UBC Botanical Gardens Redevelopment Rainwater Harvesting System

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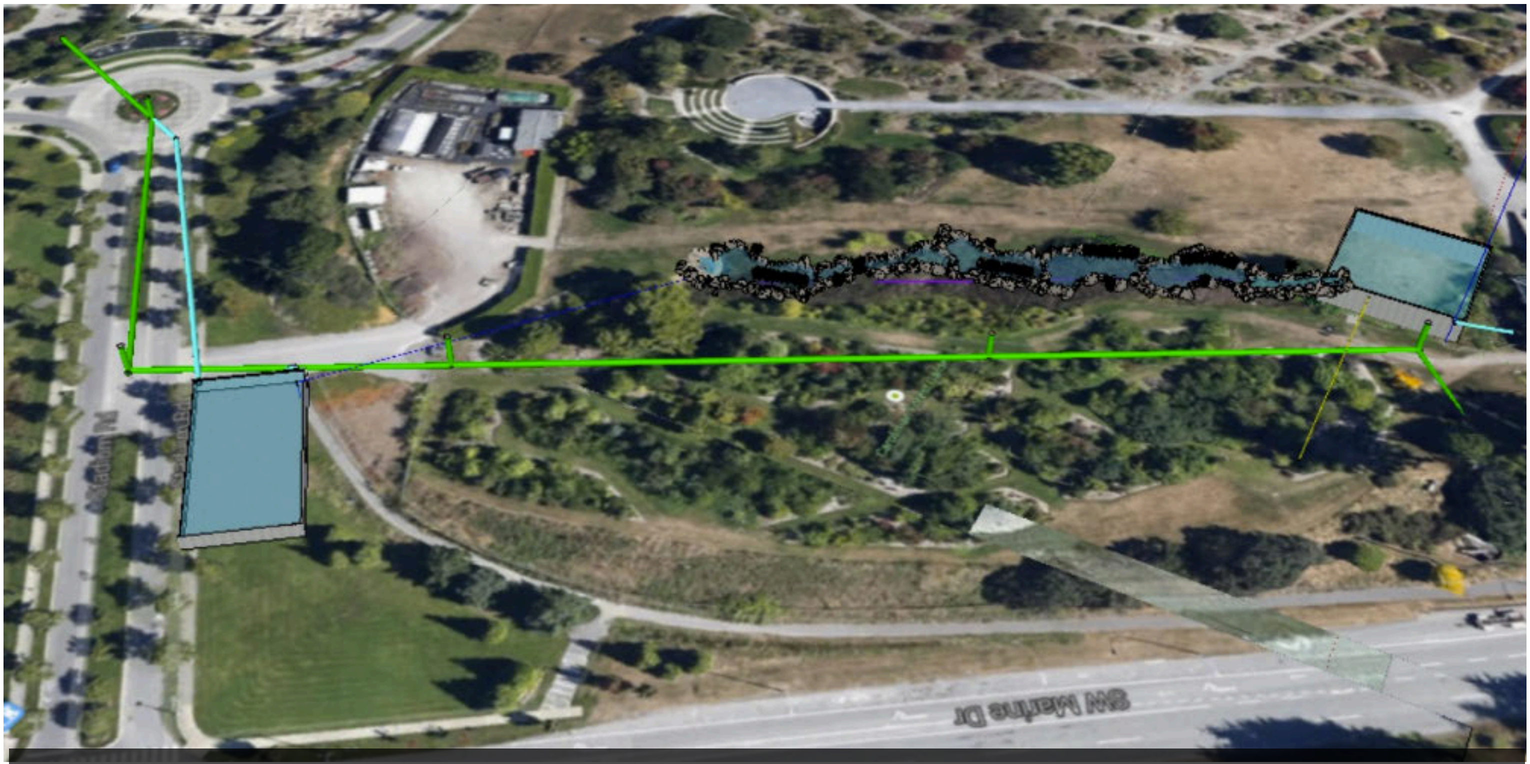

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G3 WATER CONSULTANTS

Civil 446 Final Project Report

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Executive Summary

The UBC Botanical Garden (UBCBG) is a necessary component of the society to maintain and conserve diverse and exotic collections of plant species. The 40 hectares of the UBCBG boast a collection of over 7,000 rare species and provide a unique opportunity for research. To irrigate the collections, the UBCBG uses approximately 20,000 m3 of potable water annually, which is a concern, and a solution to which is addressed in this report.

The main goal in the design was to enhance economical benefit through implementation of sustainable systems in the garden, which will recycle stormwater for irrigation and decrease the usage of potable water. The second goal was to partly mitigate cliff erosion at the Trail 7 Outfall by decreasing the amount of water leaving UBC campus and the third goal is to increase the quality of water that will be discharged into the ocean.

The scope of the report is limited to concentrating on three engineering disciplines in the detailed design of three system components. The scope of work also includes providing justification for the design, as well describing implementation strategies and submitting materials cost estimate.

The report describes the design of the system that consists of three components: collection and distribution, storage, and biofiltration, where each is related to the hydrotechnical, geotechnical and environmental engineering discipline respectively. Water will be collected from the existing stormwater pipe that runs along Stadium Road and redirected into the underground upstream reservoir. The water will then be slowly distributed into the bioflтration system, and finally into the second, downstream storage reservoir. The approximate duration and material cost of the project are 6 months and $350,000. Justifications, designs, and costs of each component are discussed in detail in the report.

1.0 Introduction

With water consumption in Vancouver continuing to increase, rainwater harvesting is quickly becoming a very attractive option to conserve water. In fact, UBC is developing a Water Action Plan that targets an establishment of a campus-wide closed loop water system (Water Action Plan, n.d). In order to take a step towards achieving this goal, G3 Consultants have developed an efficient rainwater harvesting system that will reduce the UBC botanical gardens potable water usage and the expenses associated with it, while mitigating erosion problems at the Trail 7 Outflow from stormwater runoff caught in the west side catchment area. The system will clean and store the harvested water and be connected to the Gardens current irrigation system. The system will reduce the Gardens reliance on potable water by almost 13,000 m^3 a year, thus decreasing the amount they spend on water from approximately $20,000 to $7,000.

The detailed design of three specific portions of the water harvesting system will be discussed in this report, each of which relates to a specific engineering discipline. More specifically, this report will discuss the hydro-technical, geotechnical and environmental engineering disciplines associated with the water collection and distribution, storage, and filtration systems respectively.

2.0 Project Purpose

There are two main benefits associated with the proposed rainwater harvesting system: the preservation of potable water and the mitigation of erosion to the western cliffs.

2.1 Preservation of Potable Water

The main objective of implementing this rainwater harvesting system is to preserve potable water, which will provide substantial environmental and economic benefits. Currently, UBC utilities purchase potable water from Metro Vancouver and redistribute the required amount to the Botanical Gardens. The Gardens uses potable water for all of its daily activities including irrigation, water features, toilets and taps. The amount of water attributed to irrigation is approximately 19,000 m^3 per year (UBC Properties Trust, 2002). Metro Vancouver charges rates of \$0.84/m^3 and \$1.06/m^3 of tap water during low and high seasons respectively, which yields an annual expense of almost \$20,000. Table 1 below provides a monthly comparison of current water usage and potential water and dollar savings Based on the analysis described in Section 3.2, it was determined that making the garden fully dependent on stormwater wasn't feasible, as the storage reservoirs and costs associated with them would be too large. The proposed system is to decrease current usage and expenses by 70%.

Table 1 - Irrigation Demand and Dollar Savings

Month	UBCBG Water Demand	Current Cost of Tap Water ($)	Water Savings (m3)	Dollar Savings ($)
Jan	-	$-	-	-
Feb	-	$-	-	-
Mar	5.00	$4.20	5.00	$4.20
Apr	1140.00	$957.60	1140.00	$957.60
May	1387.00	$1,470.22	1387.00	$1,470.22
Jun	2453.00	$2,600.18	2453.00	$2,600.18
Jul	5103.00	$5,409.18	2453.00	$2,600.18
Aug	4080.00	$4,324.80	810.00	$858.60
Sep	2970.00	$3,148.20	2970.00	$3,148.20
Oct	1515.00	$1,272.60	1515.00	$1,272.60
Nov	220.00	$184.80	220.00	$184.80
Dec	-	$-	-	$-
Total	18873.00	$19,371.78	12953.00	$13,096.58
			69%	68%

2.2 Mitigating Cliff Erosion

Almost all of the rainwater collected at UBC is transported through underground pipes and discharged at four different outfalls, namely the North, West, South and 16th Avenue outfalls (UBC Properties Trust, 2002). Recently erosion of the western cliffs has been becoming a major issue, which can be attributed to the high water flows through Trail 7 Outfall from the West Side Catchment area. This catchment area is shown in Figure 1 and has an overall surface area of 49.3 Ha (Shen and Wong 2013).

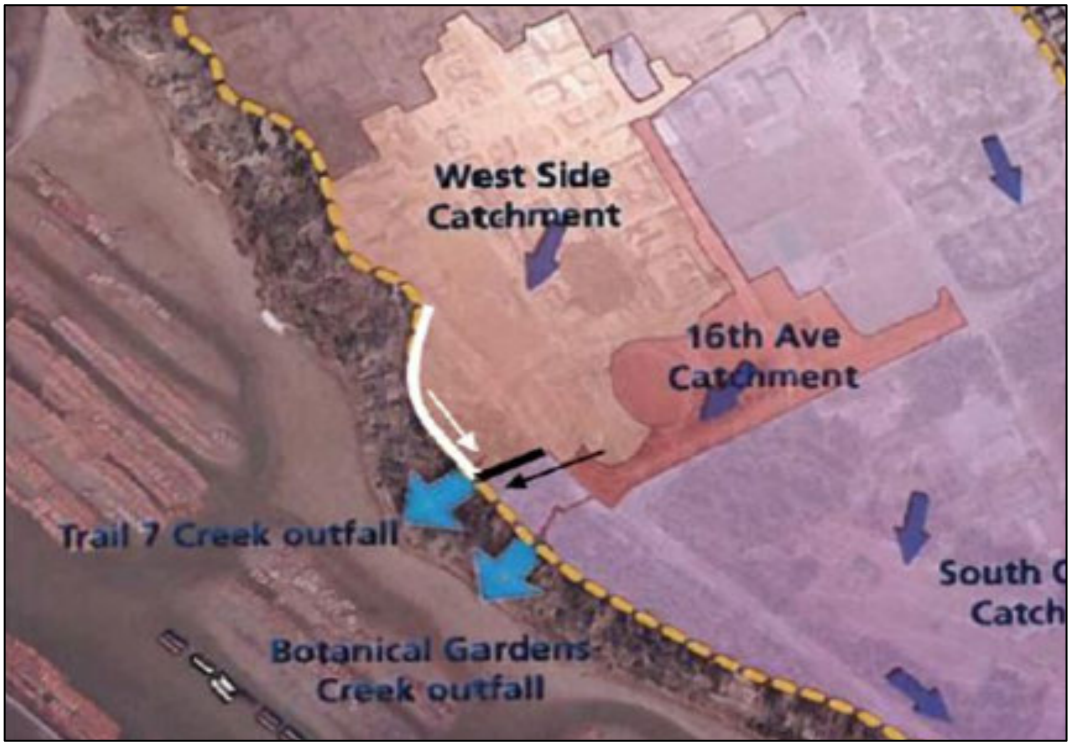


Figure 1 - West Side Catchment Area

The proposed rainwater harvesting system will tap into a 900mm storm pipe that currently runs along the Stadium Road. This pipe has a catchment area of approximately 17 Ha that is within the West Side Catchment area. The implementation of new harvesting system will reduce flows heading to the Trail 7 Outfall by capturing flows in the 17 Ha area during heavy storm events and then releasing them at more adequate rates.

3.0 Design of System

The system, 3D model shown in Figure 2, begins from an existing storm pipe located near the West Mall and Stadium Road roundabout. By tapping into this existing storm pipe and essentially running another pipe along Stadium Road, the water is collected in the upstream reservoir. The collected water is then pumped to a bio-filtration system where it is cleaned of any contaminants before it flows into the larger downstream reservoir. Finally, the larger reservoir is connected to the garden's existing irrigation system for use. A detailed description of each component can be found in the subsequent sections.

Figure 2 - Overview of the System

3.1 Water Collection/Distribution System

The following sections will outline the design and locations of the water catchment and distribution system. The size and materials of the each pipe and hydrotechnical issues such as garden demand and system capacity were considered in order to adequately design the water collection and distribution system.

3.1.1 Estimation of Storm Water Flow

Before designing the subsurface reservoirs, the amount of storm water that we have at our disposal was calculated. First of all, all existing storm pipes in the vicinity of the Botanical Garden were identified by overlain GIS satellite photos and underground utilities drawings in the Vancouver area obtained from The City of Vancouver's website. Upon inspection, our group decided that the 900mm storm pipe that runs along Stadium Road and turns south into the Gardens would be a suitable choice for tapping into the storm system, as it is the closest to the garden boundaries.

In order to estimate the flow going through the 900mm storm pipe, the SCS Curve Number Method was used. This method was chosen because it is designed to estimate excess precipitations based on the type of land use. The soil type, land use, and antecedent moisture were considered when determining a curve number, which was later used in the SCS method to relate cumulative precipitation and excess runoff (Bedient, 2013).

The total average annual rainfall amount at UBC was determined to be 1288.7mm according the UBC HydroGeo Study conducted in 2002. This report breaks up the precipitation amounts into monthly values allowing us to determine the flow rate for each month. Most of the surface soil at UBC can be categorized as Podsols, Gleysols or Organic Soils. Podsol soil covers the majority of UBC and has relatively good drainage (UBC Properties Trust, 2002). Thus the soil cover type was categorized as Group B, which gives a minimum infiltration rate of 0.15-0.30 in/hr. The land use is residential with roughly 65% of the land being impervious. Thus a curve number of 85 was chosen. Furthermore, each month the antecedent moisture type must be categorized as dry, normal or wet. If the conditions are either dry or wet, the curve number of 85 must be changed to account for this. (UBC Properties Trust, 2002)

By looking at the GIS photos and the utilities line work, it is evident that the area of land draining into the 900mm storm pipe includes everything south of Thunderbird Boulevard and north of Stadium Road, and everything west of East Mall and east of West Mall. This area is roughly equal to 170,000 square meters.

Table 2 summarizes the input values necessary to calculate excess flow using the SCS Curve Number method. The total monthly volume represents the storm water flow available in the 900mm storm pipe each month; this is compared to the monthly irritation demands for the Botanical Gardens. Refer to Appendix A for sample calculations.

Table 2 - Garden Demand and Water Collection

Month	Antecedent Moisture Condition	Adjusted CN	Total Rainfall (mm)	Direct Runoff (mm)	Area (m^2)	Total Monthly Volume (m^3)	Garden Demand (m^3)	Remaining Demand (m^3)
January	Wet	92.9	165.3	144.0	170000	24482	0	0
February	Wet	92.9	137.9	117.0	170000	19888	0	0
March	Wet	92.9	118.9	98.3	170000	16717	5	0
April	Wet	92.9	81.9	62.4	170000	10610	1140	0
May	Normal	85.0	65.0	31.1	170000	5292	1387	0
June	Normal	85.0	47.9	18.1	170000	3077	2453	0
July	Dry	70.4	39.6	2.7	170000	453	5103	4650
August	Dry	70.4	46.4	4.8	170000	810	4080	3270
September	Normal	85.0	68.0	33.6	170000	5705	2970	0
October	Wet	92.9	132.7	111.9	170000	19019	1515	0
November	Wet	92.9	188.9	167.4	170000	28453	220	0
December	Wet	92.9	196.2	174.6	170000	29683	0	0

Based on the comparison of the last two columns above, the 900mm storm pipe can theoretically provide enough flow to meet 100% of the Garden's irrigation demands in all months of the year except for July and August.

3.1.2 Location of Collection Pipes

At the roundabout between West Mall and Stadium Road there is a storm manhole labeled L3D-NW175D, which contains a 900mm storm pipe at an invert elevation of 73.99 meters above sea level. An additional

900mm pipe from that manhole will be used to redirect all flow towards the first subsurface storage reservoir, which will be located on the south side of Stadium Road, just west of the Botanical Gardens maintenance yard access road (Figure 3).

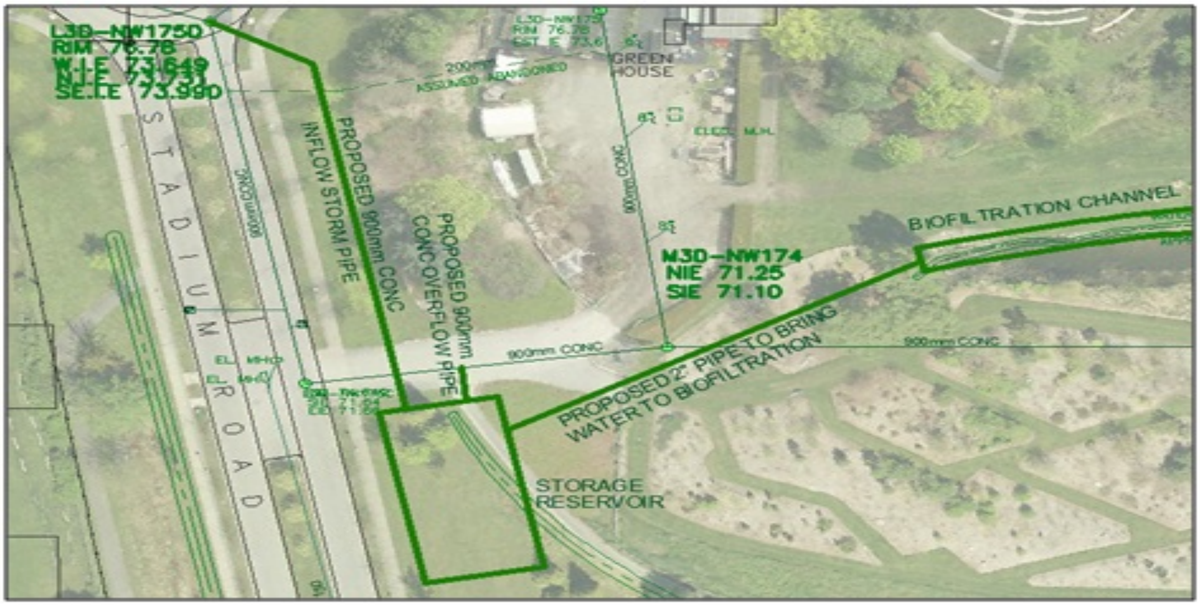


Figure 3 - Location of Collection Pipes

The purpose of connecting to manhole L3D-NW175D is to allow the inflow into the first reservoir and overflow back into the existing storm system, both connections will be gravity fed. By using a 1.5% slope for the inflow pipe we ensure the invert into the storage tank will occur at an elevation of 72.7 meters above sea level. This provides roughly 0.5m of cover from the top of the inflow pipe to the ground surface. Furthermore, an overflow pipe can easily travel from the same invert elevation at the reservoir towards the storm pipe near manhole M3D-NW174 that is located within the Garden next to the maintenance yard. This manhole is directly downstream of manhole L3D-NW175D and thus there would be no changes to the existing hydraulic regime, except for the water that is stored in the storage reservoir. Manhole M3D-NW174 also has an invert elevation of 71.2 meters above sea level. Thus the overflow pipe can easily travel downwards from the storage reservoir, back into the existing storm system without the need of a pump. A 2" pipe will be used to transfer water from the storage tank to the biofiltration channel. The transfer pipe is located at the bottom of the reservoir so that the potential head can be maximized. Since the elevation difference of 5m between the reservoir and the biofiltration channel exceeds the potential head (tank depth is 2 m), the 2” pump is required. A 0.33 hp pump is adequate to pump the peak flow of 69.6 L/min, and change in elevation of 5 m.

3.1.3 Sizing of Collection Pipes

The size of both the inflow pipe and overflow pipe will match the size of the existing pipes that the stormwater currently travels through in order to avoid the possibility of new pipe capacity exceedance during peak events. A pipe of bigger diameter is not preferred as it will unnecessarily increase material costs. Furthermore, The City of Vancouver underground utilities line work was followed to determine pipe material. Both pipes will be 900mm in diameter and made of concrete.

3.1.4 Length of Distribution Pipes

The distribution system will consist of three separate pipes. The first distribution pipe will be used to transport water from the secondary storage reservoir, which is located next to the Garden Pavilion Building and contains cleaned water, to the existing irrigation system. The second pipe will act as a recycling pipe and will transport water from the secondary storage tank back to the top of the biofiltration channel. The purpose of this is to ensure that water will be flowing through the biofiltration channel at all times. If water were to stop flowing through the channel, the plants contained in it would dry out and the functionality of the channel would decrease. The third pipe will act as an overflow pipe and will take excess water from the second storage tank to a stream located within the Garden next to the Garden Pavilion Building. The purpose of having an overflow pipe is to ensure that water can continue to flow through the biofiltration channel during the winter months when the water demands in the garden are zero.

As the irrigation pipes are pressurized, it will be more difficult to tap into the existing irrigation system without disrupting garden operations. Thus it is recommended that the hot-tapping technique be used, as this will allow the Botanical Gardens to continue watering plants without disruption if the construction occurs during the summer months.

3.1.5 Sizing of Distribution Pipes

The size and material of the distribution pipe will be the same as the existing irrigation system within the Botanical Garden. As per the City of Vancouver underground utilities line work, the pipes for the irrigation system where we will be tapping in, is cast iron and is 100mm in diameter.

3.2 Storage System

The following sections will outline the design and locations of the upstream and downstream storage reservoirs. The size and materials of the tanks and geotechnical issues such as liquefaction and bearing capacity are considered.

3.2.1 Analysis and Description

The storage system will consist of two concrete reservoirs, an upstream storage reservoir located before the filtration system, that will be used to provide the biofiltration channel with a constant flow and provide a buffer to the systems storage capacity, and a downstream reservoir that just after the channel that will be used to store the clean water before it is distributed to the Garden's irrigation network. In order to ensure that our irrigation system is mainly gravity fed, the storage tanks have been located at points of high elevation in the Garden. In order to minimize disturbance to the existing plants and vegetation during construction, the tanks have been located in areas that are currently void of any of the Gardens collections and close to access for heavy equipment and materials. For this reasoning, the most feasible locations for the downstream and upstream storage reservoirs were determined to be in the north garden, adjacent to the existing Garden Pavillion and at Southeast corner of the SW Marine Drive and Stadium Road intersection respectively, as shown in Figure 2 on page 4.

3.2.1.1 Upstream Storage Reservoir

As was stated above, the upstream reservoir will be located upstream of the biofiltration channel. Due to the lack of precipitation in the summer months, especially August, the Garden relies heavily on potable water from the Greater Vancouver Water District (GVWD) to meet irrigation needs. For this reason, the storage capacity of the upstream reservoir was chosen based on the peak rainfall event in the month of August to be able to store the entire volume of water that will be captured by the UBC stormwater catchment infrastructure. Based on historical data, the peak event volume that will be captured by the stormwater system in the month of August will be approximately 810 m3. Based on this volume and the justification stated above, the upstream tank was designed to hold a capacity of 900m3 with dimensions of 30m L x 10 m W x 3m H (see Figures 5-7).

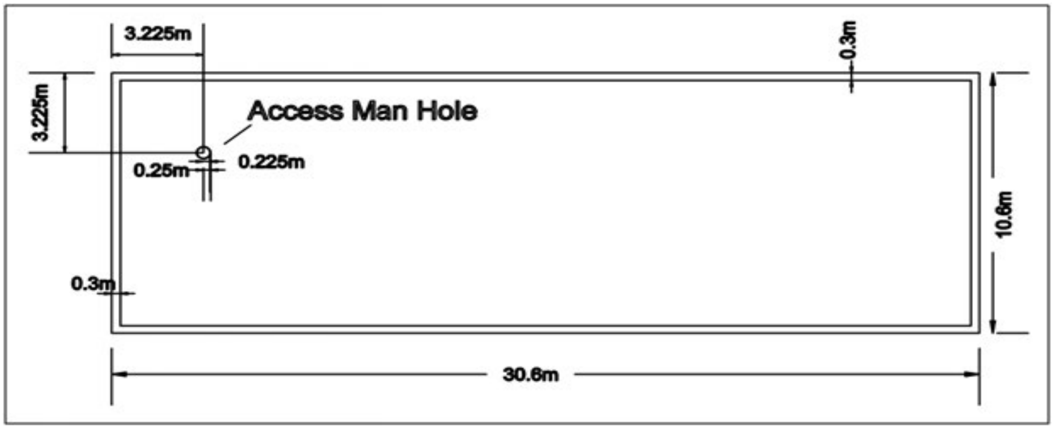


Figure 4- Plan View of Upstream Resevoir

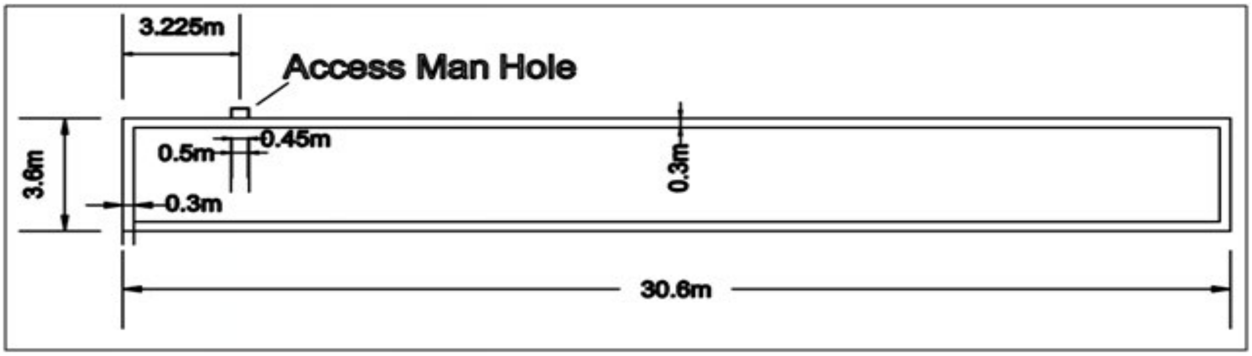


Figure 5 - Side View (Long End) of Upstream Resevoir

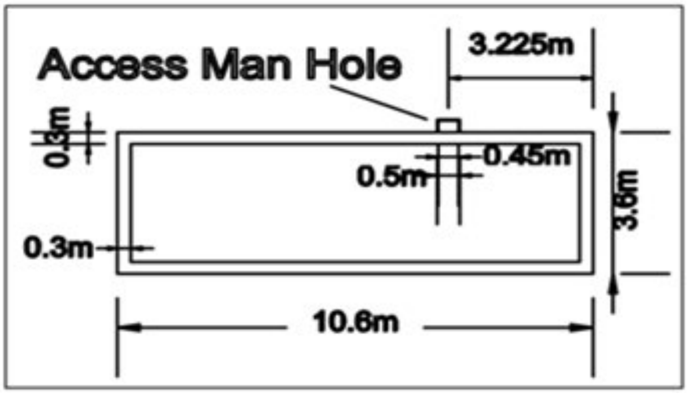


Figure 6- Side View (Short End)

3.2.1.2 Downstream Reservoir

The downstream storage reservoir will be located just after the biofiltration channel, to capture and store the filtered water. When choosing tank dimensions we aimed to minimize tap water usage, minimize cost of the storage tank, and minimize time until the project breaks even. In order to achieve this, material costs for four different volumes with varying dimensions were considered and the cheapest option was selected for each capacity. The capacities of tanks considered were: 2,000 m3, 3,000 m3, 4,000 m3, and 5,000 m3. These optimized dimensions were then compared with their corresponding estimates of the amount of potable water that could be saved annually, as shown in Table 3.

Table 3 – Dollar Savings For Proposed Tank Sizes

	Dollar Savings by (N) m3 tank				
	1000	**2000**	**3000**	**4000**	**5000**
Total Savings	$ 8,369	$ 13,097	$ 14,157	$ 15,217	$ 16,277
Materials Cost	$ 98,168	$ 172,392	$ 242,785	$ 311,742	$ 380,699
Tap Water Expenses	$ 11,002	$ 6,275	$ 5,215	$ 4,155	$ 3,095
Total Expenses	$ 109,170	$ 178,667	$ 248,001	$ 315,897	$ 383,794
Breakeven period	13	14	18	21	24
Ammount of Water Saved	8,428.00	12,953.00	13,953.00	14,953.00	17,113.00
Percentage Savings	43%	68%	73%	79%	84%
Cost per m3 of water saved	$ 12.95	$ 13.79	$ 17.77	$ 21.13	$ 22.43

This table shows that of the reservoir capacitates analyzed, a capacity of 1000m3 gives the lowest cost per m3 of water saved. However, it also shows that the tank size can be doubled to 2000m3 for a cost of only $0.71 (5.9%) more per m3 of water saved, and will allow for the Garden to use 25% less potable water throughout the year. For this reason, a tank with a capacity of 2000m3 was chosen with dimensions of 20m L x 20m W x 5m H. Its plan and elevation view are shown in Figure 7.

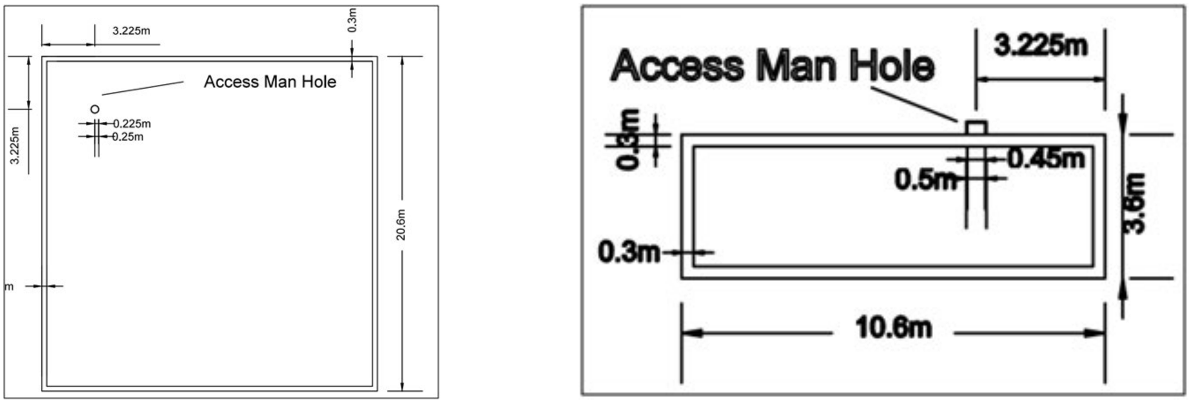


Figure 7 - *Plan and Elevation View of Downstream Reservoir*

It should be noted, that for the calculations in Table 3, construction, maintenance, and operational costs for the different sizes were assumed to be the same.

3.2.2 Material Selection

A number of different materials were considered for the storage reservoirs: stainless steel, concrete and AquaBlox D-Raintanks. Upon speaking with a sales person from AquaBlox, it was discovered that each unit can hold 0.1 m3 of water and costs roughly $60. Hence, for a tank size of 2000m3, these lightweight structural modules would cost approximately $1.2 million, which is not feasible. Next Blue Water Systems Vancouver Canada was contacted regarding stainless steel tanks. Again, upon speaking with their sales representative, it was determined that for underground storage of water some confinement has to be built around steel tanks for support. It was concluded that constructing a supportive shell around the stainless steel tank is almost identical to building a concrete storage tank, which again, is not feasible. Concrete did not seem very appealing to begin with, but after performing some research, and speaking with industry professionals and suppliers it was determined that with modern coating technologies, a concrete structure can perform as good as a stainless steel tank or Aquablox modules for the purpose of water storage. Cost estimates of concrete tanks are outlined in Section 6.

3.2.3 Design and Features

The two reservoirs will contain all necessary piping connections, to coincide with piping described in section 3.1. The tanks will also feature 450mm manholes and stainless steel ladders to allow for access for maintenance and repairs (CSA-B128.1-06). All interior surfaces will be sprayed with 3-layer coating of Tnemec product to ensure waterproofing and long-lasting durability of concrete. Each tank will have a concrete “lid” that is proposed to be supported by columns. Please note that structural design is not part of the scope, hence design of columns is to be performed by structural engineers.

3.2.4 Geotechnical Issues

In order to assess the geotechnical viability of the project, issues relating to the bearing capacity, settlements, liquefaction, and construction process of the structure were considered.

3.2.4.1 Settlements

As the weight of soil removed was more than the combined weight of concrete and water replacing it, it was conceived that settlement would not be a major issue. That being said, a more detailed site investigation will need to be undertaken to determine the exact composition of the underlying soils in order to determine if differential settlements could occur.

3.2.4.2 Liquefaction

The soil composition of the Point Grey Peninsula is glacial till underlain by sand. A glacier deposited this layer of glacial till overlying the sand during the past ice age, and for this reason, the sand underlying it can be assumed to be significantly dense. Because of this, the liquefaction potential of the area is considered to be very minor.

3.2.4.3 Bearing Capacity Calculations

The bearing capacity of a soil is the capacity of a soil to support the loads that are applied to the ground. The allowable bearing capacity of the soil underlying the storage facilities was calculated for the long-term condition using the formula for Mat Foundations found in Budhu's Foundation and Earth Retaining Structures and the Allowable Stress Design Method (Budhu, 2007). The required capacity of the soil was determined by calculating the pressure that the concrete and water would impose on the soil when the storage facility was at capacity. Calculations using the formula below, as well as any assumptions, can be seen in Appendix D.

$$q_u = \gamma D_f (N_q - 1) S_q D_q W_q + 0.5 \gamma B N_\gamma S_\gamma D_\gamma W_\gamma$$

The calculated allowable and required bearing capacities, as well as a factor of safety for both facilities can be seen in Table 4.

Table 4 – Bearing Capacities of Storage Tanks

Tank	Base Area (m^2)	Required Bearing Pressure (kPa)	Allowable Bearing Capacity (kPa)	Ratio of Allowable to Required Pressures
Upstream Storage	324.36	130.26	206.96	1.56
Downstream Storage	424.36	162.65	333.86	2.05

The soil parameters used in the above formula were taken from tables of common soil parameters found in Budhu's Foundations and Earth Retaining Structures (Budhu, 2007). The assumed parameters can be found in Table 5. Parametric analysis was carried out on the unit weight and friction angle of the soil to determine the critical values that would result in a factor of safety less than one. These values can be seen in Table 5 below.

Table 5 – Soil Parameters

	Dry Unit Weight (kN/m^3)	**Peak Friction Angle (°)**
Assumed	16	30
Critical	11.6	18.5

The wall thickness and slab depth were assumed to be 0.3m for all calculations pertaining to the bearing capacity. These numbers have no justification from a structural point of view, and should be verified by a third party structural engineer, as the structural design was outside of the scope of our contract. That being said, any slab depth greater than the specified 0.3m will not have a negative effect on the bearing capacity of the soil.

3.2.4.4 Issues During Construction

During construction of the reservoirs, depending on the construction method utilized and mitigation measures incorporated, some issues could arise. Some of the issues that should be planned for are an increase in lateral earth pressure on the reservoirs walls and deterioration of the tanks soil base.

Increase in Lateral Earth Pressure – This issue could arise when backfilling the completed structure. Because the reservoir walls will be constrained on both the top and bottom by the roof and floor slabs, the structure can be assumed to be at rest. A drainage system should be installed to minimize the amount of water pressure the wall feels from the backfill material. We recommend incorporating a layer of gravel between the wall and soil to help militate against these issues.

Deteriorating of soil base – Depending on the exact location of the ground water table, water flowing into the excavation might be an issue. G3 Water Consultant recommends constructing a ditch around the edges of the excavation and using a small submersible pump to catch and redirect any water that may flow into the excavation.

3.3 Bio filtration System

With the depletion of naturally occurring freshwater resources, innovative solutions related to water treatment and reuse have become a widespread practice. To comply with UBC's Water Action Plan, G3 Consultants will utilize a free water surface constructed wetland to treat the collected storm water. This solution will create an esthetically pleasing landmark, create a closed loop system, will make up the environmental component of our design and will organically remove harmful contaminates in the influent stormwater, improving water quality to an acceptable level.

3.3.1 Justification for Treatment with Biofiltration

Rainfall and snowmelt flows over impervious surfaces such as streets, parking lots and roof drains, is collected in municipal drainage systems and discharged into the closest waterway. However, this water usually contains debris, sediments, motor oil and grease, fertilizer and other contaminates, compromising water quality and the ecology of the receiving waterways. If no action is taken, the environmental, economic, and social impact of cleanup and rehabilitation of these waterways is extremely costly, thus emphasizing the importance of developing an Integrated Stormwater Management plan to mitigate these effects. A UBC project was completed to determine the contaminate levels of stormwater on campus. Table 6 outlines these findings at the Trail 7 Outfall as well as the corresponding water quality criteria as defined by British Columbia Water Quality Guidelines for aquatic life. The usage of the Trail 7 outfall was identified as aquatic life water use and is not to be used for the purpose of human consumption (Fowler, Phillips & Robinson, 2005, p.2). The Contaminated Sites Regulation, which is regulated by the Environmental Management Act (1997), defines aquatic life water use as "the use of water as habitat for any component of the freshwater or marine aquatic ecosystem, including phytoplankton, zooplankton, benthos, macrophytes and fish".

Table 6 - Heavy Metal Contaminates Found in the Trail 7 Stormwater Outfall

Metal	Concentration Range at Trail 7 Outfall (mg/L)	BC Water Quality Guideline (mg/L)
Aluminum	0.05 – 0.2[1]	None Proposed[2]
Arsenic	0.001 – 0.008[1]	0.0125[2]
Copper	0.125 – 0.2[1]	0.003[2]
Iron	0.25 – 0.45[1]	1[2]
Lead	0 – 0.0005[1]	0.14[2]
Mercury	0 – 0.0001[1]	None Proposed[2]
Zinc	0.01 – 0.02[1]	0.01[2]

As seen in Table 6, the primary heavy metal contaminates of concern are Copper and Zinc. The primary sources of these metals are due to runoff from vehicle exhaust, pesticides, fuel additives and construction sites (Fowler et al., 2005). Heavy metals are of particular interest in storm water management practices, not only due to their toxicity to marine life but also because of their inability to be chemically transformed or destroyed (Coulson, 2009, p.7). In the wetland treatment system, the metals are removed from influent water from adsorption onto the wetland bed and also from plant uptake (Onwumere, 2000, p.33).

Among a wide variety of treatment options, biofiltration was chosen as the best option. Constructed wetlands utilize aquatic plants in shallow channel to treat wastewater. Although the initial cost of a biofiltration system is rather high, it is considered to be a more sustainable method of stormwater treatment as it does not require additional chemicals and has low energy requirements due to its gravity fed nature.

3.3.2 Design of Constructed Wetlands

The design of the biofiltration channel provides a meandering shape with varying depths and pools to best match naturally occurring water features. As shown on Figure 8, the biofiltration channel will be located in the footprint of the current Cattail Pond. This option would minimize dredging and excavation during construction. Furthermore, the channels meandering shape will attempt to best mimic the aesthetics of the current Cattail Pond.

Figure 8 - Conceptual Layout of Wetland

3.3.2.1 Design Criteria

In order to provide efficient and effective contaminate removal, a wetland treatment system must contain the following components: a forebay, high and low marshes, an open pond area, a micropond, and semi-wet area.

First of all, a forebay is a deeper (>1m) pond area located at the inlet structure. The purpose of a forebay is to slow the velocity of the incoming water and also provide initial sedimentation of coarser sediments ("Standard for Constructed Stormwater Wetlands", 2009). The forebay is followed by marsh areas, which have shallower water depths to support emergent vegetation. These areas are fully vegetated to maximize surface area contact between the plants and influent water. There is an open-water pond area between marsh components. These areas have larger depths (>1m) and provide some particulate settling but their primary purpose is for the re-aeration of the water to support the aerobic process in water treatment (EPA, 1999, p.83). Next, microponds also have increased pond depths but have a smaller surface area. They are located immediately upstream of an outlet structure to protect the outlet from clogging but also to slow the velocity of water exiting the system, thus avoiding the re-suspension of settled particles. Finally, Semi-wet areas are located on the banks of the of the wetland channel. The intention of these areas is to support the inundation of water levels during storm events ("Standard for Constructed Stormwater Wetlands", 2004). These gradually sloped areas also allow for a natural continuation of emergent plan species and reduce erosive effects of the water flow through the channel (Jones, 1995). Using a series of component parts in the wetland system allows for different physical, biological and chemical processes to take place to remove contaminates in a sequential fashion (EPA, 1999).

3.3.2.2 Design Description

The components of the wetland will coincide with the design criteria described above. To determine the dimensioning, G3 Consultants followed the Best Management Practices Guide for Stormwater Guide, provided by Metro Vancouver. The profile of the wetland is shown in Figure 9.

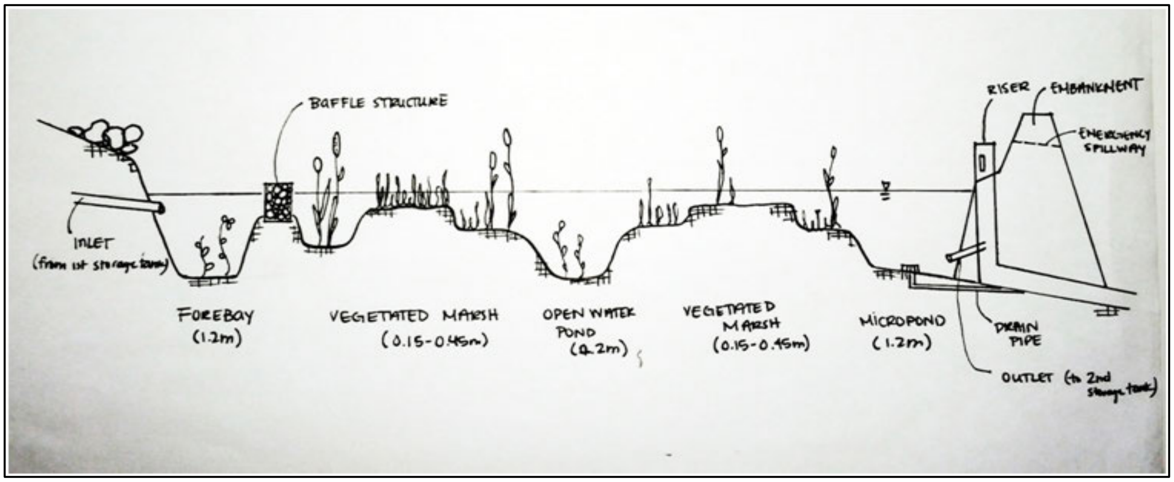


Figure 9 - Profile of Wetland

The channel will be approximately 10m wide and 50m in length to achieve a length to width ratio of 5:1. The dimensions, volume and surface areas of each component are outlined in Table 7. Baffle structures will be located at the forebay to prevent short-circuiting (high velocity flow) of the system. The bed of the wetland will be comprised of silty-clays that can support the vegetation and also be lined to prevent seepage into the porous media below. The slope of the pond will be approximately 1.0%. The design flow rate of the system is 3000 m^3/month, which corresponds to the peak demand in September.

Table 7 - Design Specifications for the Wetland Treatment Channel

Component	Depth (m)	Surface Area (m^2)	Volume (m^3)
Forebay	1.2	50	60
High Marsh	0.15	200	30
Low Marsh	0.45	170	76.5
Open Water Pond	1	30	36
Micropond	1.2	50	60

3.3.2.3 Contaminate Removal with Wetland Vegetation

Stoke's Law was used to calculate the settling velocity of very fine sand particles. Using the design depth of the wetland and the settling velocity the time needed for fine particles to settle. This was then compared to the hydraulic retention time of the wetland. Since the time taken to settle is less than the hydraulic retention time, the wetland is of adequate design such that the flow is slow enough to retain the influent suspended solids. Details of these calculations are provided in Appendix B.

In order to remove the identified contaminates a variety of submerged plants in deep areas and emergent in shallower depths are required. (EPA, 1999, p.25). Submerged species provide structure for microbial attachment and also provide oxygen for the aerobic processes (EPA, 1999, p.25). Emergent species provide structure to induce sedimentation and add aesthetic value to the wetland. Table 8 provides vegetation recommendations for the wetland.

Table 8- *Plant Species for Wetland*

Common Name of Plant	Type	Location
Cattail	Emergent	High/Low Marshes and Semi-Wet Areas
Bulrush		
Common Reed		
Water Sedge		
Pondweed	Submerged	Forebay, Open Water Pond and Micropond
Duckweed		
Lilly		

4.0 Proposed Implementation Plan for the Design

To implement the entire system, every component needs to be carefully considered in terms of constructability. Each component should be installed in such a way that minimizes construction cost and schedule. As stated in previous sections, the following main elements need to be constructed:

Table 9- *Construction Elements*

ITEM	DESCRIPTION	NOTE
1	900mm Concrete Pipe	Inflow
2	900mm Concrete Pipe	Overflow
3	50mm HDPE Pipe	Outflow
4	100mm Cast Iron Pipe	Irrigation
5	100mm HDPE Pipe	Recycle
6	200mm HDPE Pipe	Overflow
7	900m^3 Storage Tank	Upstream
8	2000m^3 Storage Tank	Downstream
9	Pump	Upstream To Wetland
10	Pump	Downstream To Wetland
11	Bio-Filtration Wetland	

The following sections will briefly describe the steps that need to be undertaken to install the pipe system, storage system, and the wetland bio-filtration system. Please note that the following implementation procedure is subject to change per general contractor's discretion. A detailed construction schedule and cost analysis is beyond the scope of G3 Consultants, and is to be prepared by a general contractor.

4.1 Collection/Distribution Pipe System

To install the overall pipe system the G3 consulting has identified the following steps:

1. Layout the designed pipeline system
2. Trench the pipeline layout
3. Connect L3D-NW175D with 900mm concrete tee/elbow connection
4. Install remaining pipelines/pumps
5. Backfill as installation is completed

A Gantt chart depicting the construction schedule for the collection and distribution pipe system is provided on the next page.

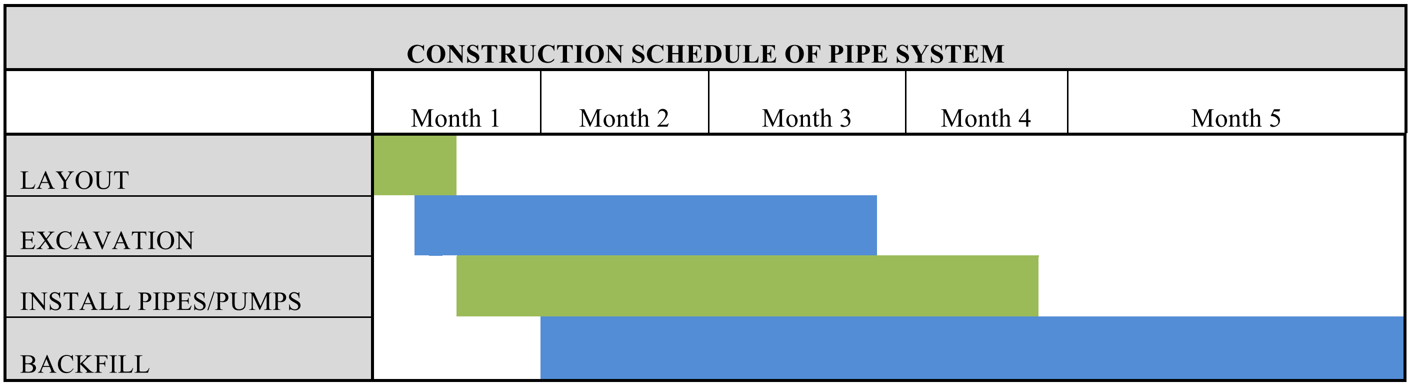


Figure 10 - Gantt Chart for the Pipe System

4.2 Storage Tank System

Both the upstream and downstream storage reservoirs will be constructed in the same way. To construct the storage reservoirs, the following procedure is to be undertaken. The steps will include:

1. Excavate for storage tank construction
2. Install rebar
3. Install formwork
4. Pour concrete using pump system
5. Remove formwork
6. Install water proof membranes & Install miscellaneous metals
7. Backfill

The figure below depicts the construction schedule of storage system.

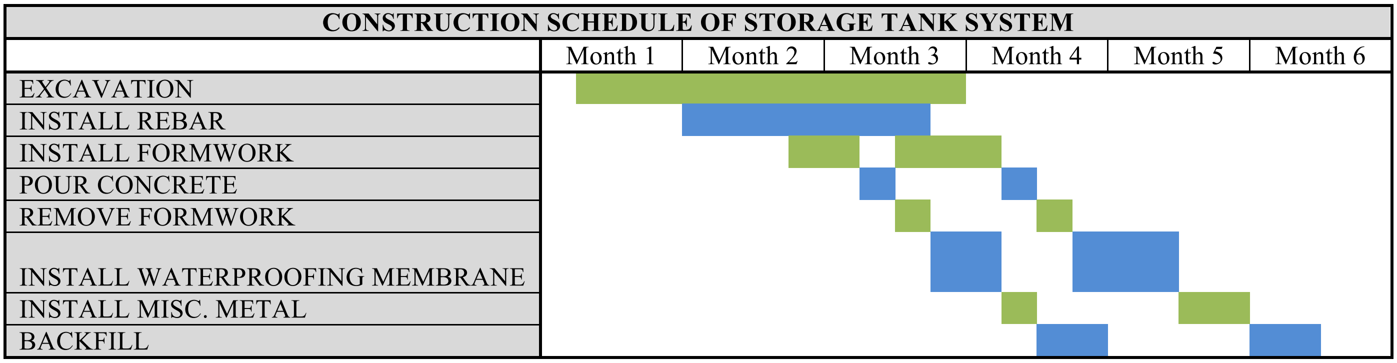


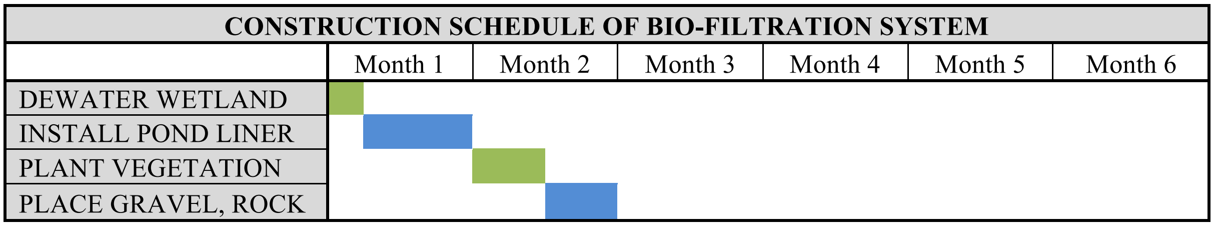
Figure 11 - Construction Schedule of the Storage System

4.3 Bio-Filtration Wetland System

To utilize the current wetland as a bio-filtration system, the following procedure needs to be undertaken. Dewatering of wetland is critical and it must happen prior to upstream storage tank excavation to eliminate the disturbance by water. The steps are including but not limited to:

1. Dewater wetland
2. Install pond liner
3. Plant vegetation
4. Place gravel, rock, soil, etc.

The figure below depicts the construction schedule of bio-filtration wetland system. As mentioned previously, the only critical work is dewatering and the remaining work can float between month 2 and month 6.



CONSTRUCTION SCHEDULE OF BIO-FILTRATION SYSTEM						
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
DEWATER WETLAND	🟩					
INSTALL POND LINER	🟦					
PLANT VEGETATION		🟩				
PLACE GRAVEL, ROCK		🟦				

Figure 12 - Construction Schedule of the Biofiltration System

4.4 The Overall Construction Schedule

Based on the schedules that were determined for construction of each system, we have combined the three systems as a whole and derived a reasonable overall construction schedule. The figure below shows the combined schedule and is relatively conservative. The entire construction is expected to be completed in 7 months. The schedule is subject to change per general contractor's discretion.

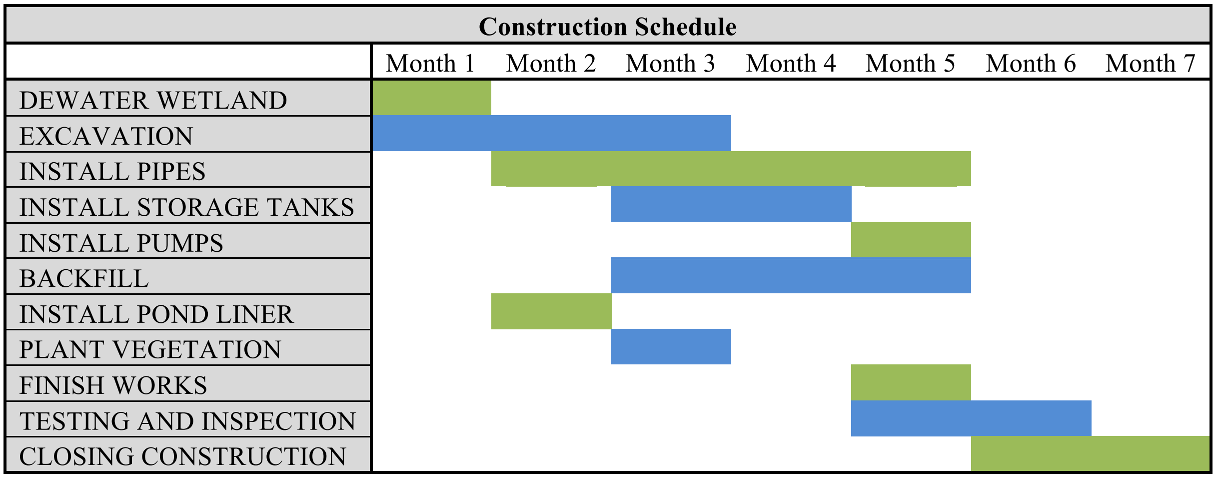


Figure 13 - Combined Construction Schedule

4.5 Required Resources

In the construction schedules shown above, G3 Consultants have assumed the utilization of at least two earthwork crews, one carpenter crew, and two rebar crews. Table 10 below shows the required resources to achieve the schedules in the previous sections.

Table 10- Resource Allocation

CREW ASSIGNMENT				
CREW 1	**CREW 2**	**CREW 3**	**CREW 4**	**CREW 5**
Carpenter 1	Crane Operator	Crane Operator	Crane Operator	Iron Worker 1
Carpenter 2	Excavator Operator	Excavator Operator	Iron Worker 1	Iron Worker 2
Carpenter 3	Skilled Labour 1	Skilled Labour 1	Iron Worker 2	Iron Worker 3
	Skilled Labour 2	Skilled Labour 2	Iron Worker 3	
	Skilled Labour 3	Skilled Labour 3		
EQUIPMENT ASSIGNMENT				
	50T Crane	50T Crane	50T Crane	
	Mini- Excavator	Mini- Excavator		

5.0 Cost Analysis

Please note that construction and operation costs were not included as it is out of our work scope. However, G3 Consultant's rough estimate of construction cost is 1.5 times the material costs or approximately $400,000. Table 11lists the unit cost of each type of pipe or material used in the collection, storage and distribution systems.

Table 11: Material Cost

Downstream Tank 2000 m^3				
Material	Unit Cost	Quantity		Sub Total
Concrete	$ 236	$ 360	m3	$ 84,960
Rebar	$ 500	$ 57	tonn	$ 28,260
Coating 3 layers	$ 49	$ 1,200	m2	$ 59,172
			Unit Cost = $	172,392
Upstream Tank 900 m^3				
Material	Unit Cost	Quantity		Sub Total
Concrete	$ 236	$ 252	m3	$ 59,472
Rebar	$ 500	$ 40	tonn	$ 19,782
Coating 3 layers	$ 49	$ 840	m2	$ 41,420
			Unit Cost = $	120,674
Pipe and Pump				
Material	Unit Cost	Diameter	Length (m)	Sub Total
Concrete	$ 240.00	900mm	85	$ 20,400
Cast Iron	$ 61.00	100mm	20	$ 1,220
HDPE	$ 6.00	50mm	65	$ 390
HDPE	$ 11.00	100mm	100	$ 1,100
HDPE	$ 35.00	200mm	20	$ 700
Pump	$ 350.00	-	2	$ 700
			Unit Cost = $	24,510
Wetlands Bio-filter				
Installation				$ 28,595
Total Material Cost				**$ 346,171**

6.0 Conclusion

With an increasing demand for potable water in Vancouver, it is necessary to implement designs which utilize the rainwater supplied by the cities climate. By creating a closed loop system, we hope to decrease potable water usage for irrigation and improve to quality of storm water leaving campus. The decrease in potable water consumption will also decrease the annual irrigation costs and will improve the image of the Botanical Gardens by promoting sustainable practices.

The main components of the design we are proposing include:

1) Stormwater Collection Pipes
2) Stormwater Storage Tank
3) Biofiltration Channel
4) Clean Water Storage Tank
5) Clean Water Distribution Pipes

We believe this design will provide the Botanical Gardens with an effective way to meet their irrigation needs and will improve the environmental efforts outlined by both the Botanical Gardens and UBC Campus.

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APPENDIX A: Botanical Gardens Cumulative Consumption

Garden Consumption vs. Needs

Date	Botanical Gardens Cumulative Consumption (m^3)	Monthly Needs (m^3)
21-Apr-11	100	100
20-May-11	550	450
21-Jun-11	3003	2453
21-Jul-11	5840	2837
22-Aug-11	9180	3340
16-Sep-11	12270	3090
24-Oct-11	13785	1515
21-Nov-11	14005	220
21-Dec-11	14005	0
24-Jan-12	14005	0
22-Feb-12	14005	0
21-Mar-12	14010	5
20-Apr-12	15150	1140
20-May-12	16537	1387
20-Jul-12	21640	5103
21-Aug-12	25720	4080
14-Sep-12	28690	2970
21-Nov-12	32045	3355
22-May-13	35282	3237
23-Jul-13	41420	6138
20-Sep-13	46480	5060
22-Oct-13	46480	0
21-Nov-13	46480	0

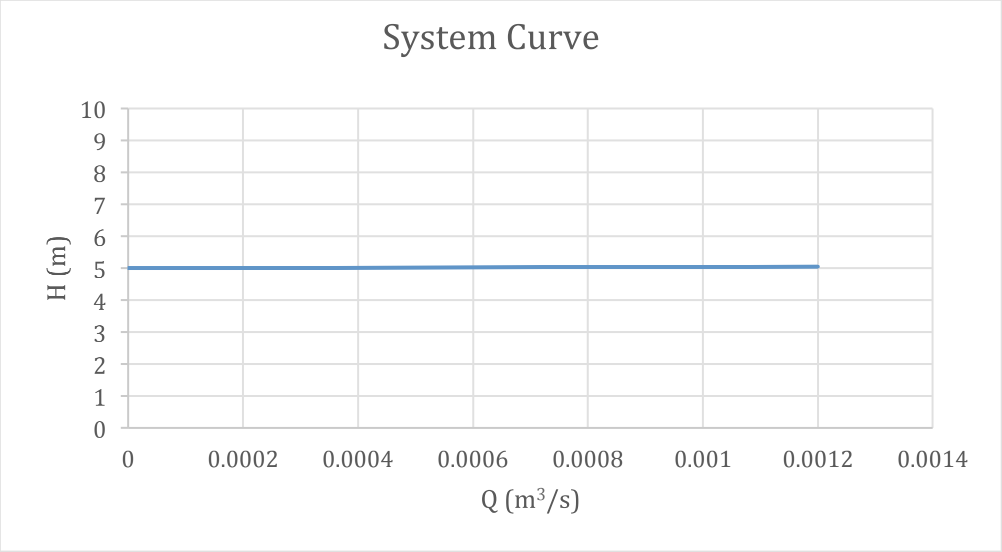
Calculation Parameters using SCS Curve Number Method

Month	Moisture Condition	CN	Adjusted CN	Total Rainfall (mm)	S	I_a	Direct Runoff (mm)	Area (m^2)	Total Monthly Volume (m^3)	Garden Demand (m^3)	Minimum Potential Remaining Demand (m^3)	Potential Water Savings (m^3)
January	Wet	85	92.9	165.3	19.5	3.9	144.0	170000	24482	0	0	0
February	Wet	85	92.9	137.9	19.5	3.9	117.0	170000	19888	0	0	0
March	Wet	85	92.9	118.9	19.5	3.9	98.3	170000	16717	5	0	5
April	Wet	85	92.9	81.9	19.5	3.9	62.4	170000	10610	1140	0	1140
May	Normal	85	85.0	65.0	44.8	9.0	31.1	170000	5292	1387	0	1387
June	Normal	85	85.0	47.9	44.8	9.0	18.1	170000	3077	2453	0	2453
July	Dry	85	70.4	39.6	106.7	21.3	2.7	170000	453	5103	4650	453
August	Dry	85	70.4	46.4	106.7	21.3	4.8	170000	810	4080	3270	810
September	Normal	85	85.0	68.0	44.8	9.0	33.6	170000	5705	2970	0	2970
October	Wet	85	92.9	132.7	19.5	3.9	111.9	170000	19019	1515	0	1515
November	Wet	85	92.9	188.9	19.5	3.9	167.4	170000	28453	220	0	220
December	Wet	85	92.9	196.2	19.5	3.9	174.6	170000	29683	0	0	0

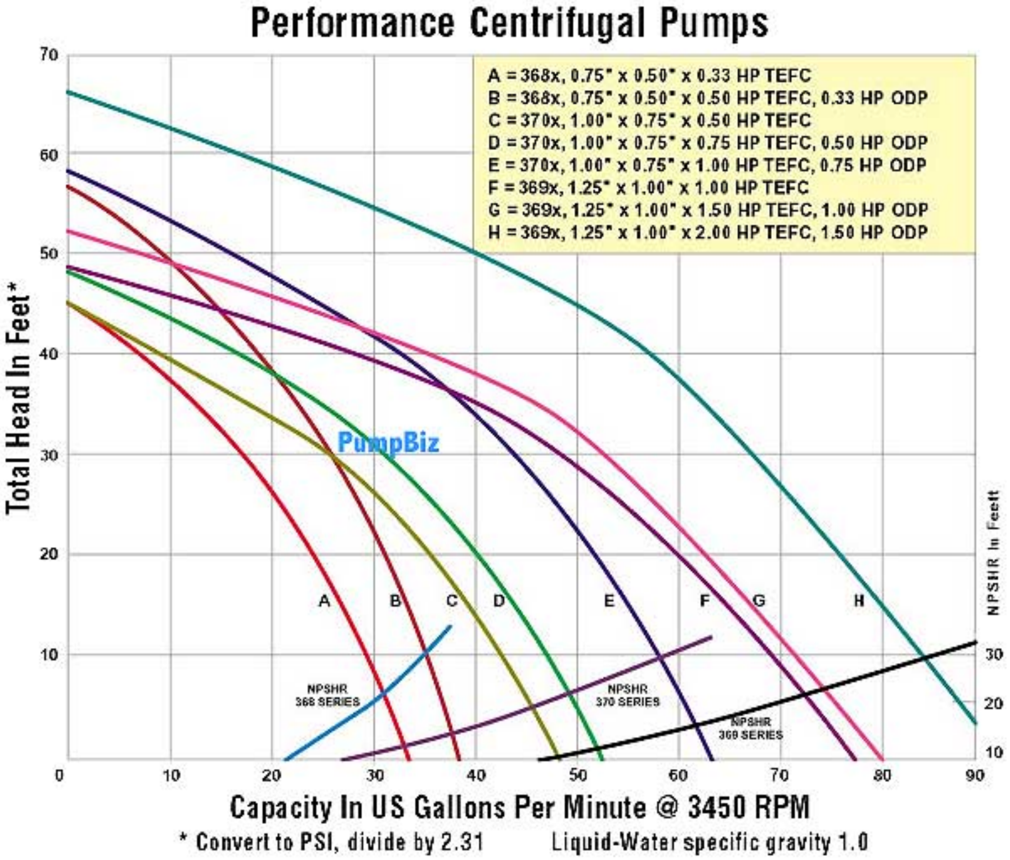
	Pipe From First Tank to Bio-filter	Pipe From Second Tank Back to Bio-filter
Q_{max} (L/min)	70	7
L (m)	65	100
D (mm)	50	50
H (m)	3>H>5	3>H>8
h_L at Q_{max} (m)	0.05	
h_L at Q_{max} (m)	0.05	0.01

APPENDIX B: Pump Calculation

System Curve for Pipe to Biofilter



Centrifugal Pump Curve



APPENDIX C: Wetland Treatment Channel Calculations

Design Criteria (BMP S8, n.d.)

- Forebay is at least 10% od total permanent pool volume
- 25% of volume should have a depth > 1.2m
- 35% of total surface area <150mm
- 65% of total surface area <450mm
- Length to width ratio should be no greater than 5:1

Width: 10m Length: 50m Total Surface Area = L*w = 500m2

Estimate lengths for each component:

Component	Depth (m)	Length (m)	Surface area (m^2)	Surface area (%)	Volume (m^3)	Volume (%)
Forebay	1,2	5	50	10	60	22.9
High Marsh	0.15	20	200	40	30	11.4
Low Marsh	0.45	17	170	34	76.5	29.1
Open Pond	1.2	3	30	6	36	13.7
Micropond	1.2	5	50	10	60	22.9

Dimensions satisfy design criteria

Flow Rate in Channel

- Design Flow: Q = 3000m3/mo = 0.00116m3/s
- Average Depth Over Length = 1.2*(13/50)+0.15*(20/50)+0.45(17/50) = 0.525 m
- Porosity, ε : Since the channel contains a large variety of vegetation, an assumed porosity is taken as 0.80 (EPA, 1999, p.88)
- Velocity:

$$v = \frac{Q}{A\varepsilon} = \frac{Q}{wd\varepsilon} = \frac{0.00116}{0.525 * 10 * 0.80} = \mathbf{2.8\times10^{-4} m/s}$$

Hydraulic Retention Time

$$HRT = \frac{L}{v} = \frac{50}{2.8\times10^{-4}} = \mathbf{2.1\ days}$$

Settling Velocity

- Use Stoke's Law to determine terminal settling velocity of particles, this assumes that the force due to gravity of the suspended particle is equal to the sum of the buoyancy force and the drag force.
- Assumed a fine sand grain size of dp = 5 μm as Zinc and Copper, the contaminates of concern have been found within this range in stormwater runoff (umass)
- Assume a density of sand for solid particles: ρs = 2.65 g/cm3, this is frequently used in other storm water runoff analysis (Karamalegos et al., 2005)
- Temperature was assumed to be 12° C at the Trail 7 outfall (Fowler et al., 2005, p.11,) corresponding to a density: ρl = 999.58kg/m3 and a dynamic viscosity: μ = 0.001236 kg/ms
- Assume an initial Reynolds number and complete iterative process to determine settling velocity

Using Stoke's Law to Calculate Settling Velocity:

Assume Re= $7.0*10^{-5}$ (Re<1):

$$\boldsymbol{v_s = \frac{g(\rho_s - \rho_l)d_p^2}{18\mu}}$$

$$V_s = \frac{(9.81)(2650 - 999.58)(5\times10^{-6})^2}{18(0.001236)} = \mathbf{1.8\times10^{-5}\ m/s}$$

Verify Reynolds Number:

$$\boldsymbol{Re = \frac{\rho_l d_p v_s}{\mu}}$$

$$\boldsymbol{Re} = \frac{(999.58)(5\times10^{-6})(1.8\times10^{-5})}{(0.001236)} = \mathbf{7.3\times10^{-5}}$$

4% error, estimated Reynolds number is reasonable

Settling Time:

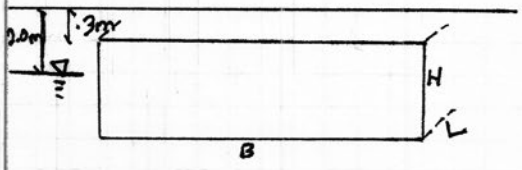
Use the time it would take to settle 0.525 m (average depth)

$$\boldsymbol{t} = \frac{d}{v_s} = \frac{0.525}{(1.8\times10^{-5})} = \mathbf{8\ hours}$$

Since the settling time is less than the hydraulic retention time, assume efficient contaminate removal.

APPENDIX D: Bearing Capacity Calculations

Bearing Capacity Calculations.



General properties taken from Budr.

$B = 10\text{m}$
$L = 30\text{m}$
$H = 3\text{m}$

$\gamma_{sat} = 20\text{kN/m}^3$
$\gamma_{dry} = 18\text{kN/m}^3$
$\gamma' = 10.2\text{kN/m}^3$

$\phi'_p = 30°$
depth to w.t. = 2.0m
Conc thickness = 0.3m

$D_f = 0.3\text{m} + 3.0\text{m} + 2(.3\text{m}) = 3.9\text{m}$

$$q_u = (\gamma_{sat} \cdot z + \gamma'(D_f - z))(N_q - 1) s_q d_q w_q + 0.5\, \gamma_{sat} B N_\gamma s_\gamma d_\gamma w_\gamma$$

$N_q = e^{\pi \tan(\phi'_p)} \tan^2(45 + \phi'_p/2) = \underline{18.40}$

$s_q = 1 + B/L \tan(\phi'_p) = \underline{1.19}$

$d_q = 1 + 2\tan(\phi'_p)(1 - \sin(\phi'_p))^2 \cdot D_f/B = \underline{1.11}$

$w_q = z/D_f + \gamma'/\gamma_{sat}(1 - z/D_f) = \underline{0.76}$

$N_\gamma = 0.1054\, e^{9.6(\text{rad}(\phi'_p))} = \underline{16.06}$

$s_\gamma = 1 - .4(B/L) = \underline{0.87}$

$d_\gamma = \underline{1}$

$w_\gamma = \gamma'/\gamma_{sat} = \underline{0.51}$

$$q_u = (20 \cdot 2 + 10.2(1.9))(18.4 - 1)(1.19)(1.11)(0.76) + 0.5(20)(10)(16.06)(0.87)(1)(0.51)$$

$\underline{q_u = 1405.71 \text{ KPa}}$.

Using ASD: $q_a = \dfrac{q_u}{FS}$

*Recommended FS for bearing capacity of a foundation is 3. (NBC)

$$q_a = \frac{1405.71}{3} = \underline{468.57 \text{KPa}}$$

Allowable Bearing Capacity: $\underline{468.57 \text{ KPa}}$.

Required Bearing Capacity: $\underline{46.72 \text{ KPa}}$.

$\boxed{q_a > q_r}$ ✓✓