance of a flood if a heavy rainfall would occur (Paderewski).

Several general stakeholders of this project include: the students, the faculty and staff members, the residents, Metro Vancouver Water System, UBC Utilities, and the current maintenance and repair contractors that service the stormwater piping.

UBC is not incorporated into the municipality of Vancouver. The University operates as an integrated institution consisting of the Senates and the University Executive – and ultimately responds to the Province (UBC Vancouver Integrated Stormwater Management Review, 1). The University, like other municipalities, is accountable for abiding to Provincial legislations such as the Municipal Sewage Regulation, which was developed by the Ministry to provide clear and effective requirements for local governments and private sewage dischargers in order to protect public health and the environment (Solid and Liquid Waste).

The entity that controls stormwater infrastructure and irrigation infrastructure within the University is UBC Utilities. UBC Utilities is responsible for the design, operation, maintenance and overall stewardship for each of the following utility services: (a) water distribution, (b) natural gas distribution, (c) steam distribution, (d) stormy drainage, (e) sanitary sewers and (f) power utilities (Paderewski, 1).

Though UBC is an authority of its own, it also tries to follow regional guidelines for stormwater management set by Metro Vancouver. Some of these guidelines include, laws that encourage more natural drainage in new developments, new education programs, and quality monitoring (UBC Vancouver Integrated Stormwater Management Review, 1).

2.0 CONCEPT DEVELOPMENT

To understand the needs of the university in regards to stormwater management, we did a background study to understand the supplies and demands of water at UBC, water infrastructure (and the jurisdiction over it), cost implications, stakeholders, and environmental and social impacts. Our background study focused on, but was not limited to, the work of previous consultants hired by UBC (Alpin & Martin Consultants Ltd.; Holland Barrs Planning Group) and work carried out by UBC itself (such as the UBC Integrated Stormwater Management Review (UBC). We also consulted the BC government's stormwater planning guidebook (Stephens, Graham and Reid), toured the UBC farm and had an in-class presentation from UBC Utilities staff, Aleks Paderewski. We concluded that technical solutions would be more ideal than policy/program solutions since policies would not apply to the South Campus Neighborhood and also that the options chosen could not involve any infiltration at all. This is due to the severe erosions problems of outfalls, cliff faces and soils from stormwater runoff and infiltration at UBC (Alpin & Martin Consultants Ltd.; Holland Barrs Planning Group).

To determine the best possible options for the stormwater erosion problems at UBC South Campus, we assembled a list containing any and every idea we could possibly think of. Some of these ideas were policy/program solutions like a new water conservation program, technical solutions like incorporating green roofs and minimizing the amount of impervious surfaces at UBC, creative technical solutions like building a gigantic umbrella that would shield UBC year round from rain. A list of all our ideas can be seen below; the **bolded** ones are selected:

<u>Possible Stormwater Management Solutions</u>

- Retrofit existing buildings to be more water efficient
- Green roofs
- Minimize impervious pavements
- Using compost for soil to help retain water
- Detention ponds
- **Water Square**
- **Swales**
- Shoot cloud condensation nuclei above the ocean to prevent rain cloud formation above UBC
- Laminate the cliffs of South campus so water runs off without causing erosion
- Build a big umbrella to cover UBC
- Regulate the size of roads to reduce impervious surface amount
- Require a 30cm top soil requirement before adding turf
- Provide subsidies to encourage use of rain barrels
- **Constructed wetlands**
- Water Conservation Program which included water metering, a new billing system and seasonal prices
- **Rainwater harvesting**
- Move the outfall in South Campus

The options chosen were determined based on whether UBC had or would implement it (in that case, we moved on to other options) and how feasible it is to implement the solution. How probable or realistic a solution's chance for implementation has been determined by looking at estimating relative feasibility (ex. Swales are a widely popular stormwater management option because of their relatively low cost (City of Duluth Stormwater Utility)), how intriguing/innovative the project was (ex. the water square is based off a project in the Netherlands which is the first of its kind (DE URBANISTEN)) and whether implementation would be difficult (ex. the water square integrates a water reservoir system with a skatepark which will require community support in order to be built). We faced many difficulties along the way, for one, the time required to complete the project limited the amount of research we could putforth and it was tough trying to make an educated guess as to the amount of work required to actually construct each idea. In addition, it was often difficult to hear back from companies for time and cost estimates as they would be spending time on a project that may not go through. We were also unable to encompass all of the collateral changes to the current infrastructures and landscape as we were not qualified to do these assessments. Initially the options: water square, new water conservation program, constructed wetlands and rainwater harvesting were chosen. After further study and input from our TA and UBC Utilities staff Aleks Paderewski, all our options were either tweaked or scraped completely because they allowed too much infiltration or had already been (or would be) implemented by UBC. Our final options were: water square, swales, rainwater harvesting and pocket wetlands. A more detailed outline of each option can be seen in the next section.

3.0 STORMWATER MANAGEMENT OPTIONS

Our analysis focuses on four main stormwater management options: pocket wetlands, wet swales, a water square and rainwater harvesting. This section discusses the principles of operation, the details of the calculations (capacity, flow rates, consumption), the layout of the design, cost analysis (installation and operational), and similar projects for each system.

3.1 Pocket Wetland

Pocket Wetlands are miniature wetlands that are capable of naturally removing pollutants from stormwater runoff. Although wetlands require more space than other concepts, it is one of the only options that would restore wetland habitat for many species of animals and plants.

Similar Projects

Because of the size of the pocket wetlands the related projects are typically larger pocket wetlands. There are several examples of wetland projects such as the one at Kennedale Wetland at Edmonton, Canada and the Inkster Wetlands at Michigan, US. The Kennedale Wetland is a $7.5 million wetland that is awarded the FCM Sustainable Community Award by the City of Edmonton as the first end-of-pipe treatment wetland. The Inkster Wetland at Michigan is a 4.7 acre wetland that costs $464,825 and was built in 1996.

Principles of Operation

The pocket wetland starts off with a forebay to collect the coarse material that settles at the bottom of the bay (BMP: Constructed Wetland 7). The water then flows to the open water zones made of one half high marshes and another half low marshes. By varying the depth of the open water zones, there is an increase in mixing and enhanced aeration of water (BMP: Constructed Wetland 7). For that reason, wetlands discourage mosquito growth. The different depths also encourage the growth of different vegetation used to remove the toxins from the water. Finally the water flows to the outlet where the outlet devices adjust the water level seasonally (BMP: Constructed Wetland 7). There is also an accumulation of settlement in the outlet. To further store and regulate the level of water at the wetlands, there is a cistern that the water is stored in once the water level reaches a certain height. This will also give some leeway for a typical 24 hour, 100-year storm of 113mm.

Calculations

All the calculations are rough estimates to the cost and size of a required pocket wetland. The calculations are based on the approximate annual rainfall in Vancouver which totals to 1.5 meters (The Weather Network) and knowing that the area of the pocket wetland is approximately two acres (8000m^2) if it is located at the south east corner of the UBC Farm. Just including the rainfall in a year, the wetlands would approximately collect 12,000m^3. The pocket wetlands would receive water from water that is infiltrated to the perforated pipes at the farm under the crops. Water could also potentially arrive at the wetland through a combination with the wet swale system discussed later. At any given time, the wetland would be able to hold approximately 1800m^3 of water in the forebay and the outlet, and approximately 700m^3 in the high marshes and 2000m^3 in the low marshes (refer to Appendix C: Sample Calculations to see details). This totals to a volume of 4500m^3 at any time. It is also stated that with a 24-hour 10 year storm, the approximate rainfall on the wetlands would be 0.081 meters (UBC), which would be acceptable to a 3” maximum height for a 10 year storm.

Design Layout

This pocket wetland is designed to be on the UBC Farm property as indicated on Figure 1: Proposed Wetland Location. This pocket wetland would be fully lined to avoid infiltration and may require a larger inlet than the swale shown on Figure 2: Top View of Pocket Wetland Layout. The inlet of the pocket wetland is a mixture of water from infiltrated irrigation water (through the topography of the farm) and a wet swale if it is incorporated into the pocket wetland (through topography of the farm). The outlet of the swale could consist of the most amount of piping to drain out water to additional cisterns for storage, as well as emergency spillways, risers, anti-seep collars, and others as indicated in Figure 3: Side Profile of Pocket Wetland.

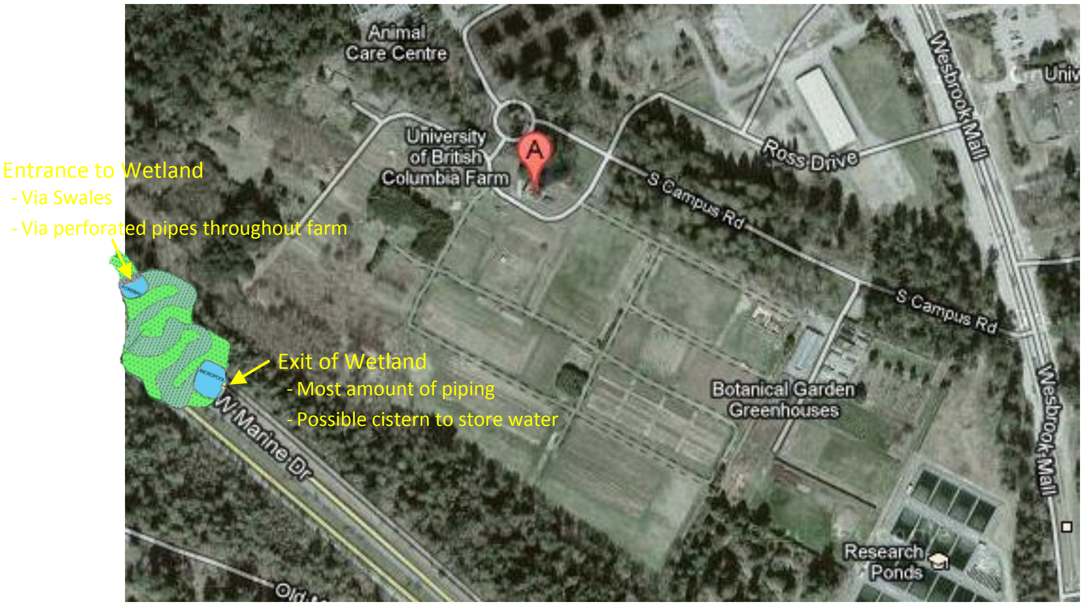

FIGURE 1: PROPOSED WETLAND LOCATION

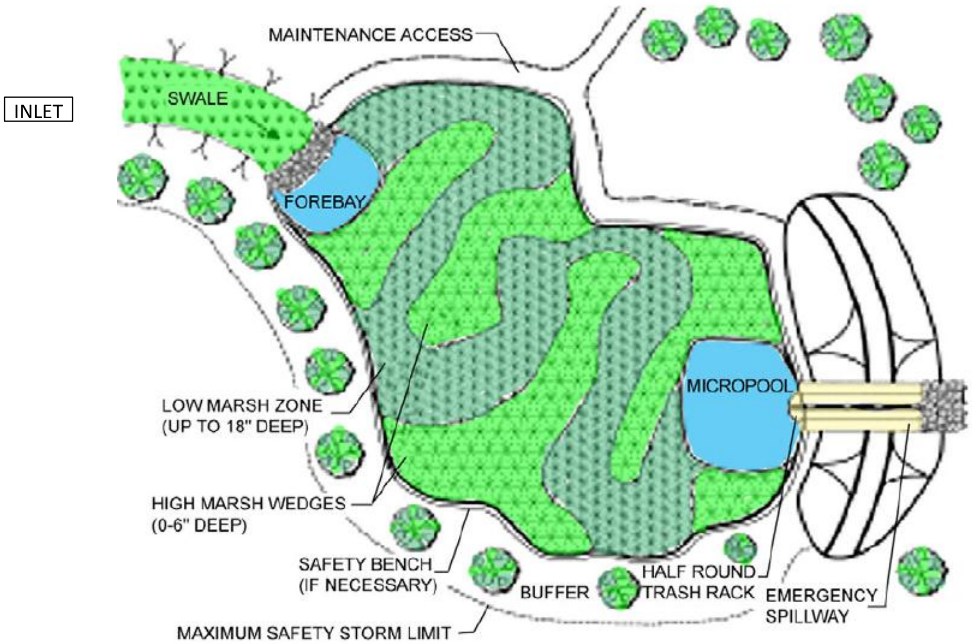

FIGURE 2: TOP VIEW OF POCKET WETLAND LAYOUT ADAPTED FROM BMP (BMP: CONSTRUCTED WETLAND 4)

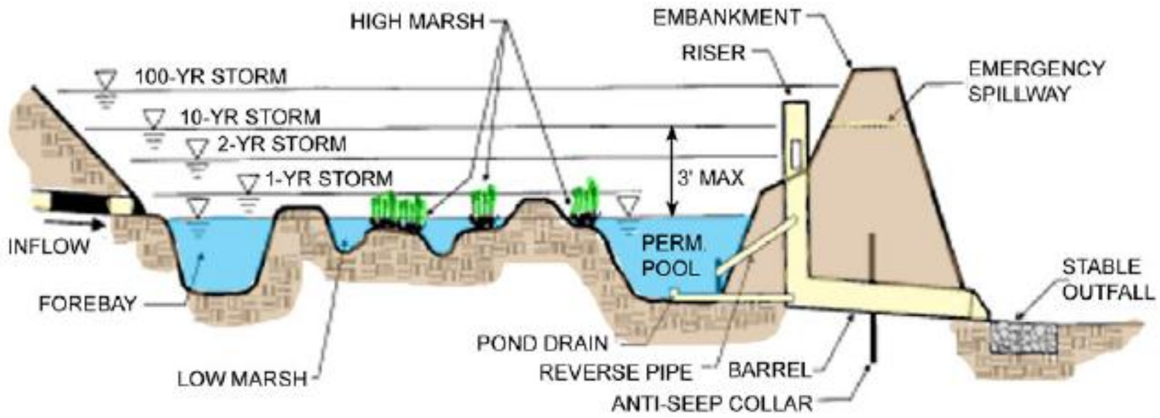

FIGURE 3: SIDE PROFILE OF POCKET WETLAND ADAPTED FROM BMP (BMP: CONSTRUCTED WETLAND 4)

Cost Analysis (Installation and Operational)

Assuming that the unit cost per acre is similar for the different types of wetland, the full construction of a wetland would average about $30,000 to $65,000 per acre. For approx. 2 acres it approximates to $60,000 to $130,000 (BMP: Constructed Wetland 7). This does not include the additional piping and a possible cistern to store excess water. The installation cost for similar systems range from approximately $80,000 to $410,000 (Boyle, Brown and Gearheart 137) thus we selected a conservative estimate of $200,000 to base our evaluation. Therefore to be conservative, the cost of a wetland may be above $200,000. For operation, the main cost is for electricity to power a pump used to pump the water to a location on the farm. This could amount to approximately $0.50/hour (refer to Appendix C: Sample Calculations to see details).

3.2 Wet Swales

Swales are shallow channels and ditches designed to collect, infiltrate, treat and/or direct water (Alpin & Martin Consultants Ltd.; Holland Barrs Planning Group 20). Wet swales are a type of bioswale that is capable of temporarily storing water and incorporates vegetation to treat stormwater runoff. They are commonly used as stormwater management practices because of their low cost and easy maintenance.

Similar Projects

The use of swales for the collection and transport of stormwater runoff is a stormwater management practice commonly used in North America (City of Duluth Stormwater Utility). The success in using swales can be seen at Crown Street in the City of Vancouver (Crown Street) as well as at the Orchard House Parking lot at UBC (UBC Vancouver Campus Integrated Stormwater Management Review). Wet swales are not typically used in residential settings because they feature shallow standing water so are often seen in industrial/commercial settings such as the Latham Business Park wet swale in New York. This wet swale treats stormwater runoff from a 2.5 acre parking lot by use of vegetation such as cattails (Connors).

Principles of Operation

Wet swales act as a natural pollutant remover by storing and slowing runoff which allows for the settling of sediment to occur as well as biological uptake and microbial decomposition (Sample and Doumar 1). To increase the efficiency of wet swales, the vegetation used can be selected based on their pollutant (ex. heavy metal, nutrient, toxins) removal abilities (from vegetative uptake) or their erosion control abilities (Jurries 8).

Calculations

The maximum capacity for our wet swale was determined by finding the volume which is approximately 850m^3. Our design layout is meant to provide efficient stormwater management for extreme storm events that occur every decade and, since South Campus will be rapidly developing over the next few years, we assumed there will be an increase in impervious surfaces which can contribute runoff to the wet swale. In the situation of a 24 hour 2 year storm (56mm for UBC), the amount direct rainfall collected is 145m^3 and the amount of stormwater runoff from adjacent roads contribute around 255m^3, so less than 50% of the wet swales total capacity would be used in a 2 year storm. In a 10 year storm, less than 70% (576m^3 from direct collection and runoff combined) of the wet swale would be met. AlthoughIt is assumed that stormwater runoff will flow off the road and directly into the swale because the topography of the South Campus slopes down and to the southeast.

Design Layout

Swales are recommended to be designed to handle a two-year 24 hours storm at the very minimum (Barr Engineer Co. 246). At UBC, a two-year 24 hour storm contributes on average 56 mm of rainfall according to the UBC Vancouver Campus Integrated Stormwater Management Review. With reference to the design criteria outlined in (Barr Engineer Co. 246), the proposed wet swale will have a trapezoidal shape, a bottom width of 1.0m, side slopes of 2:1, and a depth of 0.5m (0.25m accounts for rainwater collected and stormwater runoff in a two year 24 hour storm but a safety factor of 2 was added). The wet swale will be approximately 850m long and will be located along Wesbrook Mall (Birney Ave at Wesbrook to Gray Ave at Wesbrook Mall) and from Birney Ave at Wesbrook Mall to the central western side of the UBC Farm (see Figure 4). There, the wet swale can be connected to the proposed Pocket Wetland if the wetland is connected to cistern that can store excess water for later use for irrigation thus reducing the amount of potable water used. If the cisterns have reached their full capacity, the wet swales will drain into the sewage system.

Typically, wet swales have check dams which slow water velocity and encourage infiltration of water by increasing residence time (City of Duluth Stormwater Utility) but this is not recommended for UBC due to the significant erosion problems caused by water infiltration. To ensure that no infiltration occurs, the proposed wet swales will be lined.

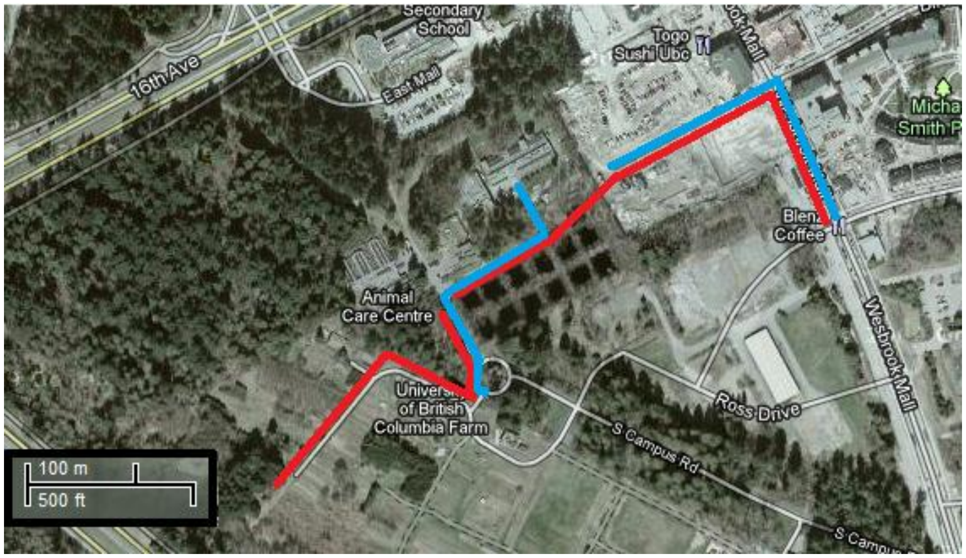

FIGURE 4: SITE LOCATION FOR THE PROPOSED WET SWALES (RED) AND WHERE STORMWATER RUNOFF WILL COME FROM (BLUE).

Cost Analysis (Installation and Operational)

The installation cost of wet swales varies depending on swale dimensions, land slope and soil type and ranges from $24 to $74 per linear meter (Lees & Associates, Karen Hurley & Associates, Dayton & Knight Engineers and Hudema Consulting Group 94). The proposed wet swale will be approximately 850m long and the approximated cost will be $20,400 to $62,900 CDN to install/construct. Wetland type vegetation can be planted or natural colonization can be allowed (Barr Engineer Co. 243). Geomembrane liners will be used to line the swales and will cost approximately $10,500 (Jackson).

The estimated operating costs for wet swales are very low since pollutant removal largely relies on the “settling of suspended solids, absorption, microbial breakdown of pollutants” (Barr Engineer Co. 244) and the biolfiltering abilities of vegetation (Jurries 7). Maintenance costs of swales are also very low and can be done by non-professionals (community members or volunteers) since it consists of vegetation upkeep and the removal of accumulated materials such as debris and sediment (Dhalla and Zimmer 146). The suggested maintenance schedule for swales is quarterly for the first 2 years and then twice for subsequent years (Dhalla and Zimmer 146).

3.3 Water Square

The water square integrates public space with a surface reservoir system that holds excess water from rainfall. It is influenced by the amount of storm water that is collected by the basins as well as the intensity of the rainfall; as there is prolonged precipitation, more parts of the system will be filled with water. The water square brings not only public amenity but brings about the collective consciousness of the community in a real and a commemorative way.

Similar Projects

Currently, the water square concept is in its final design phase in the City of Rotterdam, Netherlands, where it is being implemented to solve the flooding problem. In Rotterdam, not only would the water square be a pure water storage basin, it would be a playground as well as a small sports field, which would generate money. Also, it is expected to have a capacity to hold up to 1,000 cubic meters. For their system, the water accumulated would be deposited back into the ocean or it would act as a reservoir for filtered rainwater, holding it until the city's water system in the city has enough capacity (Boer, 44).

Principles of Operation

The water square will work in conjunction with the proposed skateboard park project and would be located beside the basketball courts across from Thunderbird Parkade near the intersection of Health Science Mall and Thunderbird Boulevard (see Fig5). During rainy days, the water square will collect stormwater which it will drain into the pipes underneath the skateboard park and through elevation, the collected water will transfer into large cisterns and then to the filtering system through an electronic powered pump. The filtered water collected from the system will be used to irrigate UBC's Farm. Every few months, the water square should be cleaned for litter from the public and debris, such as decomposed leaves, to make the water square safe for use and well maintained.

Calculations

The water square will integrate itself as a skateboard park at UBC; with the area the park encompasses and with the assumption of its depth of 2m; the maximum amount of water it can hold is 2,000 m^3. Using Vancouver's annual average precipitation recorded from the weather network and the surface area of the water square, the approximate volume of storm water collected will be about 1,500m^3, reducing the water annually used for irrigation for UBC Farm by 6% (Paderewski). Furthermore, assuming water costs \$0.88/m^3 the water square will help save water bought from Metro Vancouver Waster System by \$1,320, effectively reducing the cost of water used for irrigation by 6% (Paderewski). Assuming the capital cost of the water square, taken from Canada Mortgage and Housing Corporation, is 10% more than a detention pond (because of different material used and a preloading cost 30% greater than the detention pond), the unit cost will be around \$53/m^3, which is used to figure out the lower limit of the construction of the water square. The upper limit is determined by assuming that the water square is equal to the construction of a skateboard park; its unit cost is \$35 per square foot (Fischer). Standard steel unthreaded pipe in pipe size 3 will be used and will cost \$160 per 5 feet so the total cost for a water system using between 150m to 400m of pipes, it would cost around \$85,000 (McMaster-Carr)Refer to Appendix C for detailed calculations.

Design Layout

The water square will start at Thunderbird Boulevard and Health Sciences Mall and extend to around the basketball court across from Thunderbird Parkade (see Figure 5). The skateboard project is currently under the design development phase and feedback is presently being taken from the public to help the "development of the final concept" (Campus + Community Planning) (See Figure 6). It is assumed that the water square, implemented as the skateboard park, will have the approximate dimensions of 50 meters in length and 20 meters in width with 2 meters in depth. There, the accumulated stormwater is collected and drained into the filter system, specifically RODI's containerized water treatment system where it will be treated and stored so it can be sent to the Farm for irrigation.

FIGURE 5: WATER SQUARE LOCATION (WITHIN PROPOSED SKATEBOARD PARK LOCATION)

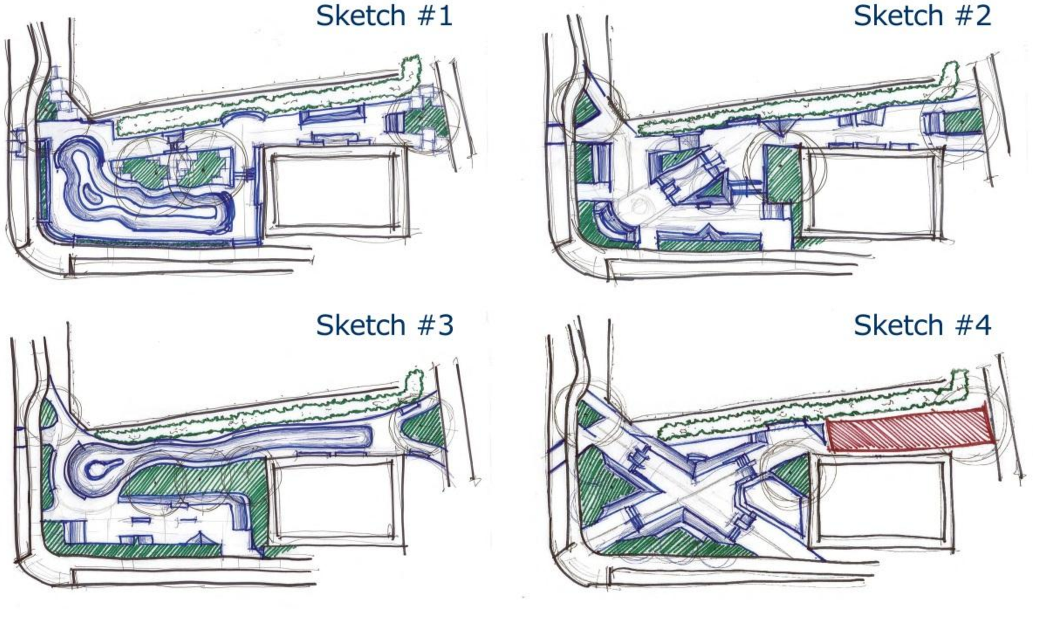

FIGURE 6: PRELIMINARY SKETCHES OF SKATEBOARD PARK (CAMPUS + COMMUNITY PLANNING)

Cost Analysis (Installation and Operational)

Assuming the skateboard park uses standard steel unthreaded pipes on both sides, collecting runoff and stormwater that drain from miscellaneous pipes to the treatment system would need approximately 150m of pipes. Assuming the cost of inspection is the same for both concrete and steel pipes, inspection would be around $300 to $1,500 every 3 years (American Concrete Pipe Association 2). However, if there are clogs (ie: via stagnation), maintenance using hydro-jetting will cost around $650-$850 per hour (H. M. Representative) . Moreover, maintenance using drain jetting will cost $675 for the first two hours, and $175/hour thereafter (D. T. Representative). It is expected that clogs would be more of a concern during certain seasons such as Autumn due to falling leaves. The installation cost of the water pipe system is assumed to be five times greater than installing a residential main line (due to a more complex pipe system and substantially larger surface area), and ranges from $10,000 to $20,000 (Ontario Contractors).

In addition, three custom Norwesco cisterns capable of holding 60m^3 will be needed to hold excess precipitation (152m^3)during Vancouver's rainiest month, March (average 152mm each year according to Weatherstats). The three cisterns will be equipped with the Pacer Electric Drive Pump so water is pumped into the filtering system; in total the electric pumps will cost approximately $2000 (Northern Tool). The total expected capital cost will range from approximately $294,000 to $596,000 (please refer to Appendix C for detailed calculations).

3.4 Rainwater Harvesting

Rainwater harvesting is a system that captures rainwater which can be used later for various purposes such as irrigation, water for livestock and providing drinking water. The option will look at providing irrigation water to the Plant Ops Nursery. The proposed system at the Nursery will provide 16% of its irrigation needs.

Similar Projects

The University of Clemson in South Carolina employs a typical rainwater harvesting system with three distinct components: catchment area (roof), conveyance and storage cistern. The University uses the collected water to meet the irrigation demands of the farm in periods of drought (Clemson University). The system was designed and built by a collaboration of students and professors. It is advertised as a solution for other campuses and also homeowners to collect and reuse rainwater.

Principles of operation

A rainwater harvesting system consists of three basic elements: a collection area, a conveyance system and storage facilities (Alternative Technologies). Typically, the collection area is a roof, which collects the run off. This generally requires filtration if the collected water is to be used for services that would replace potable water. The collection area in our proposed design are 18 open cisterns which are located north west of the Plant Ops Nursery, and do not require a filtration system since the water is not runoff but pure rainwater – which is generally clean enough for irrigation. The water collected from the system will be used to irrigate the Plant Ops Nursery only. The 9 open containers will require a porous screen to protect the water from insects and debris. This will be in the form of a stainless steel screen wire mesh (this is ordered separately and will require manual installation). Every month, the screen should be cleaned from debris and insects. To make this easier, the open containers will be designed with a small side door. When the side door is opened, the sediment build up on the screen can be collected into a bucket, wagon or something similar.

For the conveyance component, instead of connecting the system of 27 cisterns to the network of existing piping at UBC (running the risk of disturbing the current system and high costs), each open cistern will be equipped with two tubes. Each of these tubes will connect to a closed cistern at a lower elevation (since we are assuming the topography of the land slopes down and south east). Therefore, the water collected in each open cistern positioned at a higher elevation in site 1 will flow into two storage cisterns at a lower elevation in site 3, and thus the system is gravity fed. For every open container, there are 2 closed cisterns. This is effective since the diameter of the open cistern (7.04 m) is twice as large as the closed (3.52 m). The goal of the closed cisterns is to avoid loss of water through evaporation (which would occur if it were simply a system of open containers). The storage cisterns are surface level, and each will be connected to a hose.

Calculations

Each custom open container by Norwesco can collect 60.4 m^3 yearly according to present rainfall levels, and each standard closed cistern can collect 35.2 m^3 (Weather Station)(Rainwater Harvest System). If the open cisterns were to catch all the rainfall of one year, they would collect 543.6 m^3. The closed cisterns will be fed this through tubes. Knowing this, and basing our figures off of the latest meter reads, this system will provide the Nursery 16.3% of its current irrigation demands (refer to Appendix C: Sample Calculations to see details).

Design Layout

The northern, higher elevated section of the site will have 9 open custom designed containers (see Fig 7). The site has a total area of 1667 m^2 and can potentially hold 24 open custom designed cisterns. The southern, lower elevated section of the site will hold 18 closed cisterns. The site can potentially hold close to 35 closed cisterns.

FIGURE 7: THE LOCATION OF THE CISTERNS IN SITE 1

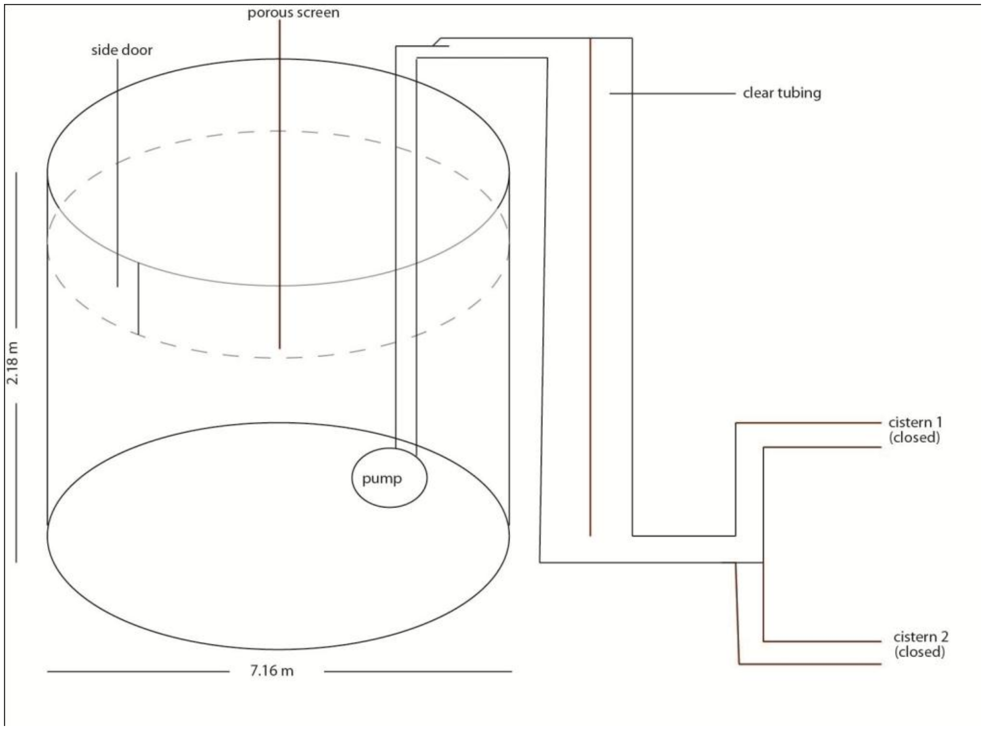

FIGURE 8 SUGGESTED DESIGN OF OPEN CONTAINERS (IMAGE NOT TO SCALE)

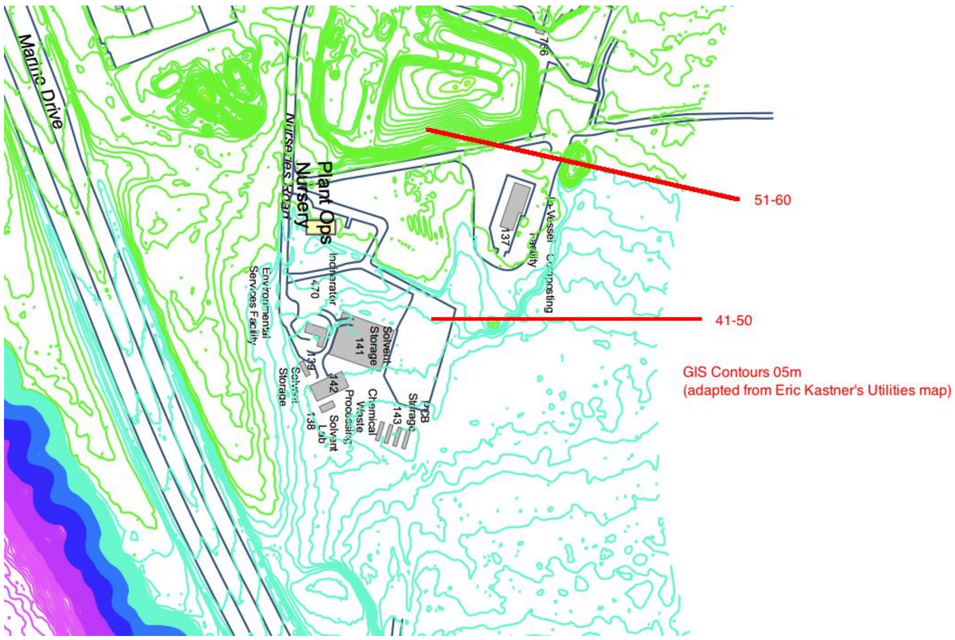

FIGURE 9 TOPOGRAPHY OF NURSERY

Cost Analysis (Installation and Operational)

Each Norwesco cistern retails for $5000 (Rain Harvest System). We will order 18 of these totaling $90,000. We will also order 9 open containers for collection. The open cistern will be custom designed to make the lid removable; a small side door to make the monthly cleaning process significantly easier and it will be twice the diameter of the standard Norwesco tank. We are including a cost factor of 2 to account for these changes; therefore each will cost $10,000, totaling $90,000. Since the custom tank is open-top, the design requires a porous screen to protect the water from insects and debris. The stainless steel screen wire mesh will cost $24 (TWP Inc), and we will require 8, totaling $192 (one for each open container). The tube for each tank costs $80, and two are required for each open cistern, resulting in $1260 (Green Trust). Each open cistern will require a pump ($700). The sum of costs for the entire system of 24 cisterns is $191, 452 including a $10,000 budget for miscellaneous/unexpected costs.

Regular cleaning of sedimentation and maintenance should occur once month through a volunteer process. There should be a start up cost of $100 for each new volunteer to be trained and organized. The farm takes volunteers during several points of the year. Cistern maintenance can easily be integrated into the farm's existing volunteer structure. The farm can provide incentives for students who opt to volunteer at the farm and at the bursary (e.g. field work credit). The ten open containers will require 6 volunteers per year, totaling $600. The volunteers will take rotating shifts. Three will clean the open containers one month and the other three the next.

4.0 CRITERIA AND INDICATORS USED TO EVALUATE OPTIONS

In this project, the four ideas: pocket wetland, wet swales, the water square and rainwater harvesting, were assessed to evaluate their overall sustainability. They were weighed with three criteria areas: social, economic and environmental.

4.1 Criterion A: Social

Out of the four ideas, the wet swales and rainwater harvesting received the best ranking in terms of social impact. The social indicators that were used were based on the concept of community volunteer involvement and outreach and involvement. The wet swales option fosters social responsibility since non-professionals can help to upkeep vegetation and also with the removal of accumulated materials such as debris and sediment (Dhalla and Zimmer 146). In the rainwater harvesting option, the community and volunteers could help clean the porous screen from debris once a month and close or remove the lid when necessary. In addition, if something were to go wrong during operation, there would be no impact on the quality of life for the community since it is not the main water source however there is a potential risk of losing conserved water since it is not connected to preexisting piping.

Social indicators, specifically those assessing the ongoing means of communication between the community and developer throughout the design phase and also verifying if the project design was influenced as a result of input from the community, were used to promote UBC's overarching goal to foster a community in the South Campus. This can potentially lead to better public participation in proposed plans or technical solutions. The other social indicator, assessing if non-professionals can help develop and maintain the new system, was created to acknowledge that community individuals with different backgrounds can contribute to maintaining the new system.

4.2 Criterion B: Economic

In evaluating the recommended options by the economic indicators, wet swales were ranked as the most economic viable. Wet swales scored well by having a low construction cost as well as having significant reduction rate in UBC Farm's water cost (approximately reduced 41%, to $13,600 per year). In contrast, the water square has an estimated construction/labour costs ranging from $294,000 to $596,000 and only reduces the cost of water by 6%. This outweighed the economic benefits of the water square, which included reliable equipment and low operational costs. The Rainwater Container had the second best economic ranking due to low operational costs but failed to provide significant savings in water irrigation cost.

The pocket wetland, water square and rainwater container all tied for having the most expensive system to build, with construction and labour costs around $200,000 or over. Although the pocket wetland is able to reduce the cost of water bought from Metro Vanouver the most (46%), it ranked last in construction, spare parts and operating costs. The rainwater container is least likely of incurring additional construction costs since some components do not cost so much in comparison to the water square's construction of 50-70%- due to current uncertainties, such as land development and design complications.

Upon evaluating the four options, the cost of labour/construction of the new system was used to give a more accurate cost analysis instead of just including material costs – to provide UBC a rough estimate to see whether they would like to pursue the project in a capital cost point of view. Other specific indicators that were important included the cost of spare parts and the amount saved for water cost in percentage. The equipment reliability correlated with the cost of spare parts was an integral part of the economic section as frequent interruptions may cause questioning of the necessity of the project and an increase of ongoing cost complications. When we look at savings in cost, pocket wetland will save the most at $12,300/year, wet swales was second with $9430/year, then rainwater container with $3680/year, and water square scored last with $1320/year.

4.3 Criterion C: Environmental

In evaluating the environmental indicators, pocket wetland was ranked as the best out of the four options. Pocket wetland scored well by effectively reducing 50% of the water used by the farm annually and its capability of minimizing the most outflow of water to Booming Creek outfall compared with the other three options. Furthermore, the maintenance and lifespan of key components was the most durable out of the four ideas. Wet swales was ranked the second most environmentally viable due to also significantly reducing water irrigation by 41% and having a low construction cost between $30,900 and $73,400. Rainwater harvesting was ranked the third most environmentally viable since having 24 tanks collecting stormwater does not significantly impact the environment negatively, and provides 16% of water for irrigating the Plant Ops Nursery. The water square was ranked last because the system requires pipe inspection once every three years (American Concrete Pipe Association) and during seasons, such as Autumn, frequent maintenance may be required for unclogging of pipes. The water square, wet swales and pocket wetland (if combined with swales) collect stormwater runoff which is high in pollutants so there is a potential for groundwater contamination if water is able to infiltrate through the soil. So if something were to go wrong, the water could infiltrate the soil and cause groundwater contamination. In comparison, the rainwater container does not collect stormwater runoff so the water is generally clean.

Specific indicators were used for evaluating the environmental standpoint for the four options. Regular maintenance and the durability of key components were used as indicators because frequent interruptions may cause doubt in the project and the life span of key parts would be able to measure the amount of waste and disturbance to the environment. The amount of water saved for irrigation per year was employed due to its effectiveness in deciding whether implementing different companies' products and their irrigation system would quantify the indicator's significance in reducing amount of water the Farm uses for irrigation. Another key indicator is the relative ranking for the approximation volume of water stored by the system since it is important to address and reduce the amount of water that goes to Booming Creek Outfall to prevent erosion (consequently reducing the environmental impact to habitats).

5.0 CONCLUSION AND RECOMMENDATION

The final evaluations of our four main concepts reveal that there was not one option that prevailed in all three categories. The wet swales option had the best results before going into our risk analysis. From our general risk analysis of unplanned and worst-case-most-reasonably-likely events, we found that the water harvesting method (using cisterns), clearly had the strongest ranking in terms of minimized consequences of failure. Even with these results we recognize that our evaluation is extremely generalized and is based off previous case studies around the world which may not accurately reflect the contributions and downfalls of our options to UBC specifically.

We suggest further research with a specialist on the wet swales and the water harvesting options to provide a more accurate evaluation for UBC. The wet swale option looks at taking runoff water from the road and sending the runoff to either the city sewage system or a small pocket wetland. The pocket wetland is much more environmentally friendly as it has the capabilities to remove the toxins in the runoff water and the water may potentially be reused. Unfortunately, the wetland appears to be much more economically unfeasible due to additional operations cost and regular inspections. The water harvesting option ranks higher in the social and economic aspects but appears to rank as the weakest option in terms of the environmental impact relative to the other options. This is explained through the life cycle of a polyethylene tank. However, due to the simplicity of the water harvesting method, it is the option with the least amount of risk.

The main concern for the wet swale option is the existence of uncharted pipelines through the path and the height of these pipelines. If UBC chooses to continue with this option we recommend that the specialists also survey the area before confirming the project.

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APPENDIX A: OPTION EVALUATION MATRICES

Social Indicators:

Criteria	Indicators	Evaluation topic:			
		Pocket Wetland	**Wet Swales**	**Water Square**	**Rainwater Container**
Community Volunteer Involvement	**Can non-professionals help to develop/maintain this new system? (1. yes; 2. no)**	[1] they can help maintain the plants and cleanliness of the area	Yes [1], since swale maintenance consists of the vegetation upkeep and the removal of accumulated materials such as debris and sediment (Dhalla and Zimmer, pg 146)	No [2], maintenance consists of careful analysis of cracks which are checked by professionals, but the community could help out with cleaning the water square after the water has been transferred	Yes [1] The community/ volunteers could close/remove the lid when necessary and clean the screen debris once a month.
Community Outreach and Involvement	**Is there ongoing means of communication between community and developer throughout design and construction? (1. Public meeting was held, 2. Public meeting not held)**	[1] yes because this was suggested by the community (ex. members of the farm)	Yes [1]. Assuming UBC continues with their goal to have an inclusive community in the South Campus. One way UBC intends to do this is through ongoing community consultations at regular intervals (Senbel, pg 62).	Public meeting was held [1], assuming the water square can be implemented with the skateboard park, feedback from the proposed designs is currently being taken. (Campus+Community Planning 1)	[1] UBC generally requires consultation with developers and community (ex Skatebaord Park consultations).
	Was project design modified as a direct result of community input or if not, was an explanation given? (1. Yes; 1.5. Maybe; 2. No)	[1.5] Because the Farm didn't appear to have a concrete plan of what they wanted so they may or may not be concerned to the design of the project given that the scope of the project is for an already specified area of land	Yes [1]. Since UBC is trying to foster a community in the South Campus, I expect they will incorporate community comments.	[1.5] Maybe, the design phase is still in progress, so information is not readily available	Yes [1], since UBC Utilities has already expressed interest in building a container to collect rainwater at the farm. Continuing negotiations can build on this foundation.
Total Score		**3.5**	**3**	**4.5**	**3**

Environmental Indicators:

Criteria	Indicators	Evaluation Topic			
		Pocket Wetland	**Wet Swales**	**Water Square**	**Rainwater Container**
Reliability of equipment used in new system	**Regular maintenance of a key component which requires shutdown of system to run scheduled maintenance (greater than 20 years = 0; 20 years = 1; 10 years = 2, 5 years = 3, bi yearly = 4; annual = 5; semi-annual v= 6; quarterly = 7, bimontly = 8)**	[3] The type of maintenance that would require the shutdown of the wetland operation would be to remove the sediments from the forebay which usually occurs every 5-7 years (Reese, Haubner and Brown 35)	[6.5] Swale maintenance includes the upkeep of vegetation and removal of accumulated material (ie. debris and sediment) Suggested maintenance is quarterly for the first 2 years and then twice for subsequent years. (Dhalla and Zimmer, pg 146)	[7.5] Suggested pipe inspection is once every 3 years (American Concrete Pipe Association 2); during seasons (ie: Autumn) where leaves fall more often, it may require maintenance due to clogging of pipes.	[4] The typical life cycle of a polyethylene tank is 10-15 years. However, several variables effect tank life. Generally, exposure to corrosive acid, sediment build up and installing hard piping significantly reduces tank life (PolyProcessing). The Norwesco tank is corrosive resistant (Rain Harvest System).
	Life span before completely replacing (Value in terms of years; Relative Ranking)	[2] Assuming that this is similar between the different types of wetlands, 10-20 years (Reese, Haubner and Brown 35)	[1] Assuming wet swales are similar in construction and durability to a grass swales since both share similar design criteria, the system has been observe to still function after 20 years. (Dhalla and Zimmer, pg 185)	[4] Assuming durability of steel pipes is approx. ductile iron pipe, it should last for a min. of 50 years (Ductile Iron Pipe Research Association 1); The typical life cycle of a polyethylene tank is 10-15 (Norwesco)	[3] The typical life cycle of a polyethylene tank is 10-15 years (See above for explanation).
	Main spare parts material (1. Renewable waste, 2. non-renewable)	[1] The main spare part of this component are the plants and when they die, they may be used as compost	[2]; The main spare part for wet swales are geomembrane liners which are not biodegradable	[1] Steel pipes can be recycled back to the steel industry (Steel Recycling Institute)	[2] system is made of Polyethylene. A renewable form exists, but this product is made of standard material (Rain Harvest System).

Environmental Indicators continued:

Criteria	Indicators	Evaluation Topic			
		Pocket Wetland	Wet Swales	Water Square	Rainwater Container
Water Conservation in Irrigation (with the use of the NDS products ie: agrifim) (Agrifim)	**% Reduction in H_2O for irrigation per year (1. 75%-100, 2. 50%-75, 3. 25%-50, 4. 0%-25)**	[3] This means that the percent reduction of water used in a year is approximately 50%. The season that the wetland would get the least amount of water is the season that the farm will require the most water, therefore it is recommended to use a cistern to collect the required water over the year and use it accordingly.	[3] The wet swale will reduce water irrigation by approximately 41%	[4] The water square will reduce water irrigation by approximately 6%	[4] Ordering 24 cisterns (18 closed and 9 open) will provide 16% of the Nursery's irrigation needs.
Minimize outflow of water to Booming Creek outfall	**Approximate volume of water stored by new system (Relative Ranking)**	[1] 4500 m^3	[3] The wet swales will mostly act as a channel to direct water to the pocket wetland however the wet swale is able to hold ~850 cubic meters of water.	[2] The maximum volume the water square can hold is 2,000m^3, but the amount of stormwater collected per year is 1,500m^3	[4] 543. 6 m^3
Habitat Conservation (Animal/ plants)	**Rating 1-3 reduction of wildlife habitat (1 - Introducing more wildlife habitat, 2 - Removing the habitat but will be a viable habitat for other species; 3 - completely removing habitat) There is a multiplier of 2 if the habitat being torn down is for endangered species**	[2] May remove current habitat in that area to create more habitat. Wetlands could also provide habitat to many endangered native plant species of Canada.	[1] Swales often incorporate native vegetation to help filter water and offer aesthetic appeal (Crown Street, 14)	[2] - water square will remove some habitat due to increase population density but it will still incorporate "green structure of high grasses, colorful flowers" (DE URBANISTEN)	[2] The Norwesco tank will replace natural areas with a non-renewable material but will not significantly disrupt the environment
Total Score		**12**	**16.5**	**20.5**	**19**

Economic Indicators:

Criteria	Indicators	Evaluation topic:			
		Pocket Wetland	Wet Swales	Water Square	Rainwater Container
Cost of labor/ construction of new system	1= $0-1000; 2= $1000-10,000; 3= $10,000 - 50,000; 4= $50,00 - 100,000; 5= $100,000- 200,000; 6= $200,000+	[6] To be conservative, the cost of a wetland may be above $200,000.	[4] The expected cost is between $30,900 and $73,400. To be conservative, the cost of wet swales may be above $50,000.	[6] The expected capital cost will range from $294,000 to $596,000	[5] The expected capital cost will be $191, 452.
Reliability of equipment used in new system	Cost of spare parts (Relative ranking)	[3] May need to replace the cistern (if we use cistern) that may cost $5,000 (Rain Harvest System), water control piping and plumbing that could approximate to $10,000 (Boyle, Brown and Gearheart 132)	[1]; The main spare part for wet swales are liners which will cost approximately $12/meter to replace ($10500 to replace everything) (Jackson)	[3] Replacing steel unthreaded pipe size 3 (that transfers water to the treatment system) will cost $160 per 5 feet (McMaster-Carr)	[2] The custom cistern costs $10,000. The stainless steel screen mesh costs $48.
Rainwater harvesting	% Savings in cost for water (1. 75%-100, 2. 50%-75, 3. 25%-50, 4. 0%-25)	[4] This is a reduction of approximately 46%	[3] The wet swales will reduce water cost by approximately 41%.	[4] The water square will reduce water cost by approximately 6%	[4] The water harvesting system will reduce cost by approximately 16%.
Operating costs	Cost of operation (Relative ranking)	[3] Approximately $4,000 operation (electrical cost, tests, miscellaneous supplies (Boyle, Brown and Gearheart 136)	[1] Minimal operating costs	[2] The skateboard park is assumed to have both on 2 sides and for the delivery of collected stormwater to the treatment system. This totals to 150m needed with an inspection cost will be $300 to $1,500every 3 years. (American Concrete Pipe Association 2)	[1] Minimal operating costs (training and organizing volunteers, cleaning sediment build up)
Total Score		16	9	15	12

Risk Matrix:

Criteria	Indicators	Indicators			
		Pocket Wetland	Wet Swales	Water Square	Rainwater Container
Recognition of Risk associated with Options	**Impact in community if something were to go wrong during operation: (1) No impact to the quality of life for the community (2) Impacts the quality of life for several members of the community but may be resolved in a week (3) Impacts the quality of life for several members of the community but can only be resolved in more than a week and will bring media attention**	[3] There may be pests (mice, birds) that create homes in that area drawing in predators (coyotes) to that region causing a more dangerous environment for the community	[2] Since the wet swale moves contaminated runoff water and is an open channel, anything that disrupts the operation could affect pets in the community but this problem can be resolved within a week by cleaning or covering swale	[2]If the pipes were clogged, maintenance would possibly be required but it is expected that unclogging should be resolved in less than a week; If there is leakage, replacing steel pipe via soldering and cutting will only take approximately one day (Family Handyman, The)	[1] There would not be a significant impact since it is not a main source of water for the community. It will only be used for irrigation (including washing fruits/vegetables). If the water source is cut off, the demands can be satisfied easily via potable water. Loss of conserved water is the only potential risk since the system is not connected to existing piping.
Recognition of Risk associated with Options	**Environmental impact if something were to go wrong during operation: (1) No impact to the environment (2) Requires specialist to resolve the issue (3) Permanent negative change to the environment; causes media attention**	[2] There is no use of chemicals or synthetic filters; all of the plants can be decomposed. If the wetland was connected to the swale, a break in the liner could result in sediments seeping underground and contaminating soil underneath	[2] Since the wet swale moves contaminated stormwater runoff, if something were to go wrong (ex. liner not put in properly), the water could infiltrate through the soil to cause erosion or ground-water contamination.	[2]; The water square collects stormwater runoff which may contain chemicals, so if there is a pipe leakage, the water could infiltrate the soil and cause contamination; This is only assumed that the problem is not immediately dealt with.	[1] The probability of a pathogen in the collected water is very small since the cisterns are not collecting runoff, but pure rainwater which is generally clean.
Recognition of Risk associated with Options	**Probability that the cost of construction is more than estimated (1: 0 - 25%, 2: 25-50%, 3: 50-75%, 4: 75-100%)**	[2] Because there's no specific pocket wetland with the same design as the one that we are planning for. Including the impermeable lining, the possible requirement for a cistern, the engineering cost may increase by roughly 50% at most	[3] Since the designated area for the swales is specifically along the road, if there is any piping along that area, the project location will need to be reassessed if it is not possible to build under the pipes. The engineering cost may increase between 50-75%	[3]; due to many uncertainties such as land development and design complications	[1] There would be a low probability of incurring additional construction costs since there are few components and are not significant in cost
Total Score		7	7	7	3

APPENDIX B: INDICATORS AND CRITERIAS

Social Indicators:

Criteria	Indicators	Objectives	Justification
Community Volunteer Involvement	Can non-professionals help to develop/maintain this new system? (1. yes; 2. no)	To create a more acceptable and involving atmosphere about the project; increase the happiness of the community	The members of the community are made up of individuals with different backgrounds, if non-professionals can easily contribute to maintaining the new system, than many members of the community would be included into the ongoing progress of the project
Community Outreach and Involvement	Is there ongoing means of communication between community and developer throughout design and construction? (1. Public meeting was held, 2. Public meeting not held)	To involve people in decisions on how the technical projects can be improved	In line with UBC's goal to foster a community in the South Campus, by involving community members, they won't be caught off guard or feel the new developments were forced upon them. This can also lead to better implementation or integration of proposed plans or technical solutions
	Was project design modified as a direct result of community input or if not, was an explanation given? (1. Yes; 1.5. Maybe; 2. No)	To encourage community participation and help UBC build a 'community' in South Campus	

<u>Economic Indicators:</u>

Criteria	Indicators	Objective	Justification
Cost of labor/construction of new system	1= $0-1000; 2= $1000-10,000; 3= $10,000 - 50,000; 4= $50,00 - 100,000; 5= $100,000-200,000; 6= $200,000+	To determine how the option compares to others in terms of construction/labour costs	For more accurate cost analysis of the option instead of just counting material costs
Reliability of equipment used in new system	Cost of spare parts (Relative ranking)	To measure the dollars spent on repairs and replacements	Frequent interruptions cause questioning of the necessity of the project and an increase ongoing costs. In addition, the life span would be able to measure the amount of ongoing waste and ongoing disturbance to the environment. The quality of the waste would be managed by the type of waste created by the material.
Rainwater harvesting	% Savings in cost for water (1. 75%-100, 2. 50%-75, 3. 25%-50, 4. 0%-25)	To monitor the dollars spent on irrigation	The capture and reuse of rainfall will significantly decrease UBC's irrigation demands from the City. These indicators will show the equivalent savings in water and costs. A possible constraint is it may require substantial time to observe if the recycled water is satisfactory for demands (~1 yr).
Operating costs	Cost of operation (Relative ranking)	To determine the ongoing cost of the project	To provide a estimate of a routine cost for the project for budgeting

Environmental Indicators:

Criteria	Indicators	Objective	Justification
Reliability of equipment used in new system	Regular maintenance of a key component (requires shutdown of system to run scheduled maintenance) that most frequently needs maintenance (greater than 20 years = 0; 20 years = 1; 10 years = 2, 5 years = 3, bi yearly = 4; annual = 5; semi-annual v= 6; quarterly = 7, bimonthly = 8; half month = 9; 1 week = 10)	1. Reduce the Environmental impact as a result of the maintenance 2. To reduce the amount of interruptions to the system	Frequent interruptions causes questioning of the necessity of the project and an increase ongoing costs. In addition, the life span would be able to measure the amount of ongoing waste and ongoing disturbance to the environment. The quality of the waste would be managed by the type of waste created by the material.
	Life span before completely replacing (Value in terms of years; Relative Ranking)	Reduce the Environmental impact of the construction of spare parts and reduce the amount of waste	
	Main spare parts material (1. Renewable waste, 2. non-renewable)	To monitor the type of waste left onto the environment	
Water Conservation in Irrigation (with the use of the NDS products ie: agrifim)	% Reduction in H_2O for irrigation per year (1. 75%-100, 2. 50%-75, 3. 25%-50, 4. 0%-25)	To reduce the cost of irrigation spent per year at UBC; Enhance growth of plants by controlling H_2O irrigation	UBC can roughly measure the total volume amount of water saved by irrigation; the collected data could be useful in deciding whether implementing this product would be efficient in reducing a significant amount of water used for irrigation
Minimize outflow of water to Booming Creek outfall	Approximate volume of water stored by new system (Relative Ranking)	To look at the % water reduction to booming creek outfall To guarantee the erosion issues at Booming Creek Outfaw have decreased	UBC's Booming Creek Outfall is currently facing erosion problems, one of the successes for our new program or technical solution must address this and show reduced flow, otherwise, the purpose of implementing the proposed solution is questionable

Environmental Indicators continued:

Criteria	Indicators	Objective	Justification
Habitat Conservation (Animal/plants)	Rating 1-3 reduction of wildlife habitat (1 - Introducing more wildlife habitat, 2 - Removing the habitat but will be a viable habitat for other species; 3 - completely removing habitat) There is a multiplier of 2 if the habitat being torn down is for endangered species	To ensure the efficient use of materials which decreases environmental impact and cost	Supports the UBC goal of sustainability, reduces the amount of waste going to landfills and reduces the amount of energy needed to produce new materials. It can also add personality to the project.

Risk Matrix:

Criteria	Indicators	Objective	Justification
Recognition of Risk associated with Options	Environmental impact if something were to go wrong during operation: (1) No impact to the environment (2) Requires specialist to resolve the issue (3) Permanent negative change to the environment; causes media attention	To predict the magnitude in the environmental impact if a malfunction (e.g. waterbreak, pathogen) would have on the community and to ensure that there is little negative change as possible	To account for the economic, environmental and social variability of components in preparing the project. This will ensure that there is no major negative impact to the society, environment and economy.
	Probability that the cost of construction is more than estimated (1: 0 - 25%, 2: 25-50%, 3: 50-75%, 4: 75-100%)	To assess the likelihood of having to pay more for an option than originally planned	
	Impact in community if something were to go wrong during operation: (1) No impact to the quality of life for the community (2) Impacts the quality of life for several members of the community but may be resolved in a week (3) Impacts the quality of life for several members of the community but can only be resolved in more than a week and will bring media attention	To assess the worst-case-most-reasonably-likely impact to the society due to the variability of each project	

APPENDIX C: SAMPLE CALCULATIONS

Pocket Wetland

Pocket Wetland Volume:
Total Area: 8000m^2
Forebay and Outlet: 500m^2
High and Low marshes: 8000m^2-500m^2 = 7500m^2 (3750m^2 for each type of marsh)
Forebay depth: 6 ft *12in/ft*0.0254m/in = 1.83 m
High marsh depth: 0.18 m
Low marsh depth: 0.5 m

$$Total\ Volume\ of\ Wetland = \left(Area_{Forebay+Outlet} * Depth_{Forebay+Outlet}\right) + \left(Area_{low\ marsh} * Depth_{low\ marsh}\right) + \left(Area_{high\ marsh} * Depth_{high\ marsh}\right)$$

$$Total\ Volume\ of\ Wetland = (500 * 1.83) + (3750 * 0.18) + (3750 * 0.5) \cong 4500m^3$$

Percent savings in water cost for Wetland:
Premium rates = \$0.88/m^3 (Paderewski)
Farm and nursery water usage = 26 000m^3 of water in a year
Total Cost of Water for Nursery and Farm in a year = 26000*0.88 = \$23 000/year for water.

Volume of water Wetland processes (amount of rainfall onto wetland) = 12 000m^3
Total Cost of water for water processed by wetland \$12 000*0.88 = \$10 000/year for water.

Cost Reduction = 100*(\$10 000/\$23 000) = 46%

Percent Reduction in H2O for Irrigation per year for Wetland:
average precipitation in Vancouver is approximately 1500mm of rainfall a year (The Weather Network) and the wetlands is approximately 8000 m^2 this averages about 12000m^3 a year. UBC Farm uses about 26000m^3 of water a year (Paderewski).

% reduction = 100*(12000m^3/26000m^3) = 50%

Energy Cost Savings:
Assuming we are using a 10 Hp pump
Cost is approx. \$0.07/kWh (based off of BC Hydro Residential Rates)
10 [Hp]*746 [Watts/Hp]*0.001 [KW/W]*0.06 [\$/kWh] = ~\$0.5/hr

Wet Swales

Wet Swale Volume: Bottom width of 1.0m, side slopes 2:1, depth of 0.5m, and length of 850m.
Volume = Width x Length x Depth = (1.0m)(850m)(0.5m) + 2([(1.0m)(850m)(0.5m)]/2) = ~850m^3

Amount of water collected in 24 hour 2 year storm:
Volume from direct rainfall: Width x Length x Depth = (3.0m)(850m)(0.056m) ≈ 145m^3

Volume from stormwater runoff collected in 24 hour 2 year storm: Due to the topography of the South Campus, water flows down and towards the southeast so only certain sections of the swale will be receiving stormwater runoff. We estimated runoff would be from 4560m^2 (length: 570m and road width: 8m). The amount of water received in a 24 hour 2 year storm is 56mm.
Volume of water from stormwater runoff: (4560m^2)(0.056m) = 255m^3

Percent savings in water cost for wet swales:
The UBC Farm uses 26,000m3 of water at $0.88/m3 for a total cost of $23,000. Wet swales collect ~10,700m3 (saving of 10,700m3 x $0.88/m3 = $9,400).
Percent reduction = ($9,400/$23,000) x 100% = 41%

Percent Reduction in H2O for Irrigation per year for wet swales:
Average rainfall in Vancouver is 1.5m per year (The Weather Network). Wet swale will collect water directly (2,550m2) and from adjacent roads (4,560m2).
(4,560m2 + 2,550m2) x 1.5m = 10,700m3
Percent reduction = (10,700m3/26,000m3) x 100% = 41%

Water Square

Water Square Capacity
Width= 20m; Length=50m; Depth=2m
Volume= Width x Length x Depth = 20 x 50 x 2 = 2000m^3

Amount of water collected from direct rainfall collection
Volume= Width x Length x average precipitation
= 20m x 50m x 1.5m (Weather Network)
= 1500m^3

Percent Reduction in water for Irrigation per year
"Amount of H2O collected from direct rainfall collection" / Amount of volume UBC Farm uses x 100% = (1500/26,000) x 100% = 6%

Percent Savings in cost for water square
UBC farm uses 26,000m^3 of water at $0.88/m^3 for the total cost of $23,000. Water Square collects 1500m^3, savings of $1500 x 0.88 = $1320
Percent Reduction = (1320/23000) x 100% = 6%

Cost of Labour/Construction of Water Square

Cost of Detention Pond: 1991 cost = ($50,000/2000m^3) = $25/m^3 (Canada Mortgage and Housing Corporation)

Using Bank of Canada's Inflation Calculator, $25/m^3 will translate to $53/m^3 in 2012

Assuming the capital cost of water square is 10% more than the detention pond because of the difference in material and assuming that preloading would cost 30% more than the detention pond

$37*1.10*1.30 = $53/m^3; Thus, $53 * 2000m^3= 106,000

Assuming water square construction cost is the same as the skateboard park (Fischer)

$35/ft^2 x (ft^2/0.0929 m2) = $377/m^2; Thus $377/m^2 *(Area of Water Square=1000m2)

= $377,000

Using standard unthreaded steel pipe size 3 (McMaster-Carr); $160/5ft x ft/0.305= $524/m

Assuming Water Square needs 150m of pipes, $524/m x 150m = $78,000

Assuming Water Square needs 400m of pipes, $524/m x 300m = $156,000

Assuming that the construction of the network pipe system costs 500% more than replacing main water line to residences because of the difference in size, the cost to install the system would range from $10,000 to $20,000 (Ontario Contractors); Three Pacer Electric Drive Pump will cost $670/each, thus it will cost $670/each* 3 = $2000; Three custom 60m^3 cisterns from Norwesko will cost $10,000 each, so total cost of cisterns will be around $30,000.

Upper Range for total cost of labour/construction of new system:
$388,000 + $156,000 + $20,000 + $2000 + $30,000 = 498,000 =>approximately $596,000

Lower Range for total cost of labour/construction of new system:
$106,000 + $156,000 + $20,000 + $2000 + $30,000 = $236,000 => approximately $294,000

Thus, the range for construction/labour of water square will range $294,000-$596,000

Rainwater Harvesting

Assessing Dimensions of Individual Site Area:

Scale: 1.8 cm = 20 m (Google Maps)

Formula: A = L * W

Site 1:

Length: 1.8 cm/5.4 cm = 20 m/(x) → 1.8 cm * (x) = 108 m → (x) = 60 m

Width: 1.8 cm/ 2.5 cm = 20 m/(x) → 1.8 cm * (x) = 50 → (x) = 27.8 m

A = 60 m * 27.8 m → **A = 1667 m^2**

Site 2:
Length: 1.8 cm/2 cm = 20 m/(x) → 1.8 cm * (x) = 40 m → (x) = 22.2 m
Width: 1.8 cm/ 0.8 cm = 20 m/(x) → 1.8 cm * (x) = 16 → (x) = 8.9 m
A = 22.2 m * 8.9 m → **A = 197 m^2**

Site 3:
Length: 1.8 cm/3 cm = 20 m/(x) → 1.8 cm * (x) = 60 m → (x) = 33.3 m
Width: 1.8 cm/ 1.6 cm = 20 m/(x) → 1.8 cm * (x) = 32 → (x) = 17.8 m
A = 33.8 m * 17.8 m → **A = 592.8 m^2**
Approximate total area available at the Plant Ops Nursery: **2457 m2**

Surface Area of Custom (Open) Norwesco Cistern:
Diameter: 7.16 m, Height: 2.184 m
Formula: $A = \pi r^2$
A = 80.43 m + 49.15 m → **A = 38.93 m^2**

Surface Area of Standard Norwesco Cistern:
Diameter: 3.52 m, Height: 2.184 m
Formula: $A = \pi r^2$
A = 77.85 m + 48.29 m → **A = 9.7 m^2**

Number of cisterns that can fit in the total available land area:
This calculation is done by measuring how many diameters of the cistern can fit in the length and width of each rectangular area:

Site 1 (image not to scale):

L = 60 m, W = 27. 8 m

L =60 m (length) / 7.04 m (diameter of custom cistern) = 8.3 cisterns can fit in the length
W = 27.8 m (width) / 7.04 m (diameter of custom cistern) = 3.8 cisterns can fit the width

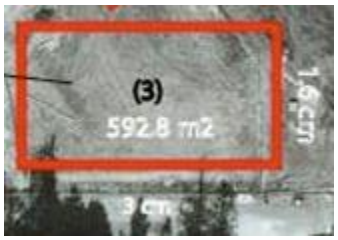
Total amount of custom cisterns that can fit the area = 8.3 * 3.8 = 31.54 cisterns. However to be conservative, approximately 24 will fit in the area (8*3).

Site 2 (image not to scale):

L = 22.2 m, W= 8.9 m

L = 22.2 m (length) / 3.52 (diameter of closed cistern) = 6.2 cisterns can fit in the length
W = 8.9 m (width) / 3.52 (diameter of closed cistern) = 2.5 cisterns can fit in the width
Total amount of custom cisterns that can fit the area = 6.2 * 2.5 = 15.5 cisterns. **However to be conservative, only 12 closed cisterns will fit in the area (6*2).**

Site 3 (image not to scale):



L = 33.3 m, W= 17.8 m

L= 33.3 m (length) / 3.52 (diameter of closed cistern) = 9.46 cisterns can fit the length
W = 17.8 m (width) /3.52 (diameter of closed cistern) = 5.05 cisterns can fit the width
Total amount of custom cisterns that can fit the area = 9.46 * 5.05 = 47.8 cisterns can fit. However to be conservative, only 35 closed cisterns will fit in the area (9*5).

Amount of rainfall collected in one year:

Open cistern= πr^2 * annual rainfall → (π(3.58^2) * 1.5) → 60.4 m^3/each
Closed cistern= can store up to 35 m^3 (Norwesco)

Amount of irrigation needs met at nursery
Current demand: 3336 m^3 (UBC meter reads).
Total volume of water open cisterns will catch = 60.4 * 9 = 543.6 m^3
543.6 m^3/3336 m^3 = 16.3%