UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC Botanical Garden Stormwater Management Project

Jacqueline Lam, Kelvin Chand, Lingfeng (Patti) Shen, Meraj Mamorafshard, Wen Chien Hsieh, Wilson Lee and Yui-Chung Wong

University of British Columbia

CIVL 498 K

May 8, 2012

Executive Summary for the Preliminary Study

The SEEDS Preliminary Study of the UBC Botanical Garden: Stormwater Management Project, includes a preliminary conceptual design, data analysis, and feasibility study. This request for a preliminary study was forwarded to the student members of CIVL 498 K by UBC SEEDS and the Department of Civil Engineering. This preliminary study, and the four reports of which it is comprised of, encompasses the final deliverables for CIVL 498 K.

The process in which the preliminary study was conducted is as follows; at the commencement of the project the available data was compiled, then the data required was outlined, this was followed by the production of a conceptual design based on several assumptions, which enabled a preliminary cost estimation to be undertaken, this was complemented by research, and finally a feasibility study was performed via an economic analysis for the payback period and the project life net savings.

Report A, “Established Information and Data Acquisition” explores alternatives to solving stormwater management issues in the UBC Botanical Gardens. Options considered included storage tank system with disinfection, water retention system, and under-pathway collection system. Five streams running through the Botanical Gardens are recognized as a potential water resource, two of which flow year-round. The sampled stream just north of the Botanical Gardens indicated a potential 9.5 million liters water supply, which is 68% of the Gardens’ total dry season water consumption. As a result, it is recommended that stormwater management practices be implemented, and flow measuring devices should be installed to determine potential water supply of the streams.

Report B, “Under-pathway Storage Tanks and Stormwater Management” investigates into the alternative of underpathway storage tanks was undertaken. Using a design with a width of 2m and a depth of 1m the storage matrix explored, AquaBlox, required a design of 5 blocks width, 2 blocks depth, and 8030 blocks length; totalling 80,300 blocks throughout the pathways. The matrix blocks were $60 each, yielding a first cost of $4,818,000 and the payback period was found to be 487 years.

Report C, “Sustainable Design for Irrigation and Stormwater Management in the UBC Botanical Garden”, includes the following. The conceptual design consists of placing dams at the ends of the two streams in the Garden and parking lot, which exhibit summer flows. The dams are then connected to an aesthetically and architecturally consistent housed water storage tank (sited southwest of the parking lot), by using a pumping and piping system. A water storage tank of 5,000 m^3 (as the initial reservoir) will provide a 100 % reduction of municipal potable water consumption. The water storage tank will have a circular footprint of approximately 32 m in diameter. The implementation of this stormwater management regime reduces the impact of a peak design flow (110 L/s) rain event by approximately 32 %. The final results of the feasibility study yielded a discounted payback period of 29 years. Furthermore, it yielded a potential project life net savings of $2,200,000.

Report D, ”Emergency Water Supply Plan”, includes the following. The objective of this report is to propose the emergency water supply plan as requested by Aleksander Paderewski from UBC. In response to that, an emergency water supply system is designed with two major components: the disinfection facility and the distribution network. The stormwater quality analysis report from CARO provides the plan with a set of background information that suggests the main disinfection goal in order to meet the Metro Vancouver Guideline for drinking water standard. The emergency storage is originally designed to be 36m^3 with a scenario of 4,000 on-campus residents, 2 liters of supply per person per day and 3 days of supply period. This design is later modified since the irrigation storage tank has an extra 300m^3 to accommodate the emergency supply with a flexibility to reach a 24-hour supply with an extra 140m^3.

REPORT A

Established Information and Data Acquisition

Executive Summary

Our group has explored some alternatives for solving the issue of stormwater management and water retention in the UBC Botanical Gardens. These options can generally be categorized into three options, namely: a water storage and treatment tank, a supplementary water retention system, and an under-pathway water collection system. However, the current level of information, gathered from various sources such as the Utilities Department and UBC Soil Science, is currently insufficient to determine a true base flow. A base flow was estimated for the stream by Old Marine Drive, but we found that no other data was available to the group in any form. A record of flow data which is required to predict future events will need to be developed. Other information such as the soil characteristics and rainfall data will be needed. It would also be helpful to have a longer water consumption record from the Garden meter. However, we were able to obtain an opinion from Douglas Justice on the feasibility of the other two alternatives for water retention. The water retention system and the ornamental pond would need to be reviewed by Garden senior management but the initial assessment is that it would be approved. Recommendations were also made regarding a future course of action to deal with the deficit of information, and these include recording occurrences of drought to see if any patterns can be found, enlarging stream channels to reduce the chance of flood, establishing response curves. In addition to these, implementing measures to reduce runoffs, such as swales, rain gardens, detention basins and rainwater collection would be greatly useful in decreasing the impact and frequency of floods.

Contents

List of Figures and Tables

Overview:

The goal of the UBC Stormwater Management and Retention SEEDS Project, as defined in the Project Outline, is to:

A. Propose implementable strategies for stormwater management in the UBC Botanical Gardens in order to:
   i. Reduce erosion and periodic flooding within the Garden
   ii. Reduce erosion of cliffs and subsequent damage to the Fraser River estuary immediately to the west of the Garden
B. Propose implementable methods for retaining seasonal runoff for irrigation use and reducing the use of potable water.

These goals aim to lower maintenance and repair costs for the Garden with respect to the periodic flooding and erosion of the stream banks and the cliffs, contribute to sustainability in a practical way by reducing the consumption of potable water for irrigation, improve the habitat of the foreshore and demonstrate how a working water sustainability project might operate. Our group was tasked with coming up with different solutions to the two above objectives, and several possibilities were also inquired about by staff members such as Brenda Sawada, Patrick Lewis and Dr Atwater. For the purposes of the SEEDS Botanical Gardens project, our group was asked to consider these ideas with regards to finding a solution to the objectives as mentioned in the Project Outline.

Through discussion with staff from the Botanical Gardens and UBC Utilities, the UBC SEEDS Program and Dr Atwater we reached a consensus in narrowing down our possible ideas to three options. These alternatives will be considered for the retention and storage of seasonal stormwater runoff in order to irrigate the Garden during periods of low rainfall, and thereby also reducing the dependency of the Garden on using potable water for this same purpose. The three options are outlined here as follows:

1. The installation of a storage and treatment tank - capturing runoff for storage would provide a convenient source of irrigation when the amount of rainfall needed is reduced in the summer months. This was mainly advocated by Aleks Paderewski and Jenny Liu of the Utilities Department, and it is also thought that this water could be used for drinking if treated. This storage tank will involve pumping and diverting processes, which will be detailed in another section of this report, Section C. This requires the flow data for the small creek running alongside Old Marine Drive, and whether it is safe to drink will also need to be determined. The water treatment process that is required will be researched in addition to this option, and will be expanded on separately in Section D.

2. Installing a water retention system - the sloped bank is situated towards the south of the Garden and mainly proposed by Dr Atwater. This system could possibly be implemented in the form of storage tanks at the location of the sloped bank. It is thought that water from the creeks running into the Garden from the north and east sides could be diverted into such tanks and would serve the same purpose as Option 1. The possibility of flooding the ornamental pond for possible storage of water further up the slope has also been brought up. These will be detailed in Section A. The flows for the various creeks will be needed for a feasibility study.

3. Installing storage tanks located under the Garden pathways - Brenda has suggested we research more into this, as Patrick Lewis would like to know if this idea is possible in the scope of this project. Information such as soil permeability, soil stability, data for the catchment and groundwater are required from sources such as UBC Soil Science in order to determine if such a proposal is feasible. This will be expanded upon in Section B of this report.

In order to find out how to proceed, it was necessary to establish the current level of information, and this in turn would allow the group to determine the knowledge deficit, especially with respect to any data that was already collected or being currently collected. Part of that process was to gather different sources of information through e-mail, phone calls, meetings in-person and put it all together, to find out what needs to be done and what is possible in the immediate future. We needed to determine what is currently known, so that a recommendation can be made on how the UBC Botanical Gardens should proceed with regard to these issues. This information could come in different forms from various sources such as anecdotal evidence, comments and opinions from experts, information in the form of data records from the Campus Sustainability Department, maps from the UBC Utilities Department and rainfall records from UBC Soil Science, as well as other sources of data that could be used as comparables to the streams in the Garden, such as FlowWorks and the City of Vancouver.

Established Information:

During the course of our study, we were able to obtain some opinions regarding the activity of the streams that flow in the Garden. As described at the beginning of the project, the Garden currently uses potable water for the irrigation of their plants – that is, the water is safe to drink. Part of the UBC SEEDS Program's push for more sustainability is to reduce this amount of water used by using other water sources instead. Our group has been looking into replacing this with stormwater runoff, as Aleks Paderewski suggested that stormwater runoff – particularly from the small creek by Old Marine Dr. – could be used, and this would come from the streams running on Garden territory. If water is extracted from these streams, the water would have to be subjected to a minimum level of treatment for irrigation, and a greater level of treatment if the water is to be consumed for drinking as well.

According to Doug Justice, all the streams within the Botanical Gardens have good flow in the winter season. Only the two biggest streams continue to have any flow at all in summer, while the rest of them dry up – these cannot be relied upon and can be ruled out as a potential water supply to any tanks in summertime. The stream with the largest flow runs between Descaisne Trail and Wharton Trail has, while the creek flowing from the top of the parking lot (by Old Marine Dr.) is the 2nd largest, and the 3rd is the stream that crosses Meyer Glade.

Figure 1 below shows the largest stream, indicated by the right-most white line, while the second largest stream runs along the bottom grey edge of the map. The right-most white line passing through Meyer Glade in Figure 2 below represents the third largest stream in the Garden.

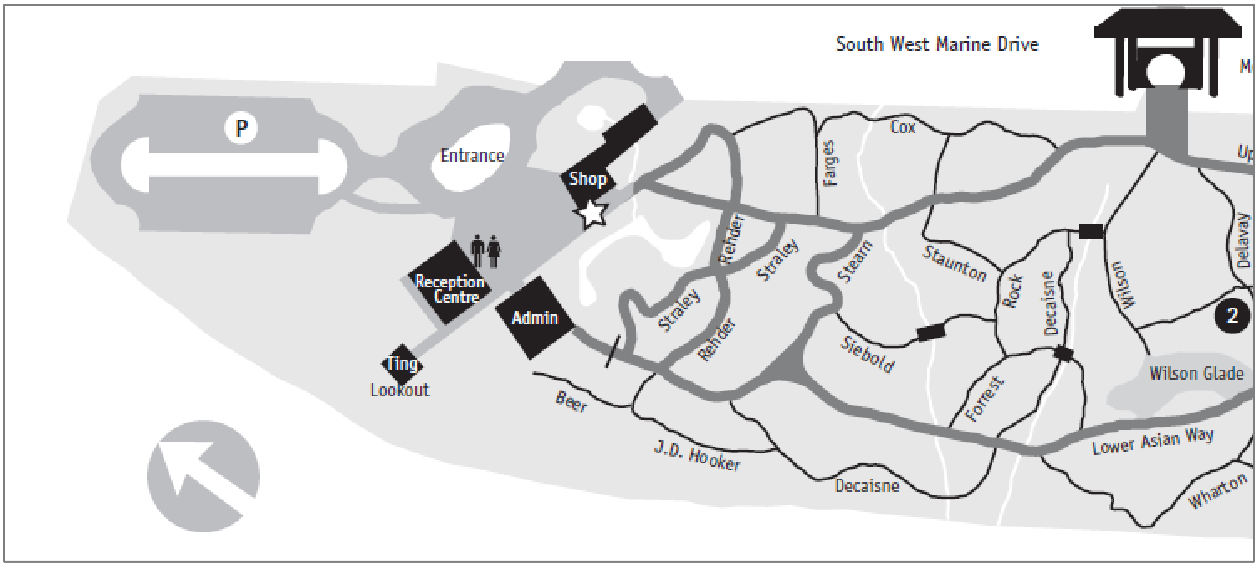


Figure 1: Map of Botanical Gardens, North.

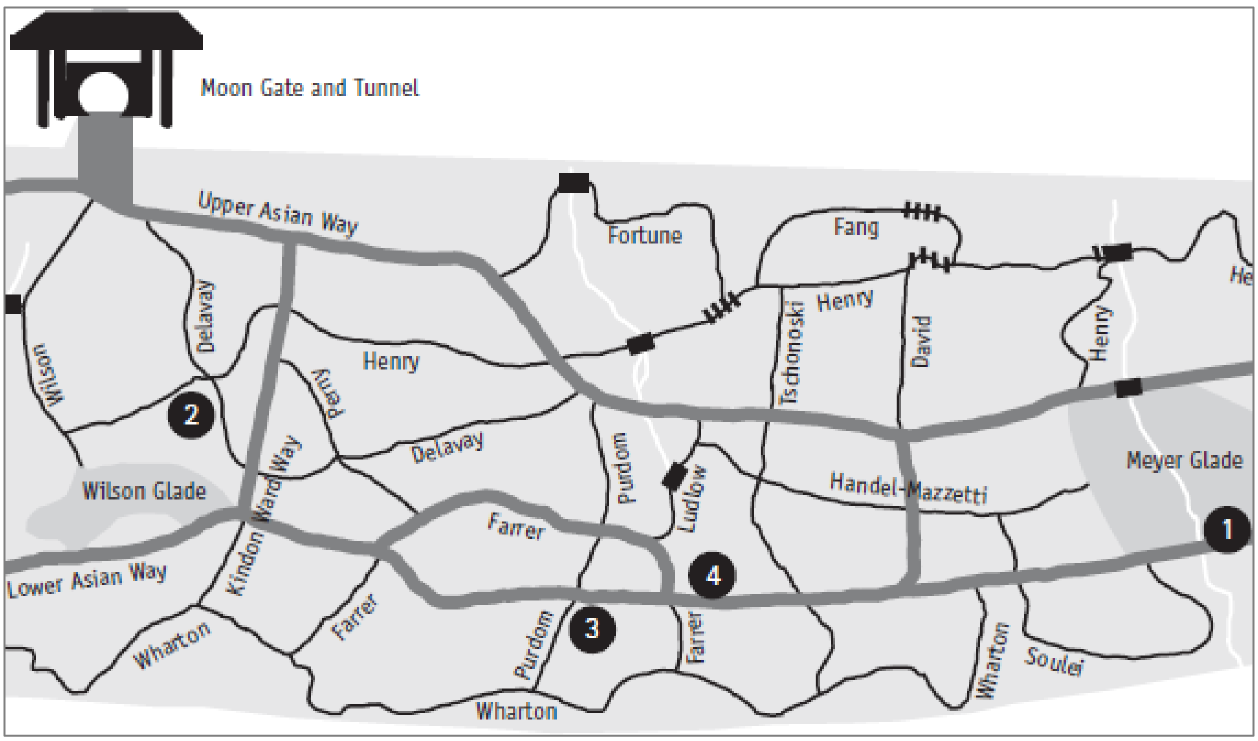


Figure 2: Map of Botanical Gardens, South.

In all, there are five streams shown on the two maps above, three of which can be used as possible water sources to calculate a 'base flow' in the dry season. Also, there are concerns of severe erosion downstream within the Gardens, and discharge over the cliffs at the Trail 7 Creek outfall is also an erosion concern.

Data Acquisition:

Currently there are no flow data for any of the streams in the UBC Botanical Gardens, after our group e-mailed Aleks Paderewski and Jenny Liu. Therefore, this will need to be measured over a certain period of time starting this summer. Upon further inquiry, we learned that a probe was used previously for water quality monitoring at the outfall at the Trail 7 Creek, while also recording water levels. However, this did not include the recording of flow data. A flow monitoring station will be installed at that location for three months, starting in July – this should allow a base flow to be established since it will be during the dry months, so a minimum amount of flow will be present that can be recorded.

Conversely, the only flow data that has been measured for the UBC campus were for the outfalls of the North and South Campus Catchment areas. Also, a meter records the cumulative water consumption for the Gardens, and all water to the Garden flows through this meter. This is shown below in Table 1, and the information was obtained with the help of Erin Kastner, who is with UBC Utilities. The measurements stopped in winter after the pipe was sealed up with air to prevent flow from coming in.

	Meter Reads (cu.m)
Date	Botanical Gardens
21-Apr-11	100
20-May-11	550
21-Jun-11	3003
21-Jul-11	5840
22-Aug-11	9180
16-Sep-11	12270
24-Oct-11	13785
21-Nov-11	14005
21-Dec-11	14005
24-Jan-12	14005

Table 1: Cumulative water consumption at the Garden

As can be seen in the table, the greatest consumption occurs in the summer months – from June to September – due to insufficient water available from the streams. A survey conducted on a stream by the Botanical Gardens – expanded upon below in Figure 3 – indicated a potential 9.5 million litres of water supply, which represents 68% of the Gardens' total dry season water consumption.

The streams that are measured on the FlowWorks website are very far away from the Endowment Lands; hence it is unclear just how relevant they may be. After some research, we also found that the City of Vancouver has no flow data relevant to the area of the Endowment Lands. The UBC Soil Science

Department has real-time data for rainfall from their Totem Field Climate Station but it is not retained beyond 14 days, so there would be a limited window of information about precipitation effects on stream flows. It is anticipated that this rainfall data would not be necessary if a larger record of information about the flow in the Garden streams is developed. Data for the catchment area may or may not be needed depending on how the flow monitoring system runs.

To further develop an understanding of the available water supply during the dry season, a survey was conducted on a stream near the Gardens. The site chosen is located near the junction of SW Marine Dr. and Old Marine Dr., which is just north of the Botanical Gardens. The location is indicated in Figure 3 below. This site was readily chosen because water flows through a culvert upstream of the site, making it simpler to estimate the flow of water. Using as-built information and common hydraulic relationships, an accurate estimate of the volumetric flow can be related to the depth of water in the culvert.

Figure 3: Site Location of Sampled Data

A data sample of this creek by SW Marine Dr. was taken over the course of several days, and the rainfall from the beginning till the end of that entire period was also recorded daily. The water depth was measured manually, by placing a ruler into the stream itself, allowing it to rest on the stream bed. The results of this can be seen below in Figure 4.

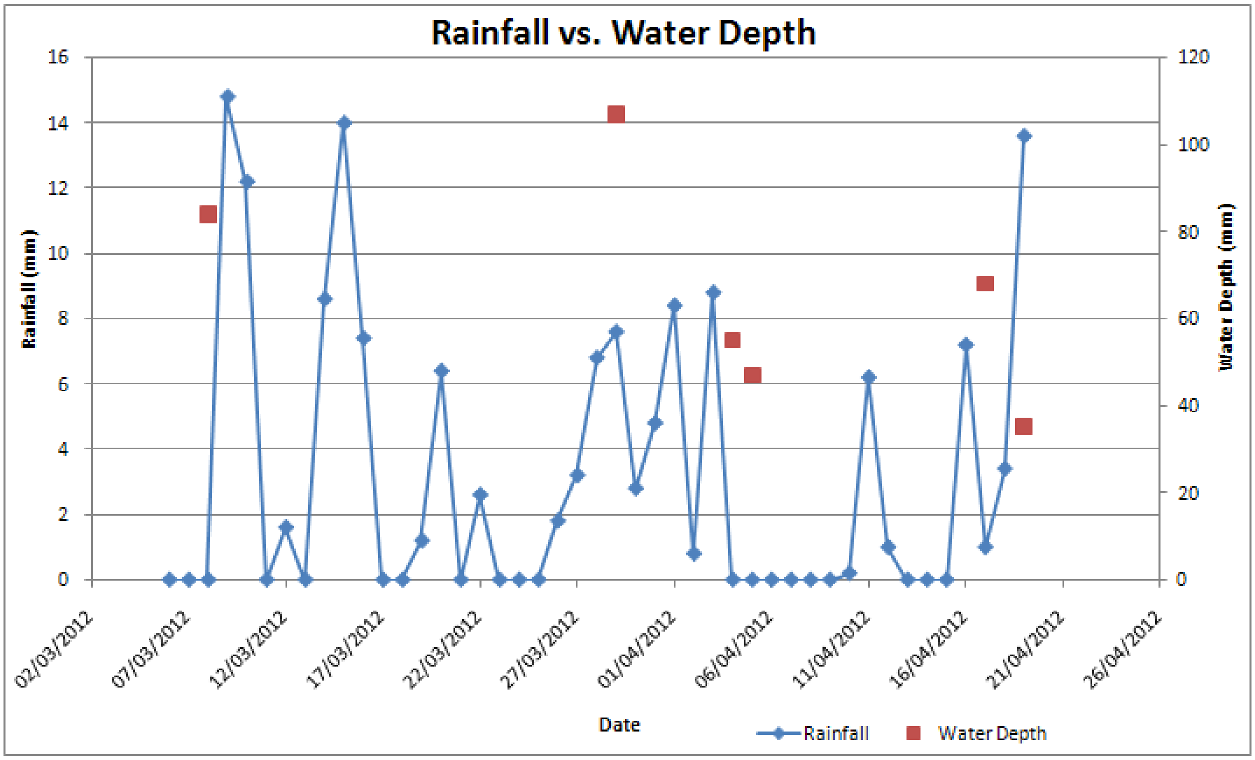


Figure 4: Stream data sample

The purpose of the survey was to determine the response curve of the sampled stream. Using a base flow established by the response curve, a diminished base flow at the end of the dry season can be predicted, and subsequently, the available water supply as well. It was determined that this stream has 9.5 million litres of potential water supply, making it viable to use this water source for irrigation and other purposes. Refer to Appendix A for detailed calculations on potential water supply. A discussion on the limitations of this method is also given in Appendix A.

However, a greater number of data points are required for the water depth, as it is hard to truly tell what sort of relationship is present using only a small sample size. Taking measurements of the water depth on consecutive days would give a better indication of how the precipitation affects the flow of the creek over the next few days. Until more information is acquired, it will be difficult to provide a good estimate of the base flow of the streams in summer.

As for drainage from catchment areas, this is shown on the map in Figure 5 below. This was obtained for the group by Waleed Giratalla from the Campus Sustainability program, and shows the different catchments on campus. Stormwater from Thunderbird Stadium falls under the 16th Ave. Catchment area, and drains to the Botanical Gardens Creek outfall, as labelled on the map. Douglas Justice, the Curator at the Botanical Gardens, mentioned that stormwater to the Garden itself is actually collected from the upstream catchment area from 3 sewers. The stormwater stream from Hawthorne Place flows year-round, while the stream next to 16th Ave. is seasonal, but greater than the one from Hawthorne Place. The creek by Old Marine Dr. is year-round and has greater flow than the one by 16th Ave.

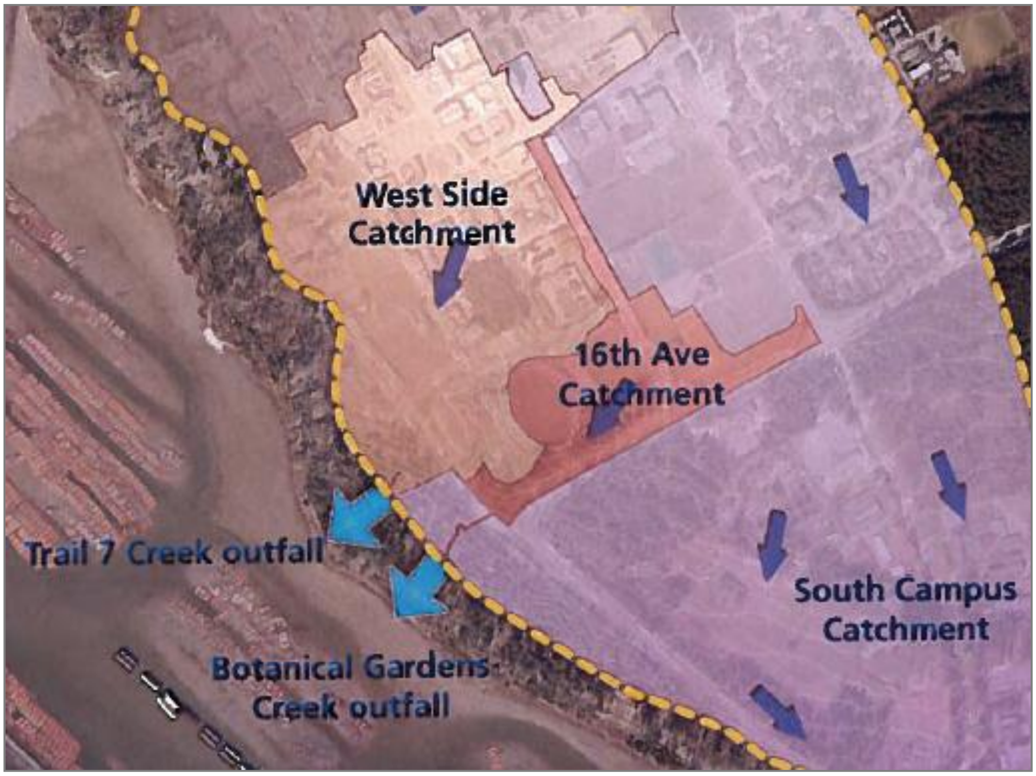


Figure 5: UBC storm catchment areas

A utilities map was acquired with the help of Erin Kastner, showing the various sewers, streams and drainage systems mainly in the West Side Catchment, which drains to the Trail 7 Creek outfall, and parts of the 16th Ave. Catchment which drains to the Botanical Gardens Creek outfall. The utilities for these two particular catchments are close enough that some minor alteration to the utilities could be feasible.

As the water flowing through the utilities in the 16th Ave. Catchment is stormwater and not wastewater, it may be possible to use it towards storage for irrigation if some level of treatment is implemented. It would be possible to divert this water, but could require some excavation under 16th Ave. and Southwest Marine Dr. More details would be needed about the stormwater flowing through the drainage system in the 16th Ave. Catchment, such as amount of flow and turbidity. Tests would need to be conducted to determine the water quality. A water quality test was performed recently for the creek by Old Marine Dr. which will be elaborated upon in Report D, but has yet to be done for this catchment.

Alternatives to Consider:

Water Retention System – The installation of a water retention system was inquired about by Dr Atwater and was mainly proposed as an alternative to the water storage tank. This could come in the form of several storage tanks at the location of the sloped bank. As mentioned previously, the bank is in the south of the Garden, southeast of the intersection between 16th Ave. and Southwest Marine Dr.

One possibility would be to use diversion weirs to bring water from the streams to fill such a system. As the land generally slopes southward and westward, gravity would work as an advantageous factor. It is possible that water from the creeks running into the Garden from the east side can be diverted into such tanks, and this water retention system would serve the same purpose as the storage and treatment tank detailed in Report C. Douglas Justice anticipates that diverting water from the bigger streams would not have noticeable effects on the environment. He also mentioned that the water currently isn't being used by the Garden for anything downstream. Depending on the water quality and level of treatment required for potential long-term storage, water retained here could be used for irrigation purposes, particularly in summer when water is most needed and rainfall is not as frequent as the wet season. A rough estimate of the costs for installing storage tanks compared to installing a retention basin was made, as shown below in Figure 6. The numbers, calculations and assumptions used to calculate these costs are attached in Appendix A.

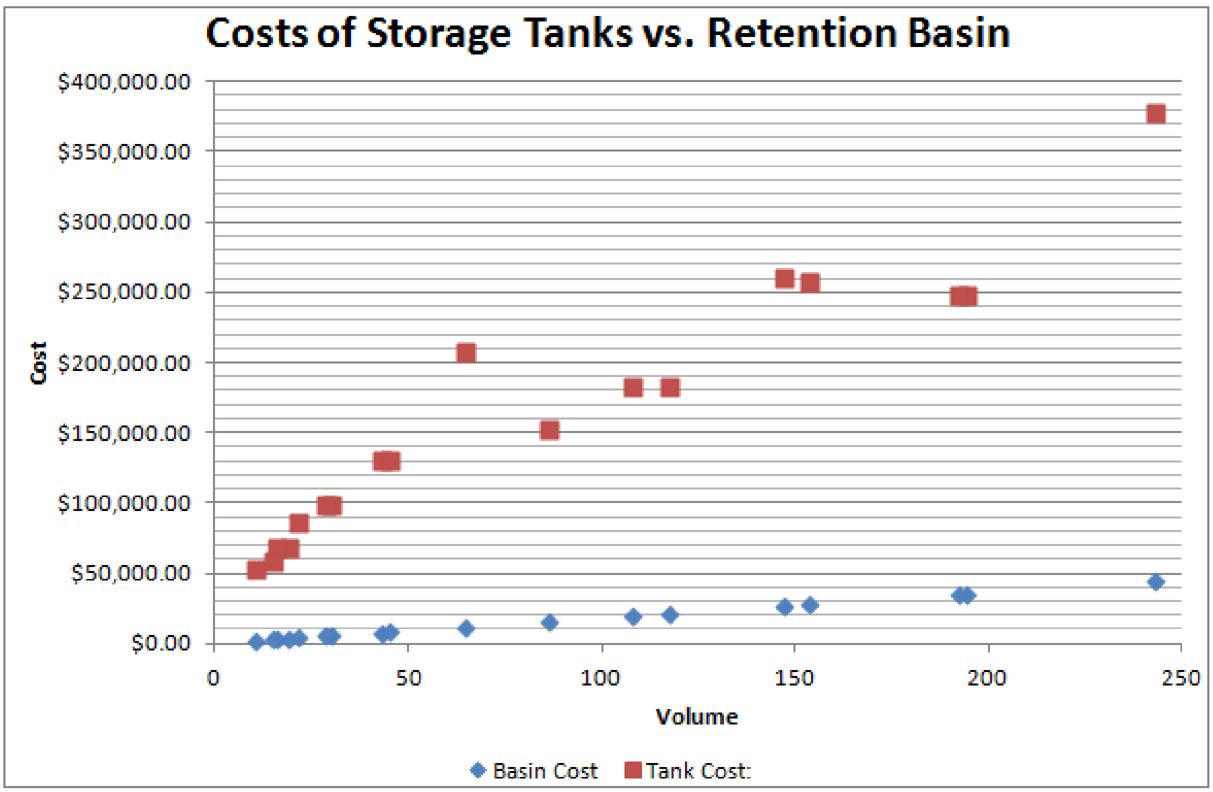


Figure 6: Estimation of costs of building a basin vs. costs of using water storage tanks

As shown in the graph, the estimated costs of building a retention basin are much lower compared to the estimated costs of installing storage tanks for the same purpose.

One concern of using diversion weirs would be water overflowing at the weirs in times of very heavy rainfall which may cause flooding. Therefore some sort of emergency release mechanism may be needed for these occasions. An additional benefit, however, is that this retention system could possibly reduce the effects of erosion on stream banks, as well as flooding, by decreasing the volume of water flowing downstream.

The location of the tanks would have to be looked over by the Garden's senior management, but Douglas' initial opinion is that this would be approved. If implemented, the system would operate in a similar way to the storage and treatment tank. A minimum level of treatment would be needed if the water is to be designated for irrigation, and even greater if the water was to be used as an emergency drinking supply. Aleks Paderewski advocated that the storage and treatment tank could function as the primary water supply for the campus residents in times of emergency – for example if an earthquake was to occur – and this water retention system could serve as a supplementary source of potable water should UBC decided that it is needed.

A more in-depth record of measurements of the flows for the various creeks will still be needed for a feasibility study, as there is no flow data for any of the Garden streams at this time.

Flooding the Pond – The possibility of flooding the ornamental pond for possible storage of water further up the slope has also been brought up. The ornamental pond, located on the other side of SW Marine Dr. near Thunderbird Stadium, contains potable water. This would present a third backup option for the local community living in UBC in these events. It may be possible to 'flood' the pond to store extra water for emergency purposes, to supplement the water storage and treatment tank proposed by our group and the water retention system mentioned above.

The approval of Garden management would be needed but an initial opinion from Douglas Justice is that it too would be feasible, and that the Garden would be open to such a move. He mentioned that seepage from the pond is minimal, so water loss should not be an issue. The only concern regarding the maintenance of the water should be evaporation in summer as it is an open-air water body. For health reasons, testing may be need to be carried out as well.

In order to explore the feasibility of this option further, the extra volume of water that could be stored here needs to be estimated, and this could be carried out by approximating the perimeter of the pond and finding the increase in height that would be allowed. Any extra maintenance costs incurred by the extra water are thought to be minimal, if any at all. As the pond could be used as storage for another source of drinkable water close by, investment in this option should be looked into as there are no real downsides.

Recommendations:

Our group has come up with several recommendations with respect to the data that is currently available and data that will be needed for future study and action.

First of all, flow data for the large streams in the Garden is needed – flow measurements are needed to establish a record. To obtain accurate results, it is highly recommended that probes be installed at strategic sites to measure water depth and flow. This will ensure a continuous record of data that will be sufficient to calculate storage potential. Utilities has said that they will be installing a flow monitoring device at the Trail 7 Creek outfall this summer, but doing the same for the other streams would be very helpful. A base flow for the creek by Old Marine Dr. was estimated but a study could be conducted in the summer to ascertain a more accurate number.

It may be helpful to note drought patterns to see if they are periodical or random occurrences. This would aid the Garden staff in preparing for any annual events. However, this would need to be taken over the duration of several years, as the problem of small sample sizes arise once again. Likewise, the flow data would also need to be monitored over several years to see if any changes in the flow are happening.

Response curves are needed for the Gardens' streams. Knowing how quickly the streams engorge after rainfall events would help prepare staff in knowing when to collect water if needed, or when to open release mechanisms for diversion weirs. Developing these would also help establish a rainfall-runoff relationship, as already plotted above in the graph. It is also important to find how sensitive the creeks really are, and how short the time intervals over which to record the rainfall should be, by testing results repeatedly. This could be done by looking at similar rainfall events (in terms of precipitation) and seeing whether the times of response are comparable. Taking measurements daily as was done in our study may or may not be accurate enough to gauge the changes in stream flow after it rains.

Other courses of action include deepening or widening the stream channels to accommodate a greater volume of water. This would help in mitigating the effects and frequency of overflowing streams as the channel can now take more flow, but we are unsure how this would affect the erosion that is currently ongoing.

Implementing swales and rain gardens wherever possible in the West Side Catchment would help to reduce runoff volumes, as these work by keeping water from easily leaving where it falls. However, even though this may be more relevant to UBC building policy on campus, the Garden authorities could work together with UBC to negotiate the installation of such features in this catchment.

Other best management practices include utilizing measures such as rainwater collection tanks, green roofs and permeable paving. All of these measures help in decreasing runoffs to the Gardens as they direct rainwater to other uses. These also contribute to the SEEDS Program's vision of fostering sustainability and environmental protection, and are all features of green urban design. As it is unclear how much jurisdiction the Garden has over land immediately in its surroundings – mainly along SW Marine Dr. and along Stadium Road and 16th Ave. – this may not be possible without communication with the appropriate parties.

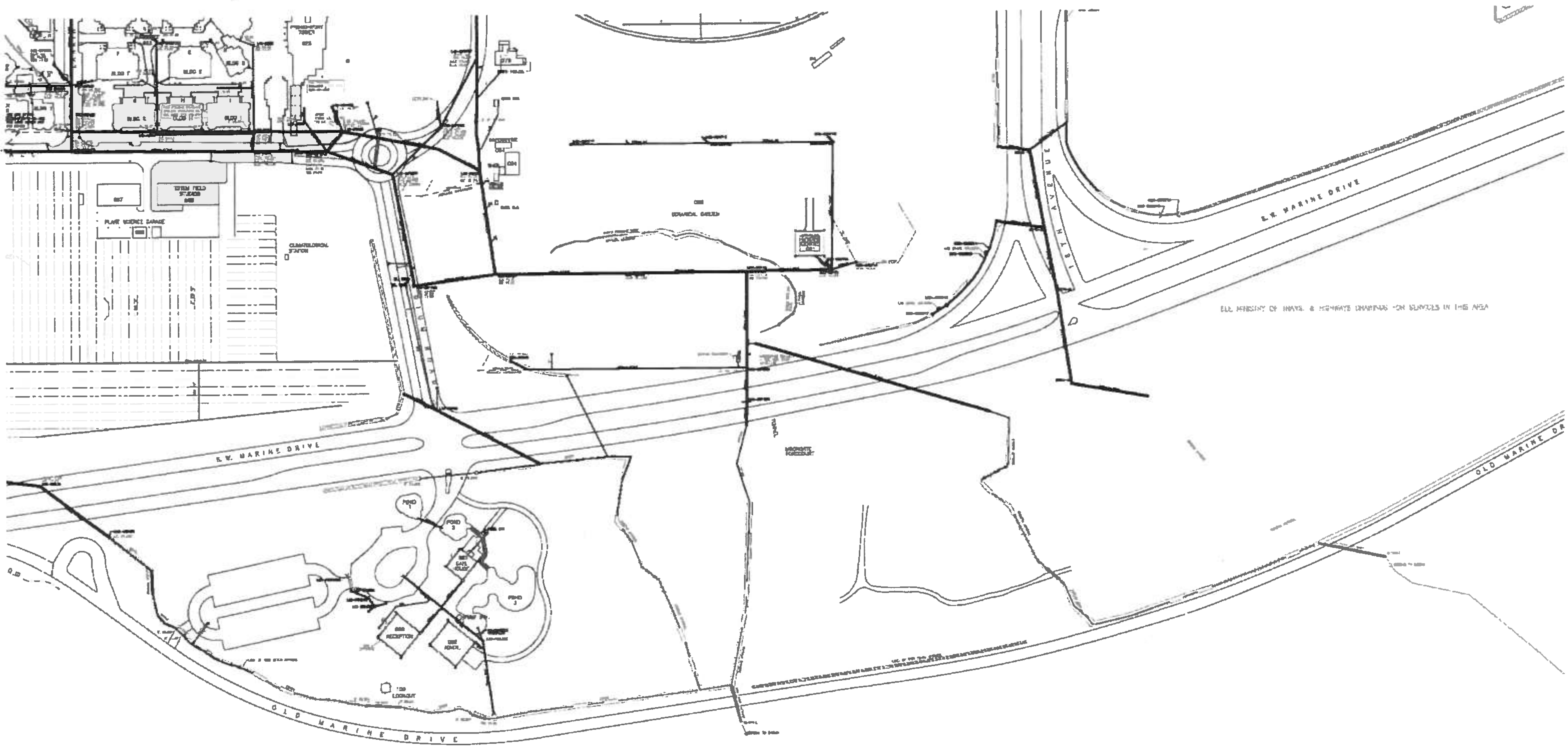
Infiltration basins and detention basins would especially fit some of the goals of this project, which are to mitigate the effects of flooding brought on by heavy rainfall and as well as downstream erosion. Infiltration basins are another way to manage stormwater runoff. They serve to prevent flooding and erosion by infiltrating stormwater into the soil, ultimately ending up as groundwater. The type of soil on the land that surrounds the Gardens needs to be known in order to see if this method is possible. A more permeable soil type would help greatly in making infiltration basins effective, so more research is required here.

Building detention basins would further this aim, and it is possible to use these two types of basins as a combination to reduce the amount of damage done by flooding provided there is enough space. In holding back water by storing it at certain locations for a period of time, detention basins allow time for the water levels in the creeks to go down before water is discharged. Essentially the same amount of water is still flowing through the stream channels, but it is much more controlled and spread out. This option may be worth looking into.

APPENDIX A

Water retention system calculations:

				USD (per m2) for 1mm:										
Circular Basin					$1.96			Tanks					/10 tanks	
Volume: (m3)	Excavation Price	Installed Price (CAD)	Area (ft2):	m2:	Liner cost	Basin Cost		Diameter	Height	Volume ft3	m3:	US Gal:	US Price:	Tank Cost:
43.2345583	2161.727916	5611.514	593.761012	55.1622	$108.12	$7,881.36		18	6	1526.81403	43.23456	11421.36	129900	129692.49
30.0239988	1501.199941	3896.885	459.457926	42.68504	$83.66	$5,481.75		15	6	1060.28752	30.024	7931.501	98740	98582.268
19.2153592	960.7679625	2494.006	339.292007	31.52126	$61.78	$3,516.56		12	6	678.584013	19.21536	5076.161	67810	67701.677
10.8086396	540.4319789	1402.879	233.263255	21.67087	$42.47	$1,985.79		9	6	381.703507	10.80864	2855.34	53050	52965.256
64.8518375	3242.591873	8417.271	763.407015	70.92283	$139.01	$11,798.87		18	9	2290.22104	64.85184	17132.04	207350	207018.77
45.0359982	2251.799912	5845.327	600.829595	55.8189	$109.41	$8,206.53		15	9	1590.43128	45.036	11897.25	129900	129692.49
28.8230389	1441.151944	3741.009	452.389342	42.02835	$82.38	$5,264.54		12	9	1017.87602	28.82304	7614.241	98740	98582.268
16.2129594	810.6479683	2104.318	318.086256	29.55118	$57.92	$2,972.89		9	9	572.555261	16.21296	4283.011	67810	67701.677
21.6172792	1080.863958	2805.757	424.115008	39.40157	$77.23	$3,963.85		18	3	763.407015	21.61728	5710.681	86040	85902.556
15.0119994	750.5999707	1948.442	318.086256	29.55118	$57.92	$2,756.96		15	3	530.14376	15.012	3965.751	58320	58226.837
86.4691166	4323.455831	11223.03	933.053018	86.68346	$169.90	$15,716.38		18	12	3053.62806	86.46912	22842.72	152880	152635.78
117.694075	5884.70377	15275.79	1138.04194	105.7276	$207.23	$21,367.72		21	12	4156.32708	117.6941	31091.49	182390	182098.64
153.722874	7686.1437	19952.05	1357.16803	126.085	$247.13	$27,885.32		24	12	5428.67211	153.7229	40609.29	257490	257078.67
194.555512	9727.77562	25251.81	1590.43128	147.7559	$289.60	$35,269.19		27	12	6870.66313	194.5555	51396.13	248230	247833.47
108.086396	5404.319789	14028.79	1102.69902	102.4441	$200.79	$19,633.90		18	15	3817.03507	108.0864	28553.4	182390	182098.64
147.117594	7355.879713	19094.74	1335.96228	124.115	$243.27	$26,693.88		21	15	5195.40885	147.1176	38864.36	260170	259754.39
192.153592	9607.679625	24940.06	1583.3627	147.0992	$288.31	$34,836.06		24	15	6785.84013	192.1536	50761.61	248230	247833.47
243.19439	12159.71952	31564.77	1844.90029	171.3968	$335.94	$44,060.42		27	15	8588.32892	243.1944	64245.16	378420	377815.5



OLD MARINE DRIVE
S.W. MARINE DRIVE
16TH AVENUE
SEE MINISTRY OF TRANS. & HIGHWAYS DRAWINGS FOR SERVICES IN THIS AREA
PLANT SCIENCE GARAGE
CLIMATOLOGICAL STATION
BOTANICAL GARDEN
RECEPTION
LOOKOUT
POND 1
POND 2
POND 3
OLD MARINE DR

Assumptions and sample calculations:

For a basin of 43.23 m^3 in storage volume:

18ft diameter: 254.469 ft^2, Depth: 6 ft

Volume: $V = \pi\left(\frac{d}{2}\right)^2 \times d = 1526.814$ ft^3

1 ft^3 = 0.0283168466 m^3, Vol.: 43.235 m^3

Excavating rate: $50/m^3, Total price of excavating: $2161.728

Installation cost for water storage: $130/m^3

Installed price: $5611.514

Surface area of basin: 55.16 m^2, Cost of liner per m^2 (1mm thickness): $1.96

Total cost of waterproof lining: $108.12

Total cost of basin = $2161.73 + $5611.51 + $108.12

= $7881.36

Prices and numbers taken from:

http://www.alibaba.com/product-gs/344241407/HDPE_LDPE_geomembrane_waterproof_pond_liner.html

http://hansontank.com/watertankpricelist2.html

http://hansontank.com/watertankpricelist3.html

http://www.oasisdesign.net/water/storage/

Utilities key

Abbreviations for the utilities map were also given:

- AC – asbestos cement
- CONC – concrete
- i.e. – invert elevation
- nie – north invert elev.
- sie – south invert elev.
- wie – west, etc.

Sampled Stream – Flow rate

Without the aid of flow measuring devices, we can obtain relate water depth to flow rate using well established hydraulic relationships, such as Manning's Equation. By considering the flow through the culvert upstream of our site, we can accurate calculate the flow rate of the stream.

Manning's Equation

One of the most common open channel relationships is Manning's Equation, which is given as such:

$$V = \frac{1}{n} {R_h}^{2/3} {S_0}^{1/2}$$

Where V is velocity of the water, n is Manning's roughness coefficient, R_h is hydraulic radius, and S_0 is slope of channel. Then, the flow rate is simply

$$Q = VA = \frac{1}{n} {R_h}^{2/3} {S_0}^{1/2} \times A$$

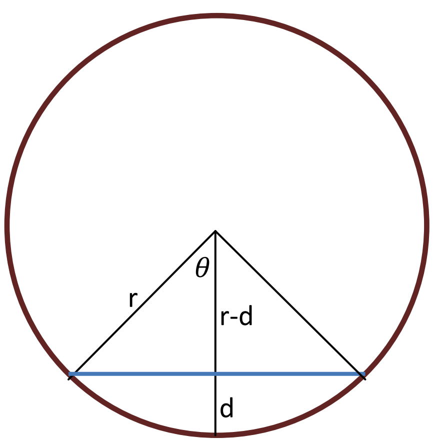
A brief description of each term is discussed in the following.

Roughness Coefficient

The concrete culvert is assumed to be steel-formed, and will have $n = 0.0011$.

Hydraulic Radius

The hydraulic radius is given by $R_h = \frac{A}{P}$, where A is cross-sectional area, and P is wetted perimeter. From the diagram below, the following relations can be made:



$$cos\theta = \frac{r-d}{d} \rightarrow \theta = \arccos\frac{(r-d)}{d}$$

$$P = 2\theta r$$

$$A = \theta r^2 - \frac{1}{2}(r sin\theta)(r-d)$$

Where r is inner radius of the pipe, and d is depth of water.

Slope

Given its invert elevations and pipe length provided by the UBC Utilities drawing, the slope of the channel is

$$S_0 = \frac{74.59m - 74.487m}{57m} = 0.00181\frac{m}{m}$$

Results

Using Manning's Equation and the surveyed water depth data, a corresponding flow rate is calculated, as shown in this table:

Date	Water Depth (mm)	Flow rate (m^3/s)
March 8, 2012	84	0.0148
March 29, 2012	107	0.0245
April 4, 2012	55	0.0061
April 5, 2012	47	0.0043
April 17, 2012	68	0.0095
April 19, 2012	35	0.0023

Table 2: Flow rate vs. Water depth

Sampled Stream – Potential Water Supply

The following method was used to evaluate the potential water supply generated by this stream:

1. Determine the base flow at the beginning of the period of interest
2. Take 10% of the base flow to be the new base flow at the end of the period of interest
3. Calculate the daily/weekly/monthly flow rates using geometric sequences
4. Determine daily/weekly/monthly volume of water
5. Total the volumes of water within the period of interest

We considered the period of interest to be between June 1 and September 30, where rainfall is minimal. Due to the lack of sufficient data, our established base flow was determined to be 2.32 L/s, the lowest number based on the surveyed data. Then, the base flow on September 30 is 0.232 L/s. Using geometric sequences, we can determine the rate of base flow decrease over this 122 day period:

$$0.232 = 2.32 \times r^{122-1} \rightarrow r = 0.981$$

This means that the flow decreases about 1.9% daily. So, the flow on June 2 is

$$2.32 \times 0.981 = 2.27\ L/s$$

Using linear interpolation, the amount of water that can be captured on June 1 is

$$\frac{2.32\ L/s + 2.27L/s}{2} \times 86400s = 198364\ L$$

Repeating this procedure for every day between June 1 and September 30, the total volume of water that can be potential captured is just short of 9.5 million litres.

Limitations

Manning's Roughness Coefficient

The chosen coefficient of $n = 0.0011$ is based on concrete that is steel-formed. With prolonged use, we would expect the concrete surface to be rougher due to wear and abrasion. Therefore, our flow values are overestimated, and the expected roughness should be adjusted to take this into consideration.

Potential Water Supply – Method

Due to the lack of continuous data, it is impossible to determine the base flow, based on the response curve of the stream. The initial base flow was established using the lowest flow surveyed, which can lead to inaccurate results. To improve the inaccuracy, we would require a defined response curve throughout the period of interest, which is during the dry season. Once established, an accurate storage potential can be calculated.

Report B

Under-pathway Storage Tanks and Stormwater Management

Jacqueline Lam

69414084

Executive Summary

An investigation into the alternative of underpathway storage tanks was undertaken. There are a total of 5380m of available major existing pathways in the north and south gardens. Using a design with a width of 2m and a depth of 1m, the pathway needed for the whole irrigation period would be 7000m since the total amount used is 14000m3. One of the storage matrix explored, AquaBlox, required a design of 5 blocks width, 2 blocks depth, and 8030 blocks length; totalling 80300 blocks throughout the pathways. The matrix blocks were $60 each, yielding a first cost of $4818000. With a water cost of $0.99/L, annual growth rate of 7.5%, the payback period was found to be 487 years. This suggests that underpathway storage tanks would be more viable for small scale projects such as home gardens, versus a large project such as the Botanical Garden. Because of the economic infeasibility of the underpathway storage tanks, other modes of stormwater management were investigated, including permeable pathways to mitigate flooding within the botanical gardens.

Table of Contents

1.0 Introduction

In order to promote stormwater management within the UBC botanical gardens, under-pathway storage tanks were considered in order to enable grey water to be used in the garden irrigation. The director of the UBC Botanical Garden and Centre for Plant Research, Patrick Lewis, was interested in the storage tanks as a means an aesthetically pleasing solution to flooding within the garden and grey water irrigation during the dry season.

2.0 Benefits of Under-pathway Storage Tanks

Permeable pavements have been used commonly in recent years to mitigate stormwater runoff. The theory behind under-pathway storage tanks is to take that stormwater and utilize it to irrigate the garden. Under-pathway storage tanks have a high void space to maximize water storage and preserve the look for the garden by not taking up above ground space.

3.0 Preliminary Design

3.1 Major Pathways

In response to Patrick Lewis' interest in under-pathway storage tanks, an investigation was undertaken to determine if it is feasible or not. The chart below was provided from utilities and is a measure of the total water used during the irrigation season. During the months of November 2011 to January 2012, the irrigation is shut off, and air is blown through the pipes to keep them from freezing during the winter months.

Date	Meter Reads (cu.m) Botanical Gardens
21-Apr-11	100
20-May-11	550
21-Jun-11	3003
21-Jul-11	5840
22-Aug-11	9180
16-Sep-11	12270
24-Oct-11	13785
21-Nov-11	14005
21-Dec-11	14005
24-Jan-12	14005

Table 1 Measurement of water demand

Therefore, the water demand for the garden needed for irrigation was taken at 14000m^3. To begin the under-pathway design, the length of total major pathways was measured and found to be 5380m. In the north gardens, there is 3100m of available major pathways, and in the south gardens, there is 2280m of available major pathways as shown in Figure 1.

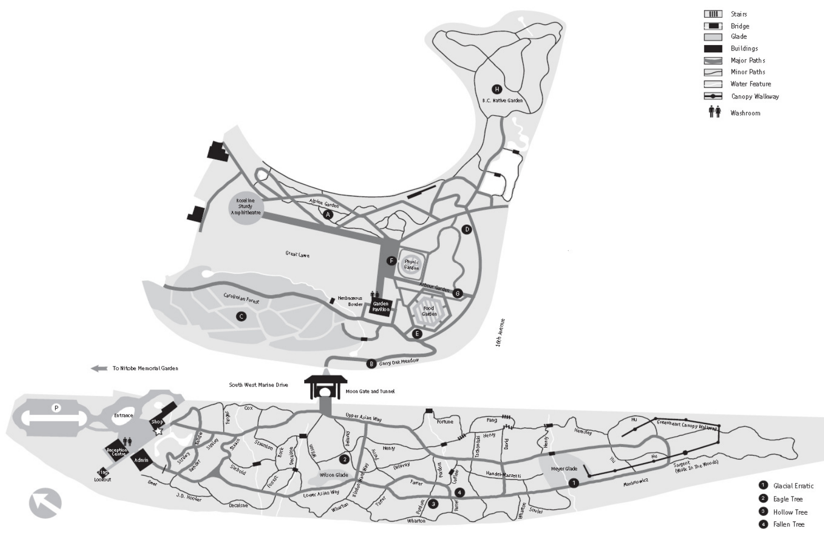


Figure 1 Map of botanical gardens

3.2 Design

3.2.1 AquaBlox

The first design explored utilised AquaBlox, a type of modular rainfall capture storage tank that comes in modular matrices. The large matrices has the dimensions of 0.67m(L) x 0.4m(W) x 0.44m(H). The existing major pathways are have a minimum width of 2 metres. Therefore the proposed design for the existing pathways have a width of 5 blocks, height of 2 blocks, and a length of 8030 blocks, totalling 80300 blocks. Each large matrix block costs $60 each (TJB, 2012), generating a first cost of $4818000. With a water cost of $0.99/L, and an annual growth rate of 7.5% (Report C), this yields a payback period of 487 years. This shows that it is economically infeasible, revealing a need for further research to be done (Rainxchange, 2008).

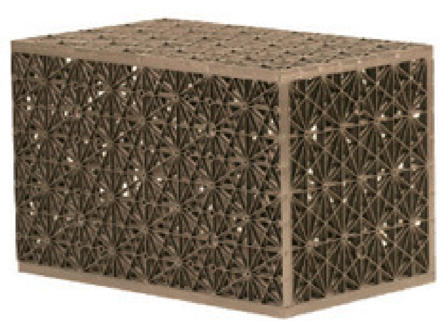


Figure 2 Large AquaBlox

3.2.2 RainStore^3

A second type of permeable pavement explored is Rainstore^3, which has the dimensions of 1m x 1m x 0.10m. In the last year, 1200mm per $1m^2$ of precipitation fell in Vancouver (Vancouver, 2012). With a pathway surface area of approximately $10760m^2$, this generates a minimum of $12912m^3$ of rainfall on the pathways alone, without factoring the water draining onto the pathway from higher ground. In order to store all the rainfall that falls onto the pathway, the total Rainstore^3 units required would be 137376, generating a first cost of approximately $4 million. These numbers were calculated from a design width of 2 units, depth of 8 units, and a length of 8586. However, to simply mitigate flooding, one layer of Rainstore^3 may be considered. This would have a much more economically feasible cost of $515160, enabling a storage capacity of approximately $1000m^3$ (Invisible Structure, 2011).

4.0 Conclusion

Although permeable pavements are effective in stormwater mitigation, under-pathway storage tanks are a very costly alternative to the above surface storage tanks and pumps investigated in Report C. Further research should be undertaken with respect to more economical alternatives to the modular stackable structures discussed in this paper.

Bibliography

Invisible Structure. (2011). *Rainstore3*. Retrieved May 1, 2012, from Invisible Structures: http://www.invisiblestructures.com/rainstore3.html

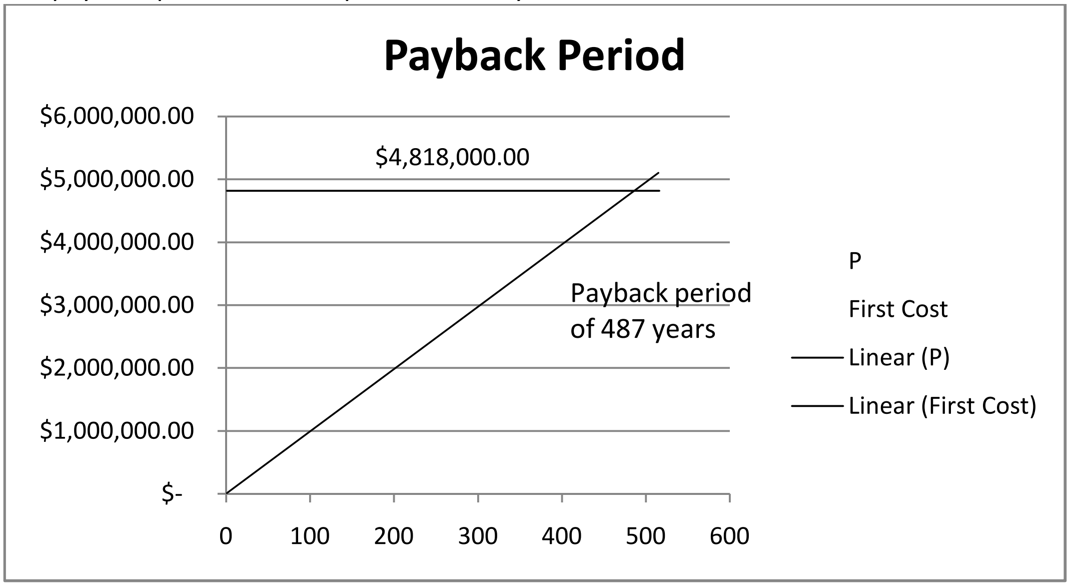
Rainxchange. (2008). *AquaBlox*. Retrieved March 30, 2012, from Rainxchange: http://www.rainxchange.com/products/aquablox.php

TJB. (2012). *AquaBlox*. Retrieved May 1, 2012, from TJB: http://shop.tjb-inc.com/aquascape-aquablox-water-matrix-for-pondless-waterfalls-wetland-systems-rainwater-harvesting-p1251.aspx

Vancouver. (2012). *Vancouver Weather Page*. Retrieved May 1, 2012, from Vancouver Weather Page: http://vancouver.weatherpage.ca/climate/

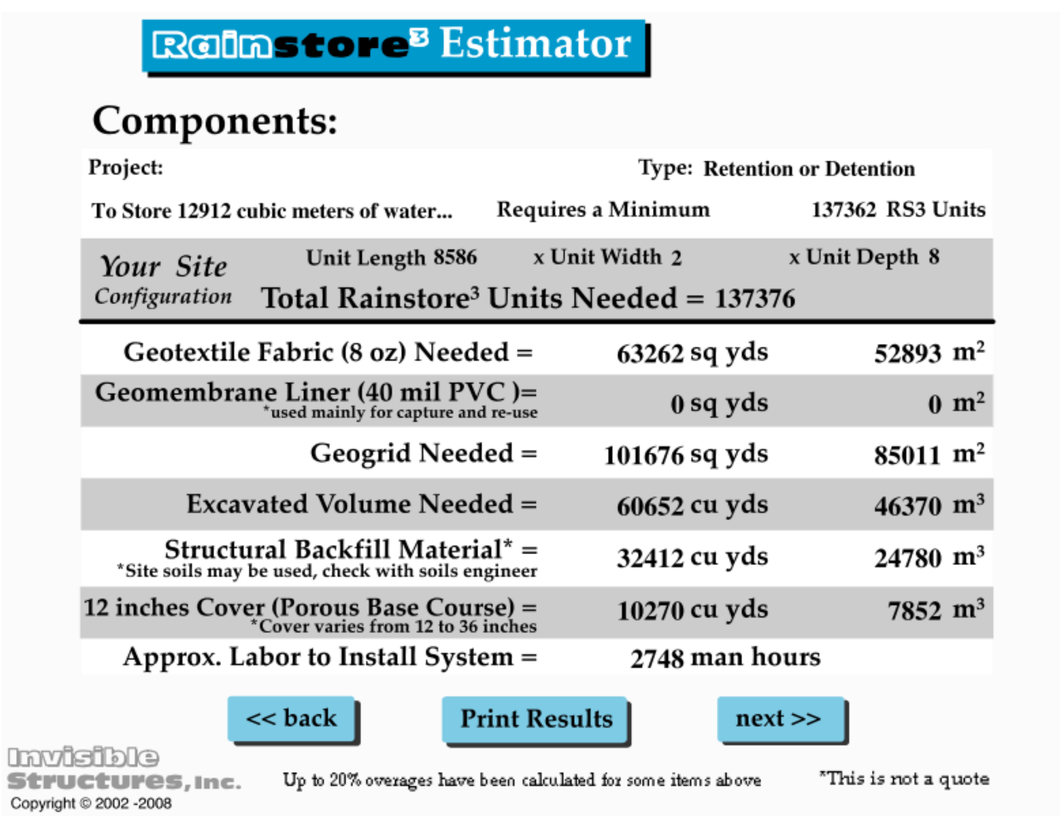
Appendix A

The payback period of the AquaBlox is 487 years as shown below.



The present worth of the project at the Nth year was calculated using P=AN/(1+g), where the interest rate is taken at 0%. The growth rate g was taken to be 7.5%.

The Rainstore3 components were estimated using the online estimator, with the results of the different flow rates shown below.


Rainstore³ Estimator

Components:

Project: Type: Retention or Detention

To Store 12912 cubic meters of water... Requires a Minimum 137362 RS3 Units

Your Site Configuration Unit Length 8586 x Unit Width 2 x Unit Depth 8

Total Rainstore³ Units Needed = 137376

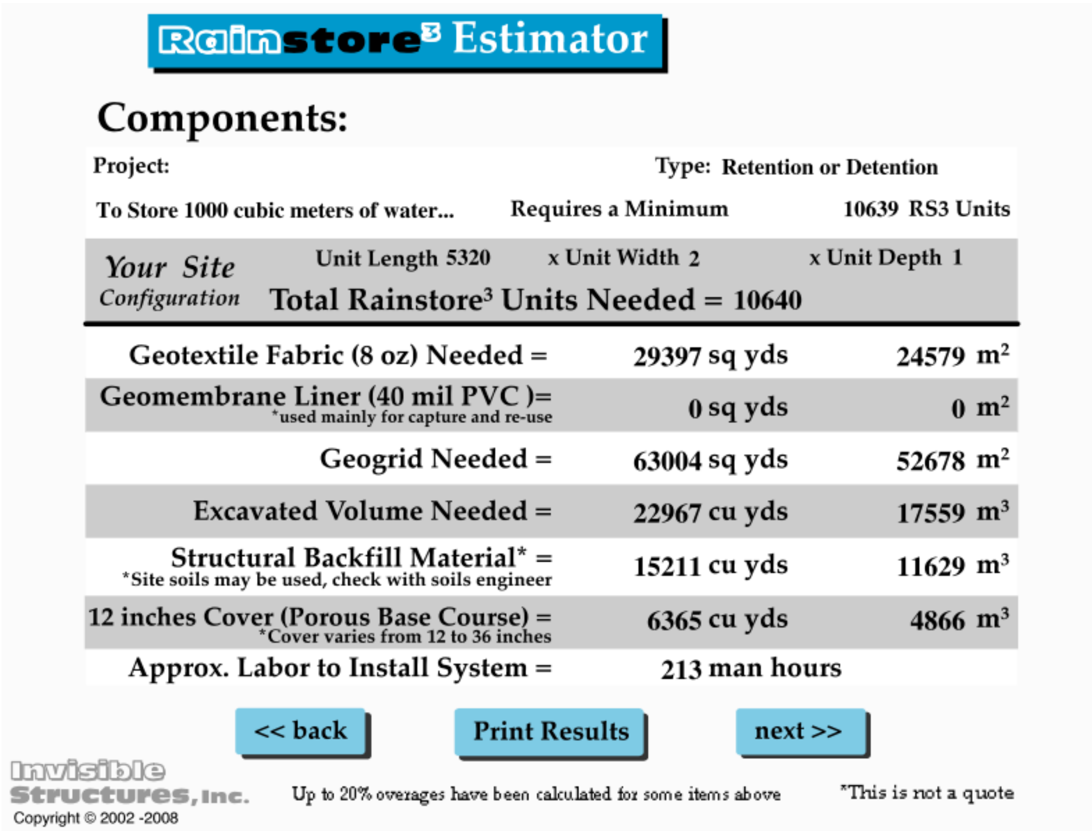
Geotextile Fabric (8 oz) Needed =	63262 sq yds	52893 m²
Geomembrane Liner (40 mil PVC)= *used mainly for capture and re-use	0 sq yds	0 m²
Geogrid Needed =	101676 sq yds	85011 m²
Excavated Volume Needed =	60652 cu yds	46370 m³
Structural Backfill Material* = *Site soils may be used, check with soils engineer	32412 cu yds	24780 m³
12 inches Cover (Porous Base Course) = *Cover varies from 12 to 36 inches	10270 cu yds	7852 m³
Approx. Labor to Install System =	2748 man hours	

<< back | Print Results | next >>

Invisible Structures, Inc. Copyright © 2002 -2008

Up to 20% overages have been calculated for some items above

*This is not a quote



Rainstore³ Estimator

Components:

Project:

Type: Retention or Detention

To Store 1000 cubic meters of water... Requires a Minimum 10639 RS3 Units

Your Site Configuration: Unit Length 5320 x Unit Width 2 x Unit Depth 1

Total Rainstore³ Units Needed = 10640

Geotextile Fabric (8 oz) Needed =	29397 sq yds	24579 m^2
Geomembrane Liner (40 mil PVC)= *used mainly for capture and re-use	0 sq yds	0 m^2
Geogrid Needed =	63004 sq yds	52678 m^2
Excavated Volume Needed =	22967 cu yds	17559 m^3
Structural Backfill Material* = *Site soils may be used, check with soils engineer	15211 cu yds	11629 m^3
12 inches Cover (Porous Base Course) = *Cover varies from 12 to 36 inches	6365 cu yds	4866 m^3
Approx. Labor to Install System =	213 man hours	

<< back Print Results next >>

Invisible Structures, Inc.

Copyright © 2002 -2008

Up to 20% overages have been calculated for some items above

*This is not a quote

SUSTAINABLE DESIGN FOR IRRIGATION AND STORMWATER MANAGEMENT IN THE UBC BOTANICAL GARDEN

: A Preliminary Conceptual Design and Feasibility Study; Report C.

Prepared as requested by UBC SEEDS, via the CIVL 498 K Project

Sub-Group Members: Meraj Mamorafshord (1805084)

Wen Chien Hsieh (47666086)

Kelvin Chand (43283084)

May 8th, 2012

CIVL 498 K
Directed Studies with Dr. James Atwater
Department of Civil Engineering
Faculty of Applied Science
University of British Columbia

M

H

C

Table of Contents

List of Figures

List of Tables

Executive Summary

Report C, "Sustainable Design for Irrigation and Stormwater Management in the UBC Botanical Garden", includes a preliminary conceptual design and feasibility study. This request for a feasibility study was forwarded to our subgroup of CIVL 498 K by UBC SEEDS and the Department of Civil Engineering. This report encompasses the final deliverables for CIVL 498 K.

The process in which the investigation was conducted is as follows; at the commencement of the project the available data was compiled, then the data required was outlined, this was followed by the production of a conceptual design based on several assumptions, which enabled a preliminary cost estimation to be undertaken, this was complemented by research for annual costs / savings / replacement costs / growth rates, and finally a feasibility study was performed via an economic analysis for the payback period and the project life net savings.

The conceptual design consists of placing dams at the ends of the two streams in the Garden and parking lot, which exhibit summer flows. The dams are then connected to an aesthetically and architecturally consistent housed water storage tank (sited southwest of the parking lot), by using a pumping and piping system. The central water storage tank is also connected to a release pipe and an emergency release pipe. It also has a proposed connectivity to the existing irrigation system and a disaster response water treatment and supply line, which are not covered in the scope of this report.

The primary usage of this infrastructure for irrigation, during the dry season (May to October), is as a reservoir. The summer flows in the two streams will fill the two dams and in turn partially replenish the reservoir. The reservoir will supply adequate irrigation through the entirety of the dry season. At the end of this time the water storage tank will only have the proposed disaster response water supply remaining. A water storage tank of 5000 m^3 (as the initial reservoir) will provide a 100 % reduction of municipal potable water consumption. The water storage tank will have a circular footprint of approximately 32 m in diameter. The water storage tank also dominates the initial cost of the project.

The secondary usage of this infrastructure for stormwater management, during the wet season (November to April), is as a stormwater detention and diversion system. The stormwater will be collected, via the dams, during rainfall events and released to the Trail 7 outfall (via the culvert at the foot of parking lot) during relatively dry days. However, during intense rain events the stormwater is diverted and released continually over the adjacent west side of Old Marine Drive. This only occurs when the tank is full, the rain has not ceased, and the water levels in both of the dams have exceeded the heights of the dams. The implementation of this stormwater management regime reduces the impact of a peak design flow (110 L/s) rain event by approximately 32 %. Furthermore, it does not affect the initial cost of the project relative to the initial cost of the water storage tank.

The economic analysis was performed using the following information; the total initial cost of the project is $711,000 (including contingency and tax), total annual savings of $15,000 (growing at 7.5% annually), total annual operating cost $8,000 (growing at 3.3%), total annual inspection & maintenance costs of $5,000, the pumping systems ($20,000) will be replaced on fifteen year intervals, and that the time frame used for this investigation is a conservative value of 50 years. The final results of the feasibility study yielded a discounted payback period of 29 years. Furthermore, it yielded a potential project life net savings of $2,200,000. However, it should be noted that due to the length of the project life all results are sensitive to the accuracy of trending the growth of water costs.

1.0 Introduction

Report C compiles the investigation performed by this subgroup of CIVL 498 K and provides a thorough economic analysis of the sustainable design for irrigation and stormwater management in the UBC Botanical Garden. It consists of a brief overview of our subgroup's methodology which is mainly concerned with the objectives that were delegated to us, the design approach, and the cost estimation approach. The design consists of one major and two minor observable elements. Firstly, the two dams will be implemented far downstream of both the Garden and parking lot streams illustrated in Figures 1 and 2 respectively.

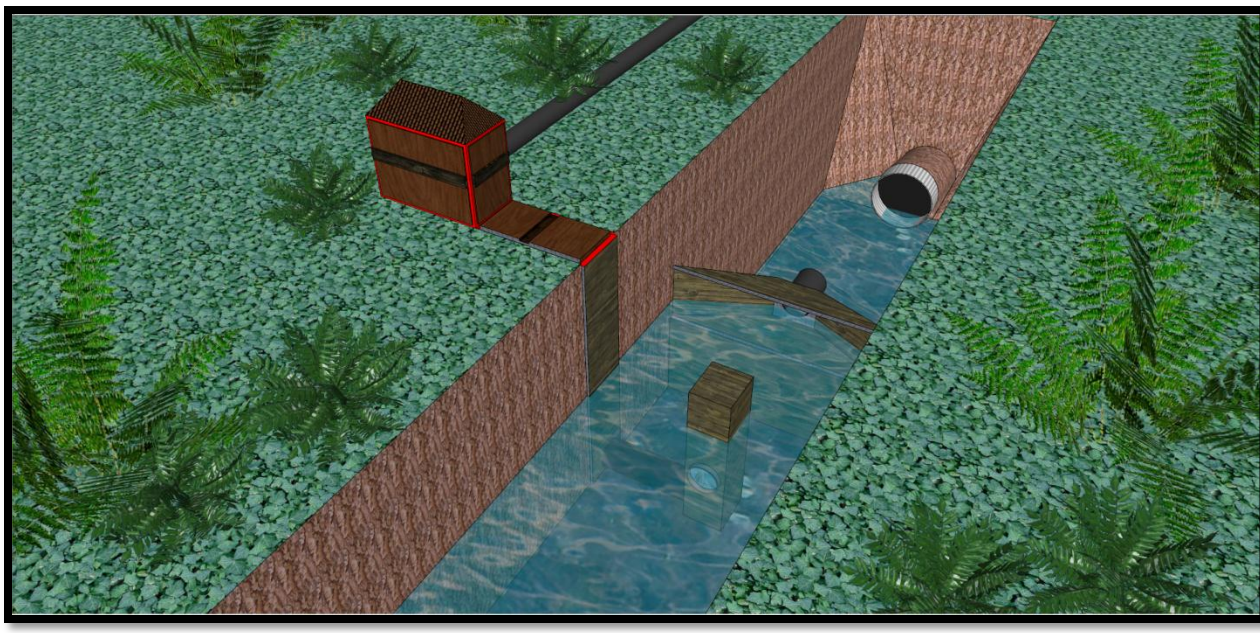


Figure 1: Conceptual Model of Garden Dam

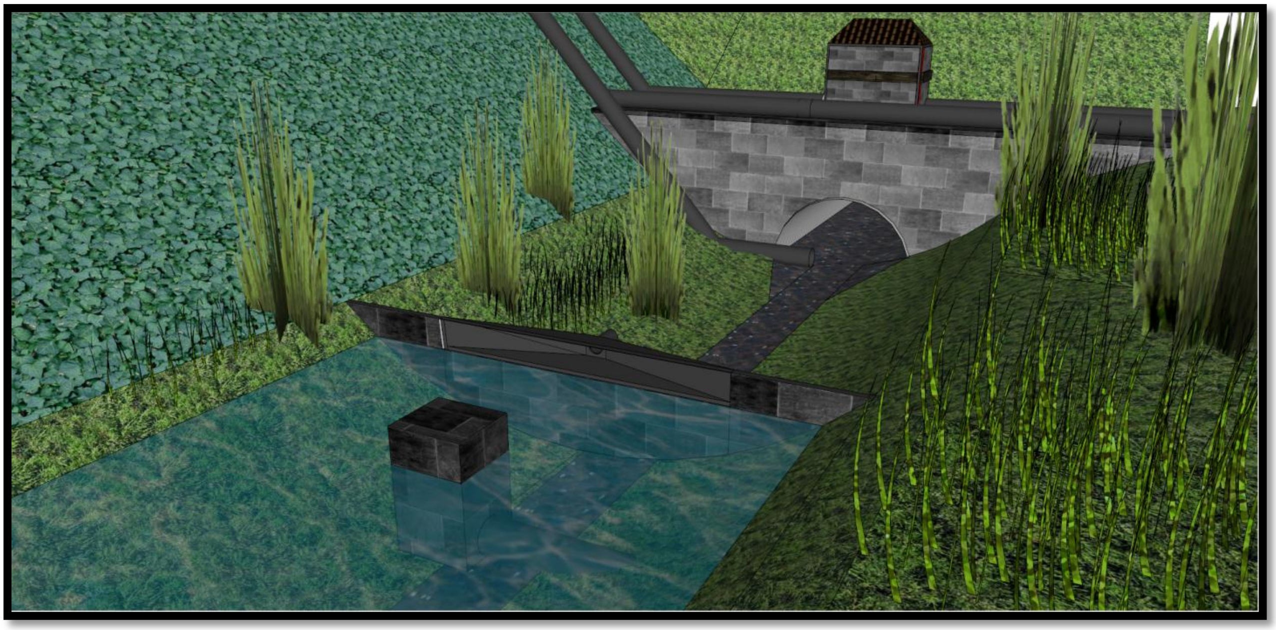


Figure 2: Conceptual Model of Parking Lot Dam

Finally the major observable element of the design is the storage tank located southeast of the parking lot dam. The Figure below illustrates the housed storage tank design.

Figure 3: Conceptual Model of Storage Tank Housing

These observable design elements give rise to two more critical systems which make up the overall conceptual design, the pumping system and the piping system. The pumping system consists of designing the intakes, pump stations, and pump sizes. The piping system consists of designing the pipe sizes, pipe path locations, and pipe connectivity. These initial designs are then modified to accommodate for implementing stormwater management practices during the wet season from November to April. The stormwater management practices consist of a control regime, a peak design flow, and flood intensity reduction.

All of the aforementioned conceptual design considerations were taken in order to develop a preliminary (early project life) cost estimate. The initial costs of the dams, storage tank, pumping system, and piping system were estimated and sent forward for the economic analysis. Before the economic analysis commenced, research was performed to acquire the annual municipal water savings, annual electricity costs, annual inspection and maintenance costs, growth rates, and replacements costs/frequency.

The economic analysis was then performed utilizing the obtained information. This analysis resulted in the production of the discounted payback period and the project life net savings which then warranted a sensitivity analysis. The sensitivity analysis investigated the following parameters; summer flow, total initial cost, electricity cost growth rate, water cost growth rate, water savings, and the worst case scenario. Finally, recommendations are derived and conclusions are drawn from the aforementioned process, which encompasses the entire feasibility study (based on the objectives of this subgroup of CIVL 498 K).

2.0 Methodology

This project covers several civil engineering disciplines, alternative solutions, and a large scope. The methodology of the CIVL 498 K class was to distribute tasks to subgroups, which essentially broke down the project to its core components, disciplines, and alternatives. This section briefly outlines the breakdown of what is investigated by this report (Report C). It begins with the overall objectives, which were then further refined and expanded by UBC SEEDS, and eventually delegated amongst the students registered in CIVL 498 K (under the guidance of Dr. James Atwater). Project data was provided by many sources and the critical data required for the completion of this investigation is outlined below. A portion of the data used in this report is directly derived from the other students registered CIVL 498 K who are not a part of the subgroup who performed the investigation for this report. Finally, the design and cost estimation methodology are outlined, with respect to the civil engineering disciplines and scope which were delegated to our subgroup.

2.1 Objectives

At the commencement of CIVL 498 K, an initial e-mail was sent describing the general outline of the course. This e-mail outlined the following scope of the project; "a number of projects involving storm water management and irrigation use within the Botanical Gardens. There are two objectives 1) to reduce the rate of storm water release to the cliffs and 2) to reduce the use of Metro Vancouver potable water for irrigation". This was simply the initial scope and objective statements, however through multiple meetings with UBC SEEDS and UBC Utilities the scope was improved upon by adding further details and refinements.

2.1.1 Objectives Outlined by UBC SEEDS

UBC SEEDS had initially provided a Project Description Form, which can be found in Appendix D. This Project Description Form briefly outlines the key Staff contributors, the overall purpose, the major details of the project, and the contribution to sustainability at UBC. A brief overview of what can be found in detail on the Project Description Form is as follows:

Overall Purpose: to propose implementable stormwater management practices

- Reduce erosion and periodic flooding in the Garden
- Reduce erosion on the cliffs west of the Garden
- To propose implementable water retention methods
- Aid in irrigation costs

Contribution to Sustainability at UBC

- Lower maintenance and repair costs
- Reduce Municipal water consumption
- Improve Foreshore habitat
- Water sustainability demonstration

2.1.2 Objectives Investigated

The investigation which was conducted by this subgroup of CIVL 498 K was delegated a primary objective and a secondary objective. The primary objective of this report is to propose a water retention system and reservoir which can effectively reduce the municipal potable water consumption of the Botanical Garden during the dry season (May to October). The secondary objective of this report is to propose a stormwater management regime, using the aforementioned infrastructure, which can effectively reduce the maintenance and repair costs of the Botanical Garden during heavy periods of rain during the wet season (November to April). More importantly though, the feasibility of these proposals being implemented were thoroughly examined based on several factors.

2.2 Project Data

As mentioned previously the data used in this report has several different origins. Some of it was provided at the onset of the project, a small portion was provided by the other members of CIVL 498 K, and the majority of the data was researched and obtained by our subgroup. The critical data parameters used in the calculations regarding the design, cost estimate, and economic analysis can be found in the sample calculations (Appendix A), Excel spreadsheets (Appendix B) and the references (Section 10.0). Furthermore, critical data input parameters are thoroughly noted throughout the entirety of this report.

2.3 Approach

The approach to determining the feasibility of our proposal was to first engineer a reservoir and water transportation system which could efficiently meet the irrigation demand during the dry season. Then the approach was to economically modify and expand the water transportation system to provide the maximum amount of stormwater management potential. Only after a thorough economic analysis, it would be possible to determine if one or both of the aforementioned objectives could be achieved completely.

2.3.1 Design Approach

The reservoir system was designed based on the simplicity and ease of construction. This would translate to above-ground construction for the storage tank which can be visually distracting to visitors and local residents. It is recommended that a natural structure be constructed over the storage tank. This would enable the storage tank to blend in with its natural surroundings. The water transportation system was designed based on cost efficiency, as this aspect would contribute to the annual costs through the entire life of the project. The modifications to implement the stormwater management regime were designed based on principles similar to what was mentioned above.

All of the designs were based on simple calculations, rule of thumb numbers, and manufacturer's specifications. This investigation and report only requires a reasonably implementable and logically engineered conceptual design based on perceived site conditions, which can be forwarded to the cost estimation process.

2.3.2 Cost Estimation Approach

The reservoir cost was dominated by the cost of the storage tank, as the design for the dams were extremely simple steel structures. The water transportation system cost was dependant on reducing the consumption of electricity, as this aspect of the project would contribute to annual costs through the entire life of the project. The costs for modifications to implement the stormwater management regime were estimated based on principles similar to what was mentioned above.

All of the cost estimates were based on simple calculations, rule of thumb numbers, and manufacturer's cost data. This investigation and report only requires a reasonably accurate and logically justified cost estimate based on the perceived conceptual design.

3.0 Reservoir Design

The reservoir design consists of three key components; the two dams and the water storage tank. The two dams are located on the Garden and parking lot streams; both of which exhibit summer flows. It is essential to utilize the summer flows in order to replenish the storage tank continually. The storage tank is located outside the Garden and near the parking lot. The reservoir design has been implemented to minimize the required storage capacity, and to a lesser extent control the flow of water during heavy storm events.

3.1 Garden Stream

The Garden stream is located directly east of the Trail 7 outfall inlet pipe. It is also adjacent to Old Marine Drive and at the foot of the Garden's property line. The approximate location of the Garden stream is shown in the Figure below.

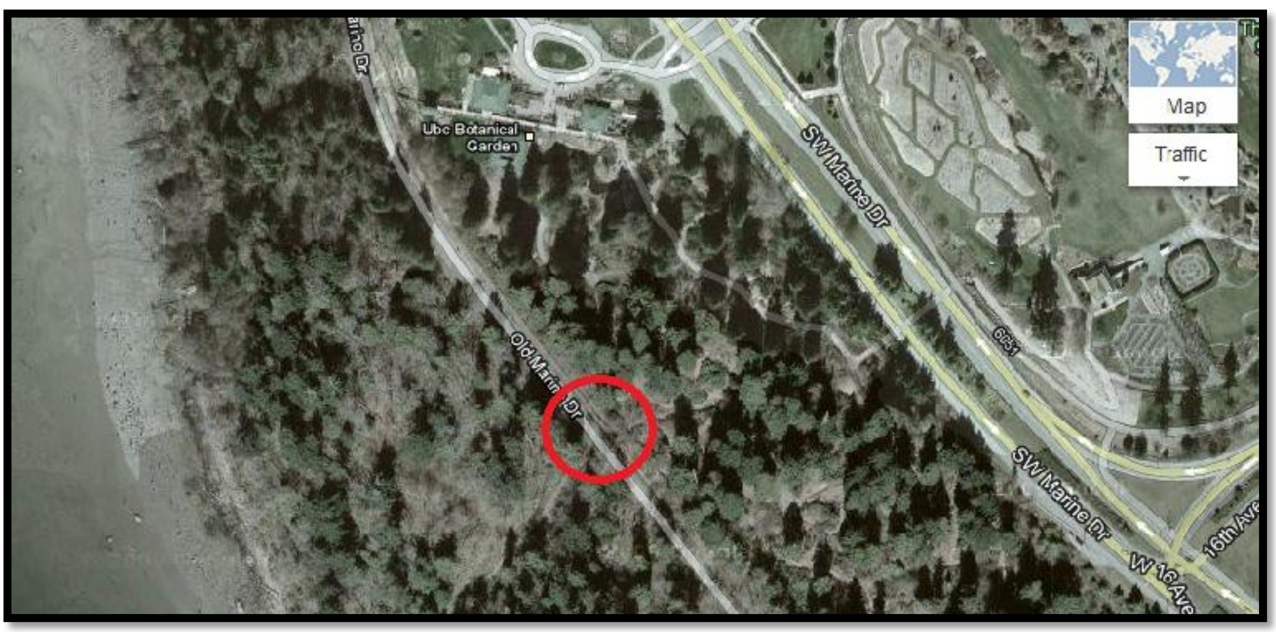


Figure 4: Garden Stream Location

The Garden stream has exceptional natural characteristics which enable it to perform efficiently as a dam. It is deep, rectangular in profile, long, and gently sloped. The depth allows for prime intake siting at a flexible location; it is desirable to place the intake slightly above the ground where sediments are not present. This prevents the extraction of sediments by the intake which can cause serious wearing and mechanical problems. The rectangular profile allows sufficient capacity, increased constructability, and easy maintenance access. The length and slope allow for minimal disruption to upstream flow and velocity when the water level rises in the dam. A picture of the Garden stream is shown in the Figure below.

Figure 5: Garden Stream

3.1.1 Garden Stream Dam

The Garden stream dam is simply a thick sheet of steel (design dimensions cannot be calculated as it heavily depends on surrounding properties including soil and rocks which are outside the scope of our subgroup). However, as illustrated in Section 3.3, this cost is dominated by the cost of a storage tank. This is still likely to be the case even if the given surrounding parameters are pushed to its lowest extremes. From observation it can be noted that the walls of the stream have eroded all the way to solid rock which will most likely aid in the structural capacity of the engineered dam. This is because, if the thick sheet of steel is supported completely by the solid rock instead of soil, the chances of it failing during peak rain events are reduced due to higher moment resistance. The most useful view of the Garden stream design is shown below and the complete additional views (in the form of an AutoCAD Drawing) can be found in Appendix C titled Drawing C.1.

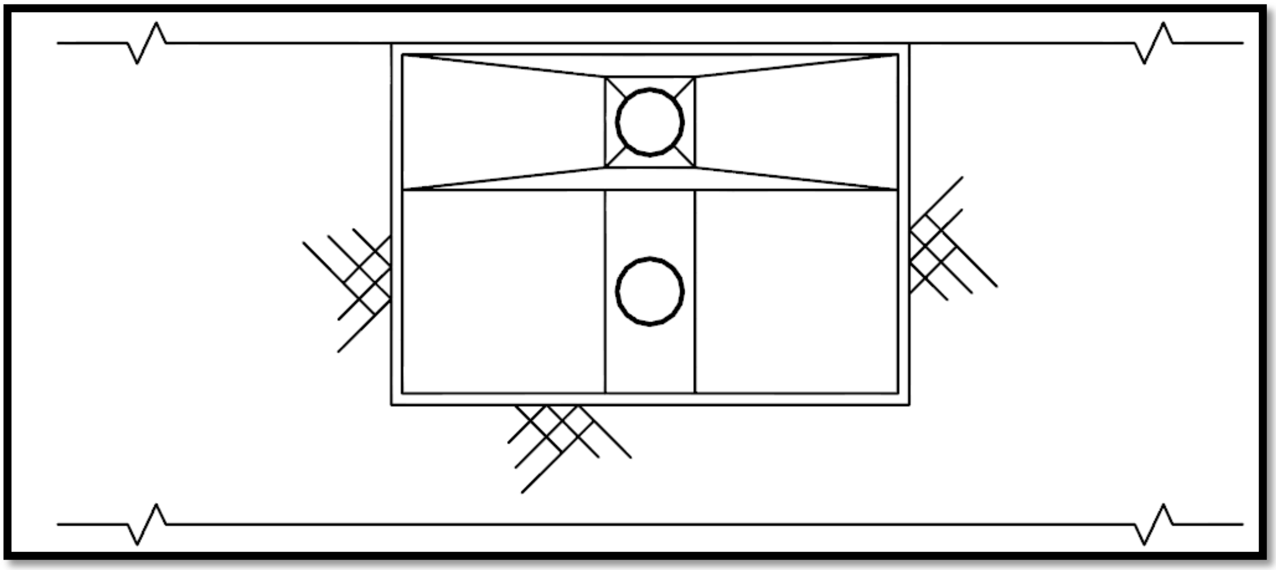


Figure 6: Garden Stream Dam Design

The design demand of the dam can be easily estimated as the hydrostatic pressure of the full dam. However to engineer the capacity of the solution, two design checks must be considered. Firstly, the sum of the lateral resisting forces should exceed the sum of the lateral acting forces. Secondly, the sum of all rotational moments should equal zero.

3.1.2 Garden Stream Spillway

The Garden stream spillway is designed to allow the dam to overflow in a controlled manner during heavy storm events. This controlled manner will mitigate erosion caused by the increased elevation head due to the dam. The diameter of the spillway is less than the diameter of the existing stream outfall; this will mitigate flooding as the capacity for water exiting is greater than the water entering. This entire conceptual design is based on a peak design flow (discussed in Section 5.2 of this report). If the peak design flow is exceeded (which is inevitable) the water level in the dam will match the height of the dam and then the water will spill uncontrollably over the dam. The consequences are mitigated by installing a steel plate under the outlet of the spillway pipe, which will effectively reduce most of the erosion where the elevated water hits the stream.

3.2 Parking Lot Stream

The parking lot stream is located directly west of the parking lot. It is also adjacent to Old Marine Drive and at the foot of the Garden's property line. The approximate location of the parking lot stream is shown in the following Figure.

Figure 7: Parking Lot Stream Location

The parking lot stream also has natural characteristics which enable it to perform efficiently as a dam. It is extremely long yet gently sloped and has a natural profile, but is quite shallow. It would seem as though the lack of depth would cause intake issues, however, the presence of natural vegetation along the stream bed enable it to retain sediments. The length and slope allow for minimal disruption to upstream flow and velocity when the water level rises in the dam. A picture of the Garden stream is shown in the following Figure.

Figure 8: Parking Lot Stream

3.2.1 Parking Lot Stream Dam

The design approach of the parking lot stream dam is exactly the same as the Garden stream dam. However, the design calculations are slightly more complicated as the profile is an irregular shape. The most useful view of the parking lot stream design is shown below and the complete additional views (in the form of an AutoCAD Drawing) can be found in Appendix C titled Drawing C.2.

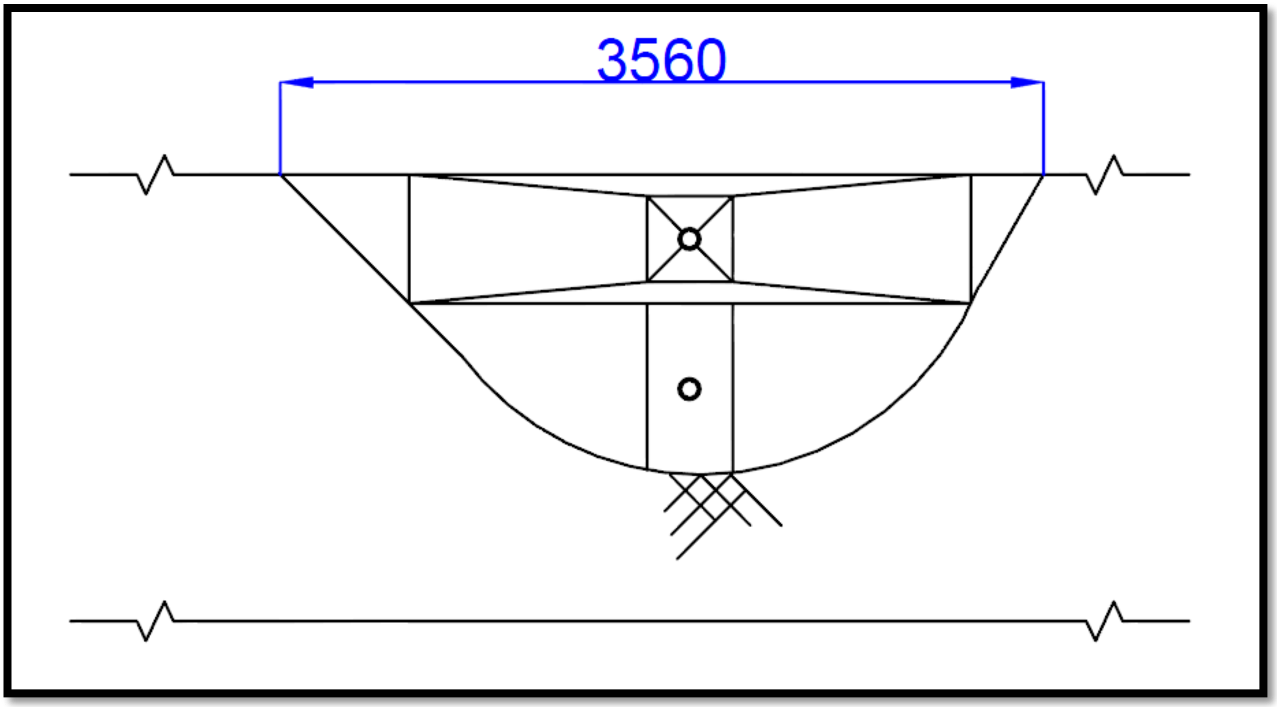


Figure 9: Parking Lot Stream Dam Design

From observation it can be noted that the soil has relatively high strength and cohesion parameters as the eastern slope of the stream is approximately 60 ^{0} and has not experienced any observable failure or erosion.

3.2.2 Parking Lot Stream Spillway

The parking lot stream spillway follows the exact same design as the Garden stream spillway. Please see Section 3.1.2 for details.

3.3 Water Storage Tank

The water storage tank is one of the most crucial elements of the design. Upon its volume, rests the success and efficiency of the irrigation reservoir and stormwater management regime. Furthermore, it is the largest contributor to the initial cost. Any comparison made, with respect to initial cost, will lead to a dominating result. The upper end of the storage tank cost will cost, if the entire demand of 14,500 m^3 of water is to be stored, approximately $918,000. Similar to its economic impact, the storage tank, also dwarfs all other infrastructure with respect to its footprint and height. The most important consideration for tank sizing is the cost. On the other hand, the most crucial consideration for tank siting is the size of its footprint. The design is approached at a balance between compromising economic feasibilities and siting possibilities.

3.3.1 Tank Sizing

The storage tank size is obtained based on several essential parameters and the reservoir calculations. Firstly, the dry season (26 weeks) irrigation demand is broken down into weekly emptying. Secondly, the weekly storage tank filling (via the summer flows in the dams being pumped in) is calculated. Thirdly, the net weekly reservoir loss (for irrigation) is calculated by subtracted the emptying from the filling of the storage tank. Finally, this net weekly loss is extrapolated through the entire dry season by multiplying by 26 weeks. This reservoir calculation results in the required volume of water existing in the storage tank at the beginning of the dry season, such that at the end of the dry season there is no water remaining in the tank. Further details, regarding the reservoir calculation, are demonstrated in Appendix A and Appendix B.1.

The storage tank volume calculated to carry on the rest of this investigation is 4,736 m^3. The capacity of the storage tank selected to meet this demand is 5,000 m^3. Another subgroup of CIVL 498 K is investigating the emergency water supply for UBC residents, and this extra capacity in our tank will accommodate that demand. Also, that emergency demand will set our minimum draw down water level. This essentially means that a certain amount of water will never be emptied in case of unexpected emergencies.

The foot print of the tank can be estimated based on a fixed value of the tank height. On the basis that the tank footprint reduces as the tank height increases, it was a logical decision to maximize the tank height. Maximum tank heights from multiple manufacturer websites were found to be between 6 m to 8 m. A maximum height of 6 m was chosen to be conservative and cautious with respect to rising costs due to additional structural requirements. As the depth increases, the hydrostatic pressures rises, and the tank consequently requires more capacity to resist lateral forces which in turn requires more structural reinforcing material. The footprint is then calculated by dividing the tank volume by the design tank height. This yields the area which is approximately 800 m^2. Storage tanks in this volume range are generally cylinders, thus the diameter of the circle is calculated as 32 m. A detailed footprint calculation can be found in Appendix A. The Figure below illustrates a storage tank similar in size and shape to what the design calls for.

Figure 10: Large (millions of Litres) Storage Tank

3.3.2 Tank Siting

Due to the relatively large footprint of the storage tank, the only reasonable place to site the tank is outside the Garden (near the parking lot). There are several alternatives to siting the tank, however at this initial phase we will consider the most economical alternative. This option is to place the storage tank above ground. An underground storage tank would result in an additional initial cost due to excavation. It is understandable that this option may not be aesthetically desirable, however if housed in a way which mimics the existing buildings, it may be acceptable. Furthermore, a housed above ground storage tank enables the building to function as centre which clearly demonstrates water sustainability to the public. Also, the housing would allow convenient and necessary accessories such as mechanical rooms, offices, and pump houses to be located directly adjacent to the tank. The proposed conceptual model of the storage tank housing is illustrated in the Introduction section of this report. The following Figure illustrates the storage tank location.

Figure 11: Storage Tank Location

4.0 Water Transportation System

The water transportation system consists of a pumping system and a piping system. The crucial components which make up the pumping system are the intake structures and pump stations. The important design elements of the piping system are the sizing, siting, and connectivity. The pumping system is heavily dependent on the reservoir design while the piping system is heavily dependent on the pumping system.

This section only discusses the pumping and piping systems for the storage tank filling. However, there are two emptying pumping and piping systems. Firstly, there is the stormwater management release regime which is discussed in Section 5.0 of this report. Secondly, there is the connection to the existing irrigation system which is excluded from the scope of this investigation and report.

4.1 Pumping System

The pumping system is a crucial contributor to the annual costs during the life of the project. It has therefore been optimized to be extremely economical to increase annual savings. There are two identical pumping system designs. The only differences between the two systems are the general dimensions and the sizes of pumps. Firstly the water level is raised by the two dams, which provides optimum intake performance due to elevated heads. In addition, the intakes are placed slightly above ground to decrease sediment transportation. This reduces the amount of screening required in the pump stations. Finally, with all of these considerations taken into place, small efficient pumps can be utilized to increase economic savings and negate frequent replacements. A complete layout of the pumping system (in the form of an AutoCAD Drawing) can be found in Appendix C titled Drawing C.3.

4.1.1 Intake

The intake structure is simply a small steel cylinder with an opening for the water to be drawn in by the pressure head created by the pump. It will be placed a few feet upstream of the dam and will be directly connected to the pump station. There will also be a wet season intake opening and a dry season intake opening; which can be open one at a time or in tandem.

4.1.2 Pump Station

The pump station is a simple steel structure which consists of multiple vertical chambers. These chambers have screens of varying nominal sizes, which capture sediments in their respective size ranges. The chambers are designed to be accessible via its roof, and the screens are designed to be removable to ease cleaning, maintenance, and the replacement process. The final chamber of the pump station houses the turbine of the pump.

4.1.3 Pump Sizing

The pump type chosen for this design is a vertical turbine pump. This pump has an orientation which makes it possible to have the pump housed above ground. That will increase the ease of inspection, maintenance, and replacement. It is understandable that this option may not be aesthetically desirable, however if housed in a way which mimics the structures in the immediate vicinity it may be acceptable. The proposed conceptual models of the pump station housing are illustrated in the Introduction section of this report. There are four pumps which are to be housed in this orientation, for the two streams. There will be a wet season pump and a dry season pump; which allows pumps to operate in their optimum efficiency range (with respect to the expected flows). The pumps are also inspected biannually, when one is shut off for the season and the other is turned on for the season. This will ensure the optimum performance of all four pumps and effectively increase their economic life.

The pump sizing is based on the expected (minimum and maximum) flows that will occur during the dry and wet seasons. The dry season flow is known as the summer base flow; which is being investigated by another subgroup of CIVL 498 K (See Report A). The impact of the summer base flow on the overall project will be discussed later in this report in Section 7.0.

The flows (can be found in Appendix B.1.) were then used to find operating power ratings where the flows were reasonably close to the high efficiency range. The Figure below illustrates some typical pump curves which accommodate the expected design flows in relatively high efficiency ranges.

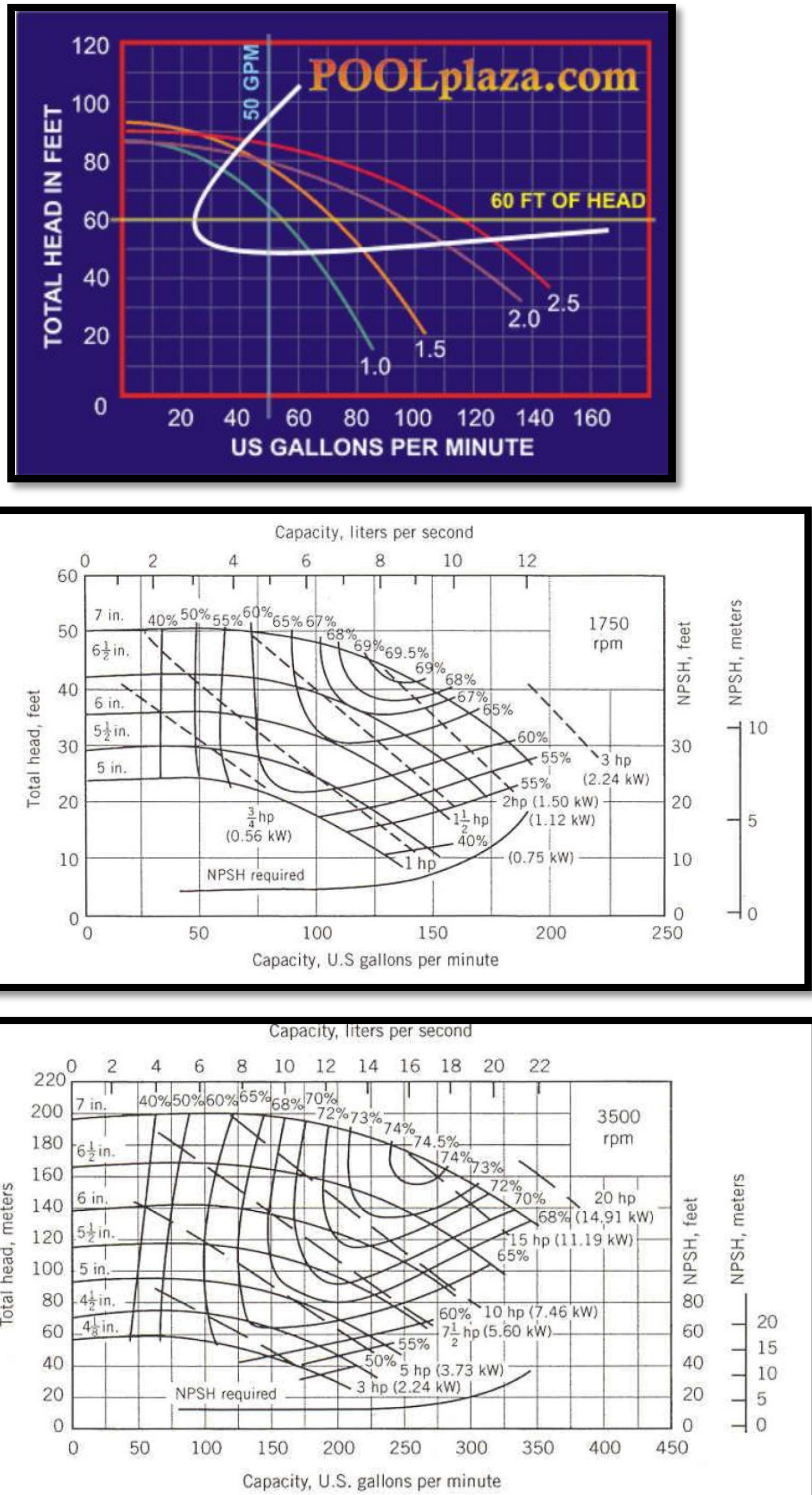


Figure 12: Optimum Pump Curves

4.2 Piping System

The piping system is the simplest yet largest part of the water transportation system. However, it is dominated by the pumping system and reservoir design. Almost every aspect of the piping system is derived from considerations regarding the other designs.

4.2.1 Pipe Sizing

Pipe sizing is a secondary consideration when sizing a pump based on flow and operating power rating. To move forward with the design a conservative estimate of 200 mm diameter was used. This is a very typical size, however it is a generous overestimate as the flows are in the mid to low range of these small pumps.

4.2.2 Pipe Path Siting

The pipe path siting is based on two principles. Firstly, reducing the impact to the Garden and secondly the shortest piping length. The pump outlet from the Garden stream will run above ground and alongside the fence separating the Garden and Old Marine Drive. This will then meet with the pump outlet pipe from the parking lot stream. They will then run in parallel to the storage tank inlet. The following Figure illustrates the connectivity between the two dams and the storage tank.

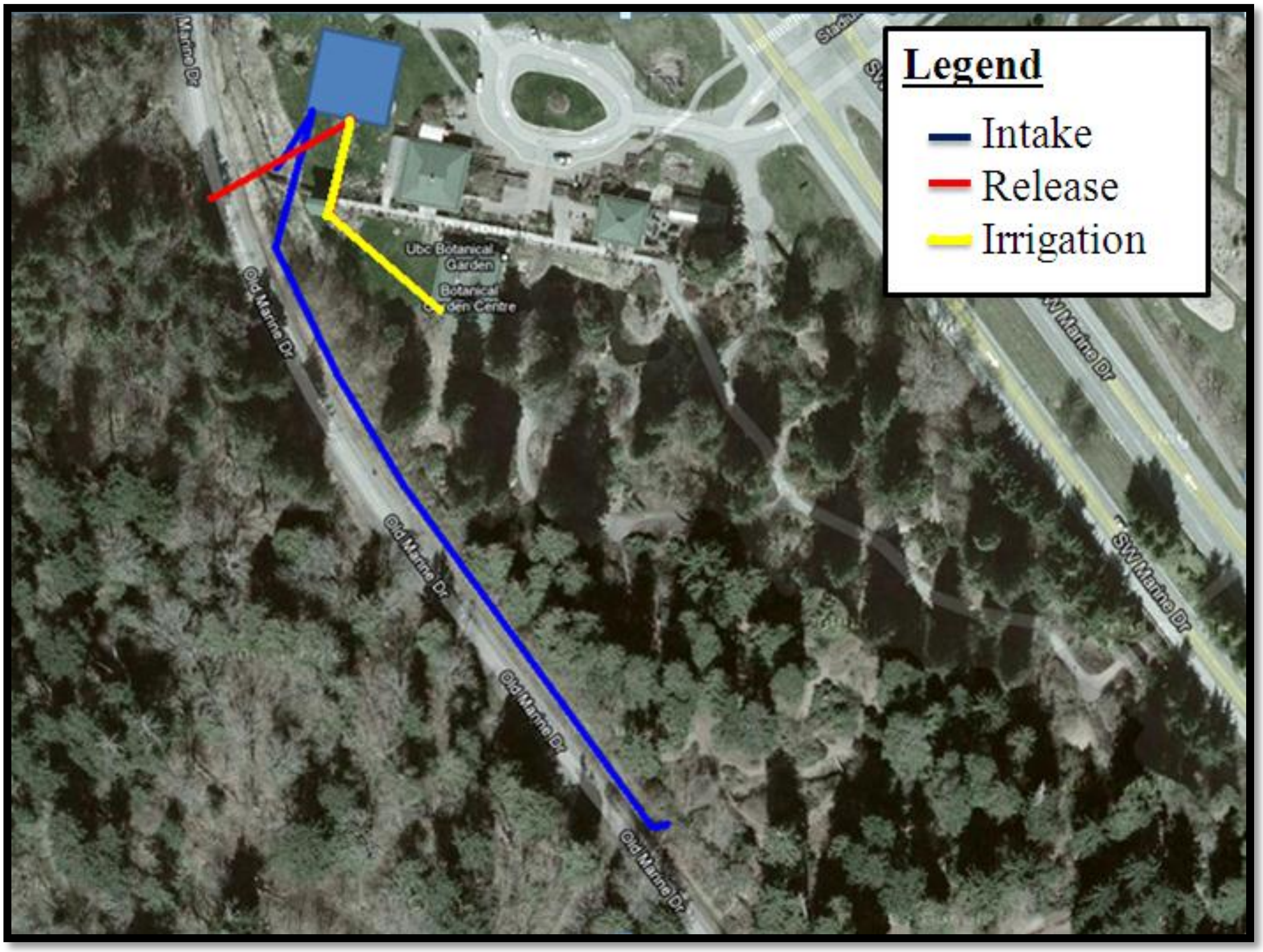


Figure 13: Piping Layout

4.2.3 Pipe Connectivity

This section covers the connectivity of all pipes that either transport water in or out of the storage tank. The connection to the existing irrigation system is shown as an outlet pipe, as previously mentioned this is excluded from the scope of this investigation and report. Also, the connections to the stormwater management release pipes are shown as an outlet pipe. What these connect to will be discussed later in this report in Section 5.0. Please refer to Drawing C.4 in Appendix C for details regarding the connectivity of the storage tank.

5.0 Stormwater Management

As stated in Section 2.3, "The approach to determining the feasibility of our proposal was to first engineer a reservoir and water transportation system which could efficiently meet the irrigation demand during the dry season. Then the approach was to economically modify and expand the water transportation system to provide the maximum amount of stormwater management potential. Only after a thorough economic analysis, it would be possible to determine if one or both of the aforementioned objectives could be achieved completely". With this in mind it was expected at this point that stormwater management effectiveness would be at the low end of what was originally expected.

The conceptual design for the stormwater management system is comprised of the following three concepts; the control regime, the peak design flow, and the flood intensity reduction. The stormwater management system is mainly limited by the volume of the storage tank which was designed before considering any of the aforementioned concepts of stormwater management.

5.1 Control Regime

The control regime is based on what can be done to reduce peak river flows during the wet season (November – April). During this time the reservoir infrastructure and water transportation system will be used to fill the storage tank when it rains, and empty the storage tank after its stops raining. This water will be released in the parking lot stream culvert (just downstream of the parking lot dam), and sent to the trail 7 outfall. Figure 13 illustrates the release pipe (see Section 4.2.2).

5.1.1 Dry Days versus Wet Days

To make efficient use of the storage tank over the entire wet season, we considered the average consecutive days of rain and the average consecutive days of no rain. This enables a calculation to be performed which determines the flow at which water can be collected and released; so as to efficiently utilize the storage tank volume.

Firstly, twelve years (2000 – 2011) of Vancouver rainfall data were compiled form Environment Canada. Then the numbers of consecutive dry and wet days were found for each year. This was then averaged, and it was found that the average consecutive wet and dry days are 3.72 days and 2.67 days respectively.

5.1.2 Storage Tank Volume Efficiency

The storage tank usage is optimized by calculating the continuously pumped flows which would fill the storage tank in 3.72 days and empty the tank in 2.67 days. This allows the maximum flows to be calculated to design the pumping and water transportation systems. This approach is very conservative and is only effective for a peak design flow, which will be discussed in the next section.

5.2 Peak Design Flow

The peak design flow is considered to be the sum of the intake flow and the two stream spillway flows. However this is augmented by the emergency flood pipe (see Section 5.3.2). So the peak design flow, during emergency flood events, is considered to be the sum of the intake flow and the two stream spillway flows plus the additional continuous flow diverted by the emergency flood pipe. The peak design flow was calculated to be 110 L/s which can be found in Appendix B.1.

5.3 Flood Intensity Reduction

The flood intensity of the peak design flow (which is distributed between the two streams) is reduced by 32% when the continuous emergency flood diversion system is utilized. This system simply diverts the release flow from the parking lot stream culvert to an outfall on the other side of Old Marine Drive. This only occurs when the tank is full, the rain has not ceased, and the water levels in both of the dams have exceeded the height of the dams. This pipe runs parallel to the release pipe until it reaches the parking lot stream culvert and then continues to run across Old Marine Drive. The pipe is secured under a steel speed bump to allow normal traffic flow, and the water is released shortly after Old Marine Drive. As the maximum flow is quite small, erosion on that undeveloped area is not going to be anywhere near the severity of the accumulated effect that the flow would have had in the Garden. Figure 13 illustrates the release pipe (see Section 4.2.2).

For rainfalls events which do not approach the peak design flow and are preceded by several consecutive relatively dry days, the percentage reduction can approach 100 %.

5.4 Release Parallel Pumping Plan

The release parallel pumping plan allows for two medium sized (6 kW) pumps to run in parallel. The main reason for this design is for redundancy in the release system. If one pump breaks down, or is unable to be repaired before a large storm event, the remaining pump should be able to greatly minimize the effects caused by a storm event. Furthermore, pumps in parallel increase the maximum flow rate capacity which can be reached before shutoff. This can accommodate future modifications to the stormwater management regime.

In addition, these pumps are to be used for the distribution of water during unexpected disastrous events. It will convey the water held in the storage tank to the onsite water treatment facility; then to the designated emergency water distribution centres. The storage tank will at all times hold approximately 300 m^3 of water, which far exceeds the demand for the disaster response water supply. Please refer to Report D for further details regarding the water quality treatment and emergency water supply system.

Finally, it is evident that pumping stormwater in order to mitigate the undesired and inevitable effects of large rainfall events is economically unjustifiable. However, our design uses the following justification; the infrastructure required is already in place, the reservoir is operational for half the year and the stormwater management regime is operational for the other half, and the cost of running the pumps will directly influence the decreased cost of yearly maintenance/repair of the Garden.

Furthermore, it has come to our attention that a heat pump system may be used to extract heat from the source (water in the storage tank). This heat extraction would occur during stormwater collection and stormwater release. The heat sink (terminal for the extracted heat) would be the existing buildings in the Garden. This system essentially provides minor heating, which will reduce the heating expenses incurred by the Garden during the wet season. This in turn will partially mitigate the cost of pumping the stormwater. For additional stormwater pumping cost mitigation, the process can be reversed during the dry season, and the heat pump system will then provide minor cooling (via the summer flow inlet pumping and the irrigation flow outlet pumping), which will reduce the cooling expenses incurred by the Garden during the dry season.

6.0 Economic Analysis

This analysis is conducted to identify the potential economic benefits of installing the reservoir system. According to a report published by the Government of Newfoundland & Labrador, the typical life of steel water storage tanks range from 50 to 100 years. To provide conservative results from the analysis, a 50-year time frame is applied. The initial cost is obtained from the costs to construct and install the dam, storage tank, pumping system, and piping system.

To measure the success of the proposed design, the annual savings and expenditures need to be considered. The annual costs include electricity costs and maintenance costs while the annual savings is derived from reduced water consumption. All outputs from the yearly calculations are converted to present worth in real dollars to reflect the present economic benefits without the influence of inflation.

6.1 Initial Cost

To obtain a more precise and realistic initial cost, a contingency budget is incorporated in the analysis for any unforeseen problems that may occur during the construction. A typical project usually includes a contingency budget of 5% to 10% of the overall cost according to Slater & Son who specializes in design-build projects. This economic analysis uses a 10% contingency budget to acquire conservative results. Furthermore, the Harmonized Sales Tax of 12% obliged by the provincial government is also included.

6.1.1 Dam Cost

The cost of creating the dams for the two streams are relatively low when compared to the storage tank cost. Furthermore, the simplicity of the design enables the dams to be built quite easily and with a readily available and economic material. As mentioned previously in Section 3.1.1 and 3.1.2, the soil conditions are of paramount importance. That alone can dominate the cost of the dams. However, if the soil parameters are found to be inadequate for our design the contingency budget should be more than accommodate the minor changes that may arise in the thickness or area of the steel sheet.

6.1.2 Storage Tank Cost

The storage tank cost was estimated using an online educational estimating tool called Matche.com. This estimating tool utilizes a user created data base of actual costs. Then using the input parameters of volume, storage tank type, and material an estimate is produced based on its database. This is an educationally produced estimating tool and is designed for use in early project life feasibility studies. Here the designed storage tank volume, of 5000 m^3, was used as an input parameter. Then the most economically efficient storage tank, whose capacity range met the demand, was input (Vertical / Cone Roof, Flat Bottom, Field Fabricated). Finally, the most economically efficient material was chosen for the input (Carbon Steel API). The cost of this tank was estimated to be $459,600 (2007 $US).

6.1.3 Pumping System Cost

The pumping system cost is dominated by the storage tank. However, due to multiple replacements throughout the project's lifetime it is important to make a conservative cost estimate which can accommodate material cost growth, higher power rating efficiency requirements due to electricity cost growth, and modifications to the required flow due to water cost growth. The design initially called for three pumps, one for each stream and one for the stormwater release. According to multiple manufactures' websites pumps with low flow and high efficiency on average cost approximately $1,500 to $2,000. A conservative estimate then, for three pumps along with their intakes, pump stations, and housing is approximately $10,000. However, the design was then modified by adding two more electrically efficient pumps to run during the summer and the release pump was split into two smaller pumps which would run in parallel. This essentially doubles the cost estimate to approximately $20,000.

6.1.4 Piping System Cost

According to the U.S. Plastic Corporation's PVC pipes cost data, a typical 8-inch PVC pipe for underground drainage purposes costs $12.04 US dollars per foot. This is approximately $12 Canadian dollars because the exchange rate between USD and CDN recently is very close to a 1-to-1 ratio. The total required length for the reservoir system is estimated to be 2,500 feet which translates to about $30,000. After including the installation cost of $20,000, the total cost for the piping system sums up to approximately $50,000.

6.2 Annual Cost / Savings Comparison

Annual cost/savings comparison is essential to the study; it demonstrates whether the accumulative savings can exceed the accumulative expenditures within the 50-year lifetime of the reservoir system. All outcomes are converted from annual worth to present worth in real dollars for an accurate comparison.

6.2.1 Annual Municipal Water Savings

Based on the City of Vancouver's Waterworks By-law, it is assumed that the Botanical Garden is currently paying $0.99 per 1,000 litres it uses for summer irrigation. The current average irrigation demand for the Botanical Garden is 545 m^3 per week from beginning of May to end of October. The irrigation period is close to 6 months or 26 weeks which requires a total of 14,170 m^3 of water annually. The reservoir system is designed to completely eliminate the dependence on the city's water. As a result, the annual saving is $14,027.

6.2.2 Annual Electricity Costs

The reservoir and stormwater systems use a total of 6 pumps to operate – two garden pumps, two parking lot pumps, and two release pumps. The Table below summarizes the power ratings and annual operating duration for each pump.

Table 1: Operation Data of Pumps

	Power Rating (kW)		Annual Duration (hr)	
	Pump #1	Pump #2	Pump #1	Pump #2
Garden Pump	1.83	0.735	2540.4	4380
Parking Lot Pump	1	0.735	2540.4	4380
Release Pump	6	6	1839.6	1839.6

The annual electricity consumption of the pumps can be obtained by multiplying the power rating by the annual duration. BC Hydro currently charges $0.0915 per kWh for commercial consumption. The annual electricity consumptions and costs of each pump are presented in the following Table.

Table 2: Cost of Electricity

	Annual Consumption (kWh)	Annual Cost ($)
Garden Pump	7868	$720
Parking Pump	5760	$527
Release Pump	22075	$2,020
Total	**35703**	**$3,267**

6.2.3 Annual Inspection and Maintenance Costs

According to the US Environmental Protection Agency, water storage tanks do not require maintenance. However, we believe that it is essential to hire an inspector to do annual checks on the storage tank to minimize any unexpected malfunctions. Additionally, the pipes and the pumps should be thoroughly examined yearly to ensure optimal performance. The hours of inspection are predicted to be about 30 hours annually at a cost of $100 per hour. Also, the pipes and pumps may require maintenance such as cleaning and replacement parts which is projected to be $2,000 a year. In conclusion, the annual inspection and maintenance costs sum up to be approximately $5,000.

6.2.4 Growth Rates

The charging rates of water and electricity grow yearly which plays a significant role in the analysis because the analysis time period is extensive. This is because the cost of water and electricity are expected to significantly and randomly vary in its growth over the 50-year period. The Consumer Price Index data provided by Statistics Canada indicates that electricity in British Columbia has increased 3.28% annually on average for the past 10 years. The cost of water in Vancouver has incremented on average 7.5% annually based on historical data according to an administrative report published by the City of Vancouver.

6.2.5 Replacement Costs

According to Pump Life Cycle Costs which is published by Energy Efficiency and Renewable Energy U.S. Department of Energy, typical pump systems need to be replaced within 15 to 20 years. For this analysis, the pumps will be replaced three times with a 15-year interval in between within the analysis period. On the other hand, the pipes are not going to be replaced because the European Plastic Pipes and Fittings Association states that PVC pipes have a life span of 50 years.

6.3 Overall Result

The first major outcome of the analysis is the discounted payback period which identifies the number of years it will take before the initial cost will be recovered. The second outcome is the potential net savings that the reservoir system can provide during the project life.

6.3.1 Discounted Payback Period

The analysis has utilized a discounted payback period instead of a conventional payback period because it delivers better results in terms of accuracy and reliability. The discounted payback period can disregard the influence of inflation, which has significant impact over an extensive project period. The following Figure illustrates the accumulative savings and expenses over the 50-year period.

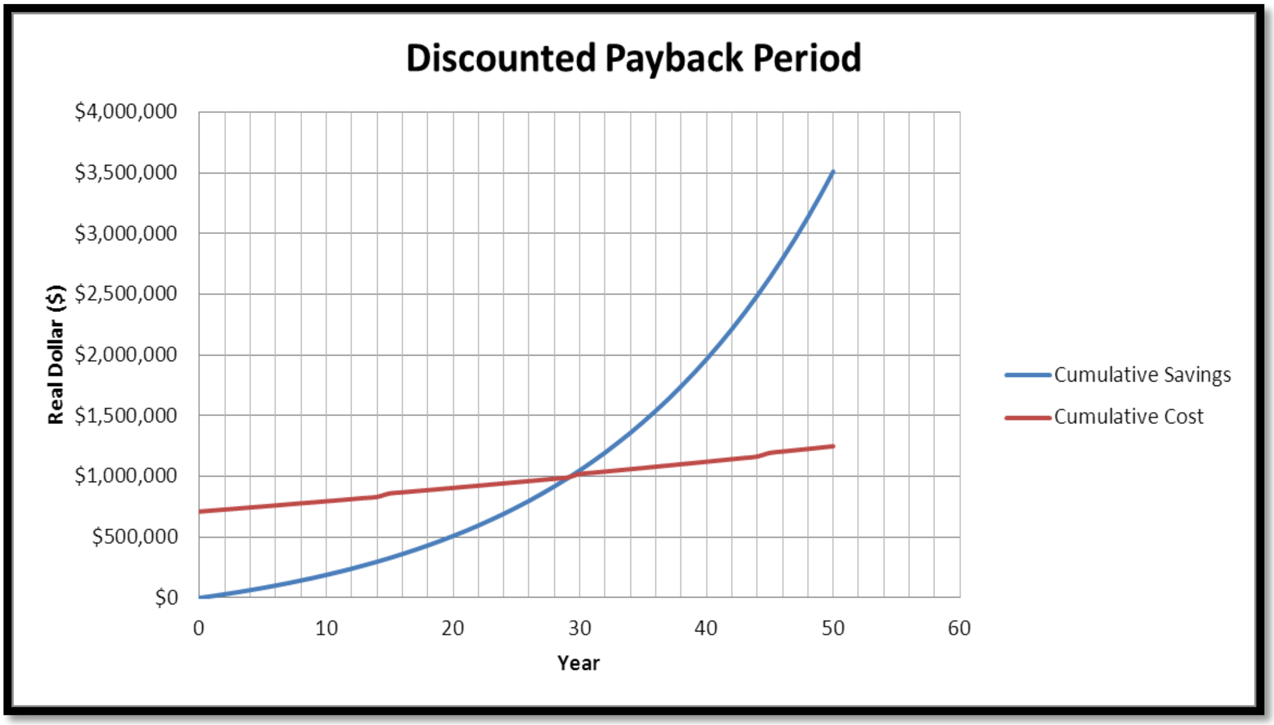


Figure 14: Discounted Payback Period

The point of intersection identifies that the discounted payback period is approximately 29 years.

Please note that the total initial cost of the project, including contingency and tax, is $711,401.

6.3.2 Project Life Net Savings

After estimating that the payback period is 29 years, there is a great potential for immense savings towards the end of the project. At the end of project life, the accumulative saving is $3,513,938 while the accumulative cost is $1,249,549. The potential savings is $2,264,390 which is outstanding considering that the initial investment is $711,401. The major contributing factor is the growth of water cost at 7.5% annually, which almost doubles the growth rate of electricity cost. Also, the initial water savings is already 5 times more than the electricity expense at the beginning of the project. In conclusion, the project is reasonably feasible in terms of this preliminary economic analysis. However, since this projection occurs over such a large time frame we must investigate the sensitivity of the results with respect to the key variables.

The table below summarizes and highlights the key components of the economic analysis. For detailed yearly expenses and savings, please refer to Appendix B.3.

Table 3: Summary of Economic Analysis

Total First Cost	**$711,401**
Cost of Water per 1000L	$0.9899
Cost of Electricity per kWh	$0.0915
Year 1 Water Saving	$14,783
Year 1 Electricity Cost	$8,308
Accumulative Saving	$3,513,938
Accumulative Cost	$1,249,549
Total Potential Savings	**$2,264,390**

7.0 Sensitivity Analysis

Because the key parameters used throughout this feasibility study are derived from research and measurements, they are subject to a moderate degree of uncertainty. It is important to know how sensitive the outcome is to the variations in these parameters. The main approach in this analysis is called the sensitivity graph. This method can clearly illustrate the sensitivity of a particular measure and identify the parameters that have significant impacts on the results relative to the others.

7.1 Summer Flow Sensitivity

Summer base flows may have large influences on the design of the circular footprint of the cylindrical storage tank. Consequently, it is necessary to understand the magnitude of effect which is plotted in the following Figure. Please note that the height of the tank is fixed at 6m in the analysis.

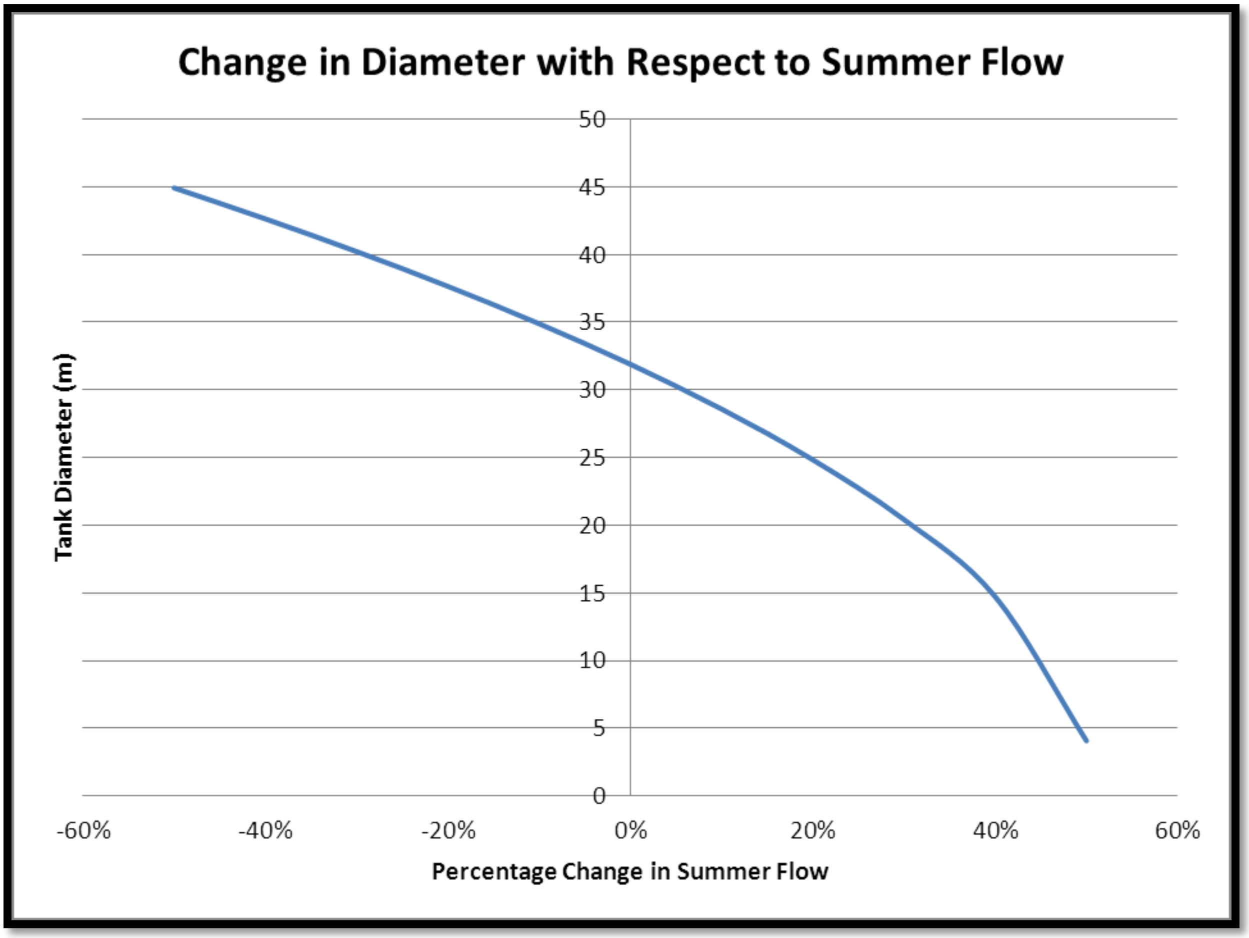


Figure 15: Changes in Diameter with respect to Summer Flow

The graph illustrates that the tank diameter can vary from 45m to 4m by adjusting the summer flow from -50% to 50% respectively. The degree of variation is very significant; therefore, it is essential to obtain accurate summer base flow data.

7.2 Economic Analysis

In terms of economic analysis, the four main parameters that may have strong influence on the potential savings are the initial cost, water cost growth rate, electricity cost growth rate, and water consumption reduction. The sensitivity graph below is completed by varying each of the parameters one at a time while holding all other parameters fixed.

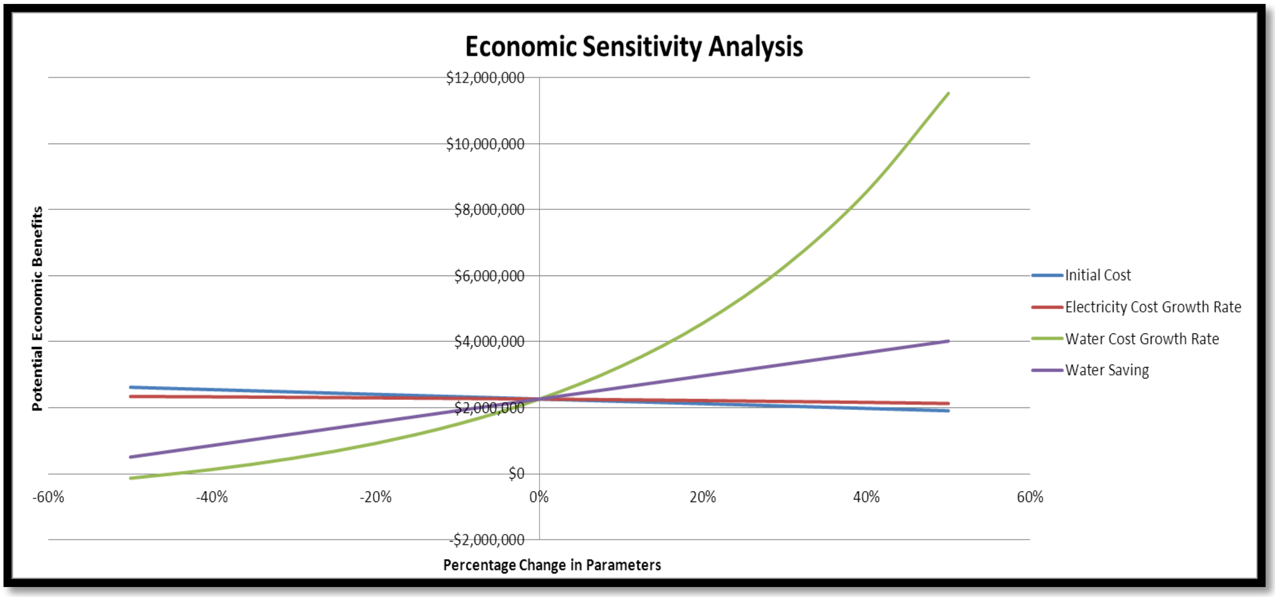


Figure 16: Sensitivity Analysis

The water cost growth rate clearly has the most impact on the potential economic benefit (this factor alone makes the results of the entire preliminary feasibility study extremely variable and cautiously advises further investigation and reliable data). Because the proposed reservoir system can satisfy the irrigation demand annually, the potential cost of water becomes the potential savings of the project. Hence, the reduction in the utilities bills is maximized and the savings increase exponentially due to the 7.5% historical growth rate in cost. The water savings are also relatively sensitive due to its direct relationship to the water cost growth rate. On the other hand, the operating cost and growth rate of electricity is a lot less than water, so its effect on the potential economic benefit is minimal. Furthermore, the initial cost of the project is proven to be relatively insignificant for a 50-year operating time frame.

7.3 Worst Case Scenario

The sensitivity analysis identifies that the water cost growth rate has the most impact on the potential saving in present worth. According to the City of Vancouver, the historical growth of water cost is 7.5% on average; however, it is not possible to predict the future growth rate. If the growth rate is reduced by 45%, the present worth in real dollars becomes $0. This essentially means that the project should not proceed if the growth rate is projected to be below 4.2%, on average, for the next 50 years.

8.0 Uncertainties & Recommendations

The tank size is directly derived from the summer base flows from the two streams along Old Marine Drive. The base flows are estimated from a few observations during the past month. Consequently, the uncertainty in summer base flows can be significant. The base flows should be monitored throughout the whole summer to obtain the most accurate data. On the other hand, the tank size is dependent on the irrigation demand. If the Botanical Garden wishes to expand in the future, irrigation demand will consequently increase and result in a larger tank size. Furthermore, if the Garden optimizes its irrigation regime, it can effectively reduce the tank size and the initial cost of the tank.

The water and electricity cost growth rates are based on historical data; however they may dramatically change in the future. The growth of electricity is based on the efficiency in which it was generated and the rate at which it is consumed. This can result in the rate rising or falling depending on the new sources of energy and the resulting habits of electricity consumers. The growth of water is based on the availability of water, the rate at which it is consumed, the ease of processing, and cost of the processing infrastructure. This can also result in the rate rising or falling depending on the diminishing sources of fresh water and the resulting habits of water consumers.

Also, the time frame of the project is 50 years, so the change can be significant. According to the sensitivity analysis, the growth rates have large impacts on the potential economic benefits. To minimize the uncertainty, it is recommended to construct multiple storage tanks throughout the 50-year time frame. Even though this can increase the construction cost due to inflation and cost of materials, this can diminish the economic risk from sudden decrease in growth of water cost. If the water cost growth is less than 4.2% on average, the reservoir system may not yield sufficient economic benefits. Moreover, this recommendation provides flexibility to construction locations due to smaller tank footprints.

The storage tank may not be visually appealing to the public because the appearance of steel material does not blend in with the Garden very well. Also, the size of the tank is vast and should not be overlooked. A simple structure can be constructed over the storage tank to cover the tank. The structure should match the style of the nearby structures to be consistent. Furthermore, the structure should be accessible to the curious public attracted by the structure. By doing so, it can then provide a great educational experience that reminds the visitors of the importance of water conservation. Also, this is a great example of a visible ``working water sustainability demonstration project``.

The final recommendation/first detailed investigation, design, and construction should be for the Garden and parking lot stream dams and pumping / piping infrastructure. This infrastructure should connect directly with the irrigation (no storage tank for now). This will then directly reduce the municipal potable water consumption, without significant initial costs. Furthermore, this initial setup will provide the necessary infrastructure required for the overall conceptual design.

However, this will not provide significant municipal potable water consumption reduction with respect to what can be achieved by utilizing a storage tank. This is due to the fact that when a storage tank is present the summer flows can be collected continually. Whereas, if a storage tank is not present the summer flows can only be used during irrigation times.

Alternatively, UBC has an ongoing effort to reduce water consumption by 50 %, this may also prove to be a good starting point for the project. The recommended tank size will effectively be halved (in volume) and the initial cost will reduce to a similar extent. However, as the Garden will now only be saving 50% of its existing water costs, it will be difficult to payback the initial cost. This is evident due to the sensitivity analysis showing that the initial cost is not as sensitive as the water growth rate, and the water sensitivity growth rate is directly dependent on the amount of water consumption.

Taking all of the results, recommendations, and discussions into account, we still recommend that the original conceptual design (in its entirety) must be investigated further, with respect to its feasibility. This is because our design is; the most effective with respect to municipal water supply consumption reduction, the most efficient with respect to utilization throughout the year for stormwater management, and the least detrimental to the existing Garden environment and infrastructure.

9.0 Conclusion

The proposed reservoir system addresses many objectives outlined in the project description form. The system is capable of entirely reducing the municipal potable water consumption for irrigation. The accumulative potential economic savings over the life cycle of the water storage tank is substantial. On the other hand, the operating cost of the pumps is minimal due to the high efficiency pumps chosen for the reservoir system. Moreover, the cost to repair or replace the pumps and pipes are relatively minor.

Stormwater management is provided through retaining and capturing of the stream water running along the Old Marine Drive. This can minimize the quantity of water flowing of the cliff on the west of the Garden and consequently reduce cliff erosion. The Botanical Garden experiences frequent flooding which is problematic. By placing pumps at the stream section located at Creek 7, the reservoir system can capture excess stormwater during peak events and retain it. After the peak events end, the reservoir system can simply release the water, at a controlled rate, back to through the outfall at Creek 7.

The system also delivers social benefits, which have values that cannot be measured quantitatively. The sizeable reduction of water consumption can reduce stress on the Metro Vancouver water treatment plants. Even though the decrease in stress may be insignificant in terms of the system itself, the lowering can be further extended by the support of the public. The presence of the tank provides educational opportunities for students, local residents, and visitors to learn about water conservation. Over the life time of the system, it is expected that many individuals will recognize the importance of water conservation and take critical actions to minimize domestic water consumption.

There exists a major drawback in the reservoir system which UBC should take into consideration. The discounted payback period is almost 30 years, and this is most likely not acceptable with respect to

UBC's standards. Nevertheless, the project should proceed because it can still provide about 20 years of savings which is projected to grow exponentially. Additionally, water storage tanks can last from 50 to 100 years, and only a 50-year time frame was used for obtaining conservative results. The possibility of the tank lasting over 50 years is high, and the savings can continue to grow.

The opportunities that this project has presented are numerous in quantity and tremendous in quality. This project not only has the potential to become one of the premier sustainability demonstrations in UBC for the next century, but also has the potential to generate substantial amount of savings. However, before this project can be viewed from this perspective, a more accurate feasibility study will be required to launch this project to its next phase and see it through to achieving its full potential.

10.0 References

Capacity and Dimensions. (2012). Retrieved from Pioneer Water Tanks: http://www.pioneertanks.com.au/technical-information/capacity-and-dimensions

City of Vancouver - Administrative Report. (2009, November 17). Retrieved from City of Vancouver: http://vancouver.ca/ctyclerk/cclerk/20091201/documents/a7.pdf

Contingency Planning. (2012). Retrieved from Slater & Son: http://www.slaterandson.com/page/article.php

Cyclone or Hurricane Rated Steel Tank. (2011). Retrieved from ACUS: http://www.acuswater.com/10089.htm

EPA Considering Requiring All Water Storage Tanks To Be Cleaned. (2010). Retrieved from Clean Water Tank Project: http://ronperrin.wordpress.com/tag/water-storage-tank-cleaning/

Evaluation of Potable Water Storage Tanks in Newfoundland and Labrador and their Effect on Drinking Water Quality. (2011, July). Retrieved from Newfoundland Labrador: http://www.env.gov.nl.ca/env/waterres/reports/drinking_water/Tank_Report_July_12_2011.pdf

Expected Lfe of existing PVC Water Systems; summar. (2011). Retrieved from The European Plastic Pipes and Fitting Association: http://www.teppfa.com/pdf/CivilsLifetimeofPVCpipes1.pdf

Fluid Flow Pump System. (2012). Retrieved from ENE: http://www.eninepump.com/zhichi/technical_6.pdf

Glencorse Water Treatment Works. (2012). Retrieved from CEEQUAL: http://www.ceequal.com/awards_119.html

Goulds Pump Technical Data. (2008). Retrieved from Goulds Water Technology: http://completewatersystems.com/brands/goulds/

Pool Pump Sizing. (2010). Retrieved from POOLplaza.com: http://www.poolplaza.com/pool-pump-sizing-2.shtml

Price Pumps. (2008). Retrieved from BPH Pump & Equipment, Inc.: http://www.bphpumps.com/price-pumps.asp

Pump Life Cycle Costs . (2012). Retrieved from U.S. Department of Energy: http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/pumplcc_1001.pdf

PVC Pipe. (2012). Retrieved from U.S. Plastic Corp.: http://www.usplastic.com/catalog/item.aspx?itemid=23979&clickid=redirect

PVC Pipes - Pressure Ratings. (2011). Retrieved from The Engineering Toolbox: http://www.engineeringtoolbox.com/pvc-cpvc-pipes-pressures-d_796.html?v=2&units=inches

Steel Tanks. (2010). Retrieved from WaterStore Poly Tanks: http://www.waterstore.com.au/waterstore-steel-tanks/

Tank Cost. (2003). Retrieved from Matche.com: www.matche.com/EquipCost/Tank.htm

Appendices

Appendix A – Sample Calculations

1. Summer Base Flow

According to Dr. Atwater, the summer base flow is approximately 10% of the April base flow.

$$Summer\ Base\ Flow = April\ Base\ Flow * \ 0.1$$

$$April\ Base\ Flow = 4\ \frac{L}{s}$$

$$Summer\ Base\ Flow = 4\ \frac{L}{s} * 0.1 = 0.4\frac{L}{s}$$

2. Required Irrigation Demand

$$Water\ Consumption\ (Irrigation) = Required\ Irrigation\ \times Area\ of\ Irrigation$$

$$Required\ Irrigation = 0.05\ \frac{m}{week}\ according\ to\ Doug\ Justice$$

$$Area\ of\ Garden = 41{,}900m^2$$

$$Fraction\ of\ Area\ Requiring\ Irrigation = 0.3$$

$$Area\ of\ Irrigation = Area\ of\ Garden\ \times Fraction\ of\ Area\ Requiring\ Irrigation$$

$$Area\ of\ Irrigation = 41{,}900\ m^2 \times 0.3 =\ 12{,}570\ m^2$$

$$Water\ Consumption\ (Irrigation) = 0.05\ \frac{m}{week} \times 12570\ m^2 = 628.5\ \frac{m^3}{week}$$

3. Irrigation Demand in 2011

$$Water\ Consumption\ (Irrigation)\ in\ 2011 = 12{,}000\ \frac{m^3}{Irrigation\ Period}$$

Irrigation period is from May to October inclusively according to Doug Justice

$$Irrigation\ Period = 6\ months = 26\ weeks$$

$$Water\ Consumption\ (Irrigation)\ in\ 2011 = 12{,}000\ \frac{m^3}{26\ weeks} = 461.54\ \frac{m^3}{week}$$

4. Design Irrigation Demand

$$Design\ Irrigation\ Demand = \frac{Required\ Irrigation\ Demand + Irrigation\ Demand\ in\ 2011}{2}$$

$$Design\ Irrigation\ Demand = \frac{628.5\ \frac{m^3}{week} + 461.54\ \frac{m^3}{week}}{2} = 545\ \frac{m^3}{week}$$

5. Water Storage Tank Volume for Irrigation

$$Volume = V$$

$$V_{tank} = V_{irriation} - V_{collect}$$

$$Summer\ Flow\ of\ Garden\ Stream = 0.4\frac{L}{s} = 241.92\ \frac{m^3}{week}$$

$$Summer\ Flow\ of\ Parking\ Lot\ Stream = 0.2\frac{L}{s} = 120.96\ \frac{m^3}{week}$$

$$Total\ Summer\ Flow = 241.92\ \frac{m^3}{week} + 120.96\ \frac{m^3}{week} = 362.88\ \frac{m^3}{week}$$

$$Design\ Irrigation\ Demand\ Flow = 545\ \frac{m^3}{week}$$

$$Irrigation\ Period = 26\ weeks$$

$$V_{tank} = \left[545\frac{m^3}{week} - 362.88\ \frac{m^3}{week}\right] \times 26\ weeks = 4736\ m^3$$

6. Peak Tank Intake/Release Flow

$$Peak\ Tank\ Flow = \frac{V_{tank}}{Average\ Consecutive\ Days\ (Dry/Wet)}$$

$$Average\ Consecutive\ Wet\ Days = 3.72\ days$$

$$Peak\ Tank\ Intake\ Flow = \frac{V_{tank}}{Average\ Consecutive\ Wet\ Days} = \frac{4736\ m^3}{3.72\ days} = 1273\ \frac{m^3}{day} = 15\ \frac{L}{s}$$

7. Peak Spillway Design

$$Q = VA$$

$$Peak\ Garden\ Stream\ Velocity = 1\ \frac{m}{s}$$

$$Garden\ Spillway\ Diameter = 300\ mm$$

$$Area\ of\ Spillway = \pi r^2 = \pi\left(\frac{300}{2}\right)^2 = 70{,}650\ mm^2$$

$$Overflow = \left(1\frac{m}{s}\right) \times 70{,}650\ mm^2 = 71\ \frac{L}{s}$$

8. Storage Tank Dimension Design

Use a circular tank with height of 6 meters.

$$Total\, Volume = Area\ \times Height =\ \pi \left(\frac{diameter}{2}\right)^2 \times Height$$

$$Diameter = 2\ \times \sqrt{\frac{Total\, Volume}{Height\ \times\ \pi}}$$

$$Volume = 4736\, m^3$$

$$Diameter = 2\ \times \sqrt{\frac{4736\, m^3}{6\, m\ \times\ \pi}}\ = 32\, m$$

9. Saving of Water in Real Dollars Present Worth

Calculate the cost at year 10.

$$Actual\ Saving = Principal\ \ \times (1 + Growth\ Rate)^n$$

$$Principal\ Saving = \$14{,}026.88$$

$$Growth\ Rate = 7.5\%$$

$$Actual\ Saving = \$14{,}026.88 \times (1 + 7.5\%)^{10} = \$28{,}910$$

$$Real\ Saving = \frac{Actual\ Saving}{(1 + Inflation)^n}$$

$$Inflation = 2\%$$

$$Real\ Saving = \frac{\$28{,}910}{(1 + 2\%)^{10}} = \$23{,}716$$

Appendix B - Microsoft Excel Spreadsheets

B.1 Reservoir System Design

Input Value
Calculated Value

Produced By: Kelvin Chand
Wen Chien Hsieh
Meraj Mamorafshord

Date: 18-Apr-12
Project: CIVL 498 K - Stormwater Management and Retention in the Botanical Garden

Garden Stream Flow

		Units / Dimensions		Unit Conversion	
April Base Flow:	4	L / sec	=	346	m^3 / day
Summer Base Flow:	0.4	L / sec	=	35	m^3 / day

Parking Lot Stream Flow

April Base Flow:	2	L / sec	=	173	m^3 / day
Summer Base Flow:	0.2	L / sec	=	17	m^3 / day

Municipal Water Supply

Storage Tank Reduction (10%):	18	m^3 / day	=	0.21	L / sec
Storage Tank Reduction (20%):	36	m^3 / day	=	0.42	L / sec
Storage Tank Reduction (30%):	55	m^3 / day	=	0.63	L / sec
Storage Tank Reduction (40%):	73	m^3 / day	=	0.84	L / sec
Storage Tank Reduction (50%):	91	m^3 / day	=	1.05	L / sec
Storage Tank Reduction (60%):	109	m^3 / day	=	1.26	L / sec
Storage Tank Reduction (70%):	127	m^3 / day	=	1.48	L / sec
Storage Tank Reduction (80%):	146	m^3 / day	=	1.69	L / sec
Storage Tank Reduction (90%):	164	m^3 / day	=	1.90	L / sec
Storage Tank Reduction (100%):	182	m^3 / day	=	2.11	L / sec

Irrigation Demand

Required Irrigation:	0.05	m / week
Area of Irrigation:	12570	m^2
Recommended Irrigation Demand:	628.5	m^3 / week

Irrigation Data (2011):	12000	m^3 per irrigation period
Irrigation Period:	26	weeks
Irrigation Demand (2011):	462	m^3 / week

Design Irrigation Demand:	545	m^3 / week

Net Weekly Reservoir Loss (Irrigation)

Net Weekly Loss:	182	m^3 / week

Storage Tank Volume (Irrigation)

Irrigation Tank Volume:	4736	m^3

Storage Tank Volume (Emergency)

Emergency Demand:	2	L / (person * day)
Emergency Period:	3	days
UBC Residents:	10000	people
Emergency Tank Volume:	**60**	m^3

Total Storage Tank Volume (Irrigation + Emergency)

Total Volume:	**4796**	m^3

Peak Design Flow

Average Consecutive Dry Days:	2.67	days	0.41784
Average Consecutive Wet Days:	3.72	days	0.58216

Peak Tank Intake Flow:	**15**	L / sec	=	**233.54**	US gallons / min
Peak Tank Release Flow:	**21**	L / sec	=	**325.38**	US gallons / min

Peak Design Flow (Sum of both streams):	**110**	L / sec	=	**1741.56**	US gallons / min
Stormwater Management (Percent Reduction):	**32**	%			

Peak Spillway Design

Peak Garden Stream Velocity:	1	m / sec
Peak Parking Lot Stream Velocity:	0.5	m / sec

Garden Spillway Pipe Diameter:	300	mm
Parking Lot Spillway Pipe Diameter:	100	mm

Garden Overflow:	**71**	L / sec	=	**1120.39**	US gallons / min
Parking Lot Overflow:	**4**	L / sec	=	**62.24**	US gallons / min

Storage Tank Design

Height:	6	m

Footprint (Area):	**799.27**	m^2

Circle Diameter:	**31.90**	m			
Square Length:	**28.27**	m			
Rectangle Width (2w = L):	**19.99**	m	**Length:**	**39.98**	m
Rectangle Width (3w = L):	**16.32**	m	**Length:**	**48.97**	m
Rectangle Width (4w = L):	**14.14**	m	**Length:**	**56.54**	m
Rectangle Width (5w = L):	**12.64**	m	**Length:**	**63.22**	m
Rectangle Width (6w = L):	**11.54**	m	**Length:**	**69.25**	m

Garden Stream Pump Design

Minimum Required Head (Underground):	8	m
Minimum Required Head (Parking Lot Elevation):	**14**	m

Flow Minimum:	**0.40**	L / sec	=	**6.34**	US gallons / min
Flow Maximum:	**9.82**	L / sec	=	**155.69**	US gallons / min

Parking Lot Stream Pump Design

Minimum Required Head (Underground):	5	m
Minimum Required Head (Parking Lot Elevation):	**11**	m

Flow Minimum:	**0.20**	L / sec	=	**3.17**	US gallons / min
Flow Maximum:	**4.91**	L / sec	=	**77.85**	US gallons / min

Tank Release Pump Design

Minimum Required Head (Underground):	0	m
Minimum Required Head (Parking Lot Elevation):	**0**	m

Flow Maximum:	**21**	L / sec	=	**325.38**	US gallons / min

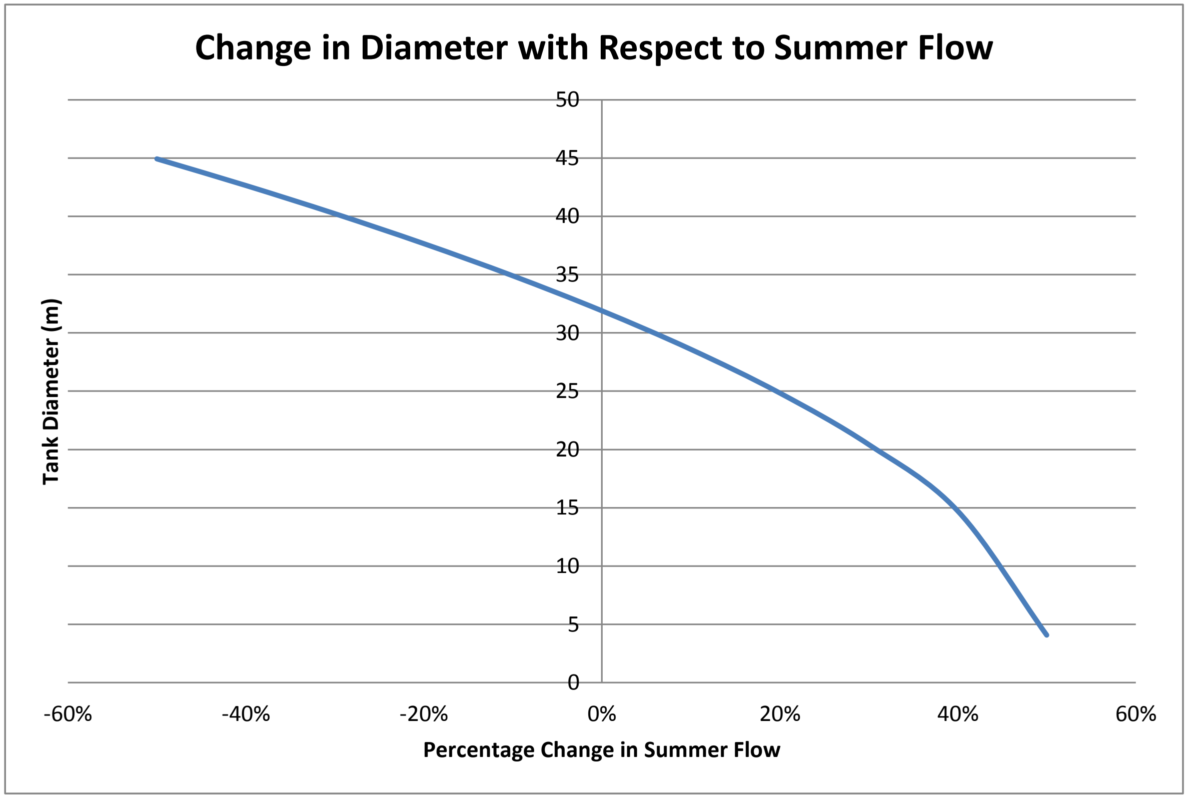
B.2 Summer Base Flow Sensitivity

Parameters Change:

	% change										
	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
Total Baseflow (L/s)	0.3	0.36	0.42	0.48	0.54	0.6	0.66	0.72	0.78	0.84	0.9

Change in Storage Tank

	% change										
	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
Tank Volume (m3)	9513	8570	7626	6683	5739	4796	3852	2909	1965	1022	78
Tank Diameter (m)	45	43	40	38	35	32	29	25	20	15	4



B.3 Economic Analysis

	Inflation	Cost		Consumption	Savings/Cost
Electricity	3.28%	$0.0915	/kWh	35703	$3,266.84
Water	7.5%	$0.9899	/m3	14170	$14,026.88
				*545m3/week	

Construction/Installation Cost		
Tank	$507,435.54	*data is from 2007, apply 5 years of inflation
Pumps	$20,000.00	*replace every 15 years
Piping	$50,000.00	
Total	$577,435.54	*Include profit and overhead
Contingency	$57,743.55	*Assume 10%
Total	$635,179.09	
Tax	$76,221.49	*HST = 12%
Total	$711,400.58	

Currency Inflation: 2.0%

	Actual Dollars			Real Dollars			Acumulatve	
Year	Savings	Cost	Conversion	Savings	O&M	Cost	Savings	Cost
0	$0	$711,401	1.00	$0	$0	$711,401	$0	$711,401
1	$15,079	$3,374	0.98	$14,783	$5,000	$8,308	$14,783	$719,708
2	$16,210	$3,485	0.96	$15,580	$5,000	$8,349	$30,364	$728,058
3	$17,426	$3,599	0.94	$16,420	$5,000	$8,391	$46,784	$736,449
4	$18,732	$3,717	0.92	$17,306	$5,000	$8,434	$64,090	$744,883
5	$20,137	$3,839	0.91	$18,239	$5,000	$8,477	$82,329	$753,360
6	$21,648	$3,965	0.89	$19,223	$5,000	$8,521	$101,552	$761,881
7	$23,271	$4,095	0.87	$20,259	$5,000	$8,565	$121,811	$770,446
8	$25,017	$4,229	0.85	$21,351	$5,000	$8,610	$143,162	$779,055
9	$26,893	$4,368	0.84	$22,503	$5,000	$8,655	$165,665	$787,710
10	$28,910	$4,511	0.82	$23,716	$5,000	$8,701	$189,381	$796,411
11	$31,078	$4,659	0.80	$24,995	$5,000	$8,747	$214,376	$805,158
12	$33,409	$4,812	0.79	$26,343	$5,000	$8,794	$240,719	$813,952
13	$35,915	$4,970	0.77	$27,763	$5,000	$8,842	$268,482	$822,794
14	$38,608	$5,133	0.76	$29,260	$5,000	$8,890	$297,742	$831,684
15	$41,504	$5,301	0.74	$30,838	$25,000	$28,939	$328,580	$860,623
16	$44,617	$5,475	0.73	$32,501	$5,000	$8,988	$361,081	$869,611
17	$47,963	$5,655	0.71	$34,253	$5,000	$9,038	$395,334	$878,649
18	$51,560	$5,840	0.70	$36,100	$5,000	$9,089	$431,434	$887,738
19	$55,427	$6,032	0.69	$38,047	$5,000	$9,140	$469,481	$896,879
20	$59,584	$6,229	0.67	$40,098	$5,000	$9,192	$509,579	$906,071
21	$64,053	$6,434	0.66	$42,261	$5,000	$9,245	$551,840	$915,316
22	$68,857	$6,645	0.65	$44,539	$5,000	$9,298	$596,379	$924,614
23	$74,021	$6,863	0.63	$46,941	$5,000	$9,352	$643,320	$933,966
24	$79,573	$7,088	0.62	$49,472	$5,000	$9,407	$692,792	$943,373
25	$85,541	$7,320	0.61	$52,140	$5,000	$9,462	$744,932	$952,835
26	$91,956	$7,560	0.60	$54,951	$5,000	$9,518	$799,883	$962,353
27	$98,853	$7,808	0.59	$57,914	$5,000	$9,575	$857,797	$971,927
28	$106,267	$8,065	0.57	$61,037	$5,000	$9,632	$918,834	$981,559
29	$114,237	$8,329	0.56	$64,328	$5,000	$9,690	$983,163	$991,250
30	$122,805	$8,602	0.55	$67,797	$25,000	$29,749	$1,050,959	$1,020,999
31	$132,015	$8,884	0.54	$71,453	$5,000	$9,809	$1,122,412	$1,030,807
32	$141,916	$9,176	0.53	$75,305	$5,000	$9,869	$1,197,718	$1,040,676
33	$152,560	$9,477	0.52	$79,366	$5,000	$9,930	$1,277,084	$1,050,607
34	$164,002	$9,788	0.51	$83,646	$5,000	$9,992	$1,360,729	$1,060,599
35	$176,302	$10,109	0.50	$88,156	$5,000	$10,055	$1,448,885	$1,070,653
36	$189,525	$10,440	0.49	$92,909	$5,000	$10,118	$1,541,794	$1,080,771
37	$203,739	$10,783	0.48	$97,919	$5,000	$10,182	$1,639,714	$1,090,954
38	$219,019	$11,136	0.47	$103,199	$5,000	$10,247	$1,742,913	$1,101,201
39	$235,446	$11,502	0.46	$108,764	$5,000	$10,313	$1,851,677	$1,111,514
40	$253,104	$11,879	0.45	$114,629	$5,000	$10,380	$1,966,305	$1,121,894
41	$272,087	$12,269	0.44	$120,809	$5,000	$10,447	$2,087,115	$1,132,341
42	$292,494	$12,671	0.44	$127,324	$5,000	$10,516	$2,214,438	$1,142,857
43	$314,431	$13,087	0.43	$134,189	$5,000	$10,585	$2,348,628	$1,153,442
44	$338,013	$13,516	0.42	$141,425	$5,000	$10,655	$2,490,052	$1,164,097
45	$363,364	$13,959	0.41	$149,051	$25,000	$30,726	$2,639,103	$1,194,823
46	$390,616	$14,417	0.40	$157,088	$5,000	$10,798	$2,796,191	$1,205,621
47	$419,913	$14,890	0.39	$165,558	$5,000	$10,871	$2,961,749	$1,216,491
48	$451,406	$15,378	0.39	$174,485	$5,000	$10,944	$3,136,235	$1,227,436
49	$485,261	$15,883	0.38	$183,894	$5,000	$11,019	$3,320,129	$1,238,454
50	$521,656	$16,404	0.37	$193,810	$5,000	$11,094	$3,513,938	$1,249,549
						Total Potential Benefits:		**$2,264,390**

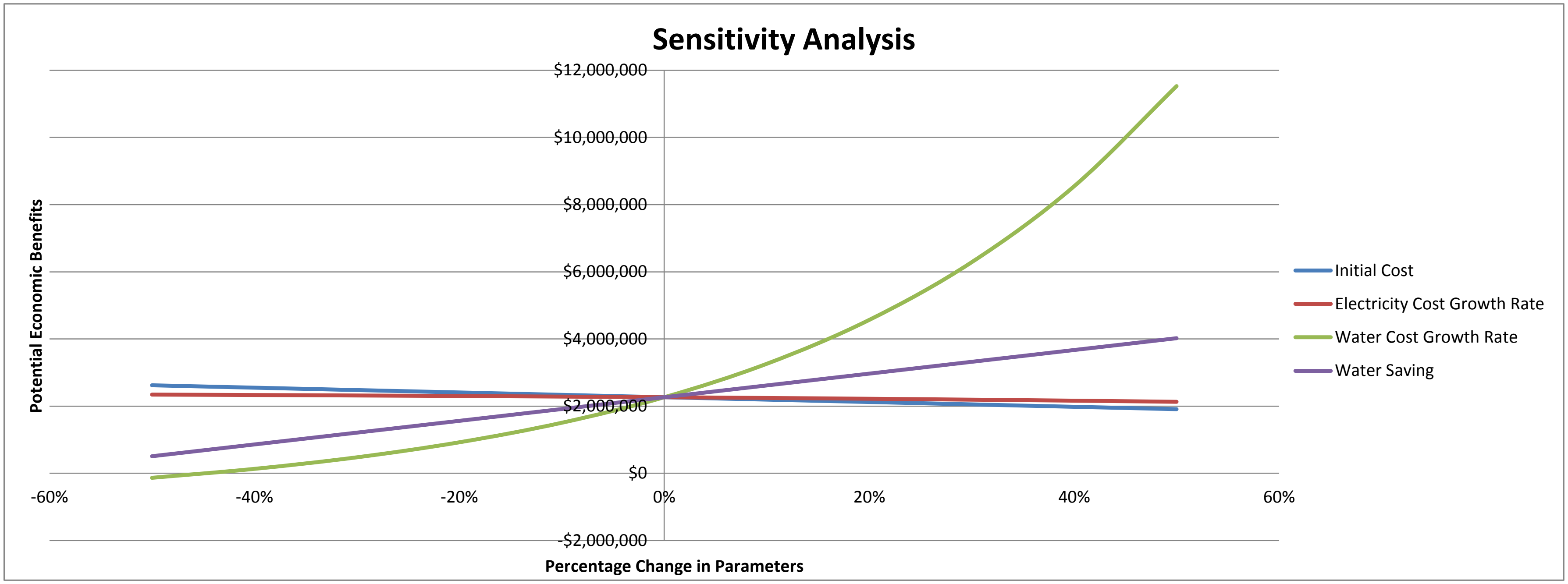
<u>B.4 Economic Sensitivity Analysis</u>

Parameters Change:

	% change										
	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
Initial Cost	$355,700.29	$426,840.35	$497,980.41	$569,120.47	$640,260.52	$711,400.58	$782,540.64	$853,680.70	$924,820.76	$995,960.81	$1,067,100.87
Electricity Cost Growth	1.64%	1.97%	2.30%	2.62%	2.95%	3.28%	3.61%	3.94%	4.26%	4.59%	4.92%
Water Cost Growth	3.75%	4.50%	5.25%	6.00%	6.75%	7.50%	8.25%	9.00%	9.75%	10.50%	11.25%
Water Consumption Saving	7085	8502	9919	11336	12753	14170	15587	17004	18421	19838	21255

Total Savings in Real Dollars PW

	% change										
	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
Initial Cost	$2,620,090	$2,548,950	$2,477,810	$2,406,670	$2,335,530	$2,264,390	$2,193,249	$2,122,109	$2,050,969	$1,979,829	$1,908,689
Electricity Cost Growth	$2,343,084	$2,330,496	$2,316,515	$2,300,970	$2,283,668	$2,264,390	$2,242,889	$2,218,887	$2,192,069	$2,162,080	$2,128,518
Water Cost Growth	-$134,403	$131,757	$475,895	$922,589	$1,504,385	$2,264,390	$3,259,715	$4,566,040	$6,283,632	$8,545,325	$11,527,038
Water Saving	$507,420	$858,814	$1,210,208	$1,561,602	$1,912,996	$2,264,390	$2,615,783	$2,967,177	$3,318,571	$3,669,965	$4,021,359



B.5 Precipitation Data (2000 - 2011)

Date	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average
	Total Rain (mm)												
1-Jan	5.8	0	11.6	21.6	0	0	4	19.8	0	5.4	12.6	0	6.73
2-Jan	2.6	1.3	3	23.4	0	0	0.4	28.2	11	0	5.6	0	6.29
3-Jan	13.5	9	1.8	2.8	0	0	7	6.8	2.2	1.6	0.8	0	3.79
4-Jan	10.8	34.3	0	13.9	0	0	2	1.6	7.2	2.6	15.8	1.8	7.50
5-Jan	0	8.6	3	0	0	0	19	4.4	1.2	1.8	1	23.8	5.23
6-Jan	13.8	0	17.6	0	0	0	7.6	4	5.4	28.6	0	23.4	8.37
7-Jan	10.4	0	13.9	0	22.2	0	10	18.2	3.4	14.6	1	7.6	8.44
8-Jan	6.4	4.2	8.7	0	3.4	0	4.8	1.8	6.8	7	13.2	0	4.69
9-Jan	9.7	0.4	0	0	3.2	0	26.8	3.4	4.6	1.6	2	0	4.31
10-Jan	4.7	0.2	0.4	0	7	0	27.6	0	31.2	34	2	0	8.93
11-Jan	5.6	0	0.4	5.8	4.6	0	3.8	0	4	2.6	36	0	5.23
12-Jan	2.1	0	7	2.6	6.4	0	19.2	0	4.8	1.6	3.8	3.4	4.24
13-Jan	3.4	5.8	0	2.8	5.4	0	14.8	0	0.8	0.6	6	8.6	4.02
14-Jan	11.4	1.2	0	0	16.6	0	0.2	0	17.8	0	26	6.6	6.65
15-Jan	1.4	0	0	0	2.2	0	0	0	0	0	24.6	10.8	3.25
16-Jan	2.6	0	1.4	0	0	14.4	29.8	1.4	0	0	0.2	7.2	4.75
17-Jan	0	1.8	0	0	2.6	56.6	6.4	2.2	0	0	8.6	0	6.52
18-Jan	0	9.9	11.6	0	17.2	44.2	3.2	16.8	0	0	3	3	9.08
19-Jan	0	3.4	5	3.4	4.8	28.4	3.8	13.4	11.8	0	0.2	0	6.18
20-Jan	3.4	7.2	9.6	0.2	0	18	10.8	1.8	0	0	0	13.2	5.35
21-Jan	3.4	16.4	0	1.8	0	1	6.6	3.8	0	0	0	19.8	4.40
22-Jan	0.2	0	6.8	21.8	5.6	39.4	3.6	19.8	0	0	0	0.4	8.13
23-Jan	0	0	3.6	6.6	1.8	1.6	3.6	14.8	0	0	0	1	2.75
24-Jan	0	6.2	10.6	3.2	5.2	0.2	0	0.2	0	0	3.8	30.4	4.98
25-Jan	5.6	0	10.1	6.5	0	0	0.8	0	0	0	5.4	0.8	2.43
26-Jan	0.6	0	0	6.9	7	5.8	5.2	0	3.2	0	0	1	2.48
27-Jan	0	0	0	0	3.4	0	1.8	0	0	3.6	0	0	0.73
28-Jan	0	5.8	0	0	6.4	1.6	15.6	0	0	0	0	6	2.95
29-Jan	0	8.8	0	14.4	21.2	2.2	23.4	0	0	0.6	1	3.2	6.23
30-Jan	3.4	4.4	2.6	12.8	1	14.2	4.2	0	4.6	0.2	9.2	0	4.72
31-Jan	13.2	1.4	4.7	0	4.4	0	17.6	0	2.2	0	1	0	3.71
1-Feb	3	1.6	3.3	1.4	0	0.2	3.6	0	1.2	18.4	5.6	0	3.19
2-Feb	0	4	0.2	0	2.2	0	7.2	0	0.4	1.4	4.4	0	1.65
3-Feb	0	0	2.8	0	5.2	0.2	5	1.8	0	0	1.6	11.2	2.32
4-Feb	0	2	0	0	5.6	21.8	13.4	13.6	1.2	0	1.6	15.8	6.25
5-Feb	0	0	2.8	0	2.6	0	0	0.4	14.4	2	4.2	0	2.20
6-Feb	4.1	4.4	23.4	0	11.4	16	0	0	7.4	2	0	7.8	6.38
7-Feb	2.6	0	0.2	0	0.2	0	1.2	6	5.4	0	0.4	0	1.33
8-Feb	6.6	4.4	0.4	0	0	0	3.2	4.8	0	0.4	0.4	0	1.68
9-Feb	1.6	0.8	0	0.6	0	0	0	2.4	5.2	1.8	0	0	1.03
10-Feb	0	0	3.8	0	0	0	0	1	0	1	2.4	0	0.68
11-Feb	0	0	0	0	0	0	0	4.2	11.6	1.2	5.4	2.2	2.05
12-Feb	0.2	0	0	0	0	3.6	0	3.2	3.4	0	2.6	16	2.42
13-Feb	0	0	0	0	0	0	5.4	2.2	0	0	2.8	0.2	0.88
14-Feb	0	0	0	0	10.4	2	0	23.2	0	0	7.8	19.6	5.25
15-Feb	0	1	0	0.7	7	0	0	14.6	9	0	2.4	1.4	3.01
16-Feb	0	0	3.8	5.6	10.2	0	0	1	0.4	0	12.8	1.6	2.95
17-Feb	0	0	3.8	3.2	5.8	0	0	1	0	0	0	3.2	1.42
18-Feb	0	4	1.2	0.4	8.4	0	0	0	0	0	0	0.2	1.18
19-Feb	0	0	4.2	3.4	0	0	0	13.2	0	0	0	0	1.73
20-Feb	0	0	0	9	0	0	0	0	1	0	0	0	0.83
21-Feb	3.8	0	26.4	1.2	0	0	0	1.8	0	0	0	0.4	2.80
22-Feb	2.4	3	17.8	0	0	0	0.4	2.2	0	8	0	0	2.82
23-Feb	0.2	0.6	9.2	0	0.2	0	2.6	0.4	1.6	12	4	0	2.57
24-Feb	3.8	0	0	0	1.2	0	0	8.6	0	3.8	10.8	0	2.35
25-Feb	12.8	0	0	0	0.8	0	1.4	5.4	0	2.6	1	0	2.00
26-Feb	2.4	0	0	0	0.8	0	12.2	3.2	0.2	0	10.6	0	2.45
27-Feb	11.1	0	0	0	9.4	0	1.4	0	2.6	0	19.8	2.4	3.89
28-Feb	2.6	0	0	1.6	0.2	2	0	1.8	0	0.2	1.6	0.2	0.85
29-Feb	12.4				1.8				2.4				5.53
1-Mar	6.6	22.4	0	0	0	12.2	0.2	3.4	0.8	9.8	0	3.4	4.90
2-Mar	6	0.4	0	1.2	0	1.2	0.6	2.6	2.8	3.8	1.4	4.2	2.02
3-Mar	20.4	0	0	0	13.8	2	0	5.4	8.8	4.2	0	2	4.72
4-Mar	7.1	0	0	0	3.4	0	0.2	0	0	0	0	6.6	1.44
5-Mar	0	0.2	0.3	0.2	6.8	0	2.8	11.6	0	0.2	0	0	1.84
6-Mar	0	0	0	0	4.6	0.6	0.2	0.2	0.6	0	0	0	0.52
7-Mar	0	0.2	0	0	14.4	0.4	7.6	7.2	4	0.6	6.2	0	3.38
8-Mar	0.2	12	0	0	1.6	2.2	25	6	2.4	0	0	3.6	4.42
9-Mar	3	0	2.3	12.4	1.6	5.6	3.2	3.4	0	0	0	11.8	3.61
10-Mar	1.6	0	6.6	1	0	0	0.6	14.6	7.4	0	3.8	10.4	3.83
11-Mar	0	0	12.4	4.1	0	0	0	39.2	1.2	0	20.8	4.2	6.83
12-Mar	2.5	0.8	3.4	21.7	0.4	0	0	0	0	0	14.4	1.8	3.75
13-Mar	13.4	0	4	10.9	0	0	0	2	0.6	0.4	5.6	6.4	3.61
14-Mar	8	0	0	2	0.2	0	8.6	0	2	11.4	5.8	6.4	3.70
15-Mar	0.2	14.2	12.1	5.6	0	0	1.6	5	0.4	8.2	5	16.6	5.74
16-Mar	11.8	2.1	0.8	2	2.2	4	2.6	7.8	3.2	0.6	1.4	1	3.29
17-Mar	3.8	2.5	0	0.9	8.6	0	0.8	30.2	5.8	1.4	0	0	4.50
18-Mar	8.4	18.2	1.8	1.8	0.2	0.4	0	0.2	0	3.6	0	4.4	3.25
19-Mar	0	0.6	1.8	11.8	0	17.2	0	10.8	5	13.6	0	8.4	5.77
20-Mar	0.6	0	0	1.8	0	13.4	0	0.2	4.4	11.4	0	0	2.65
21-Mar	1.8	0	0	13	0	0.8	0.6	3.8	2.2	0	3.6	8.2	2.83

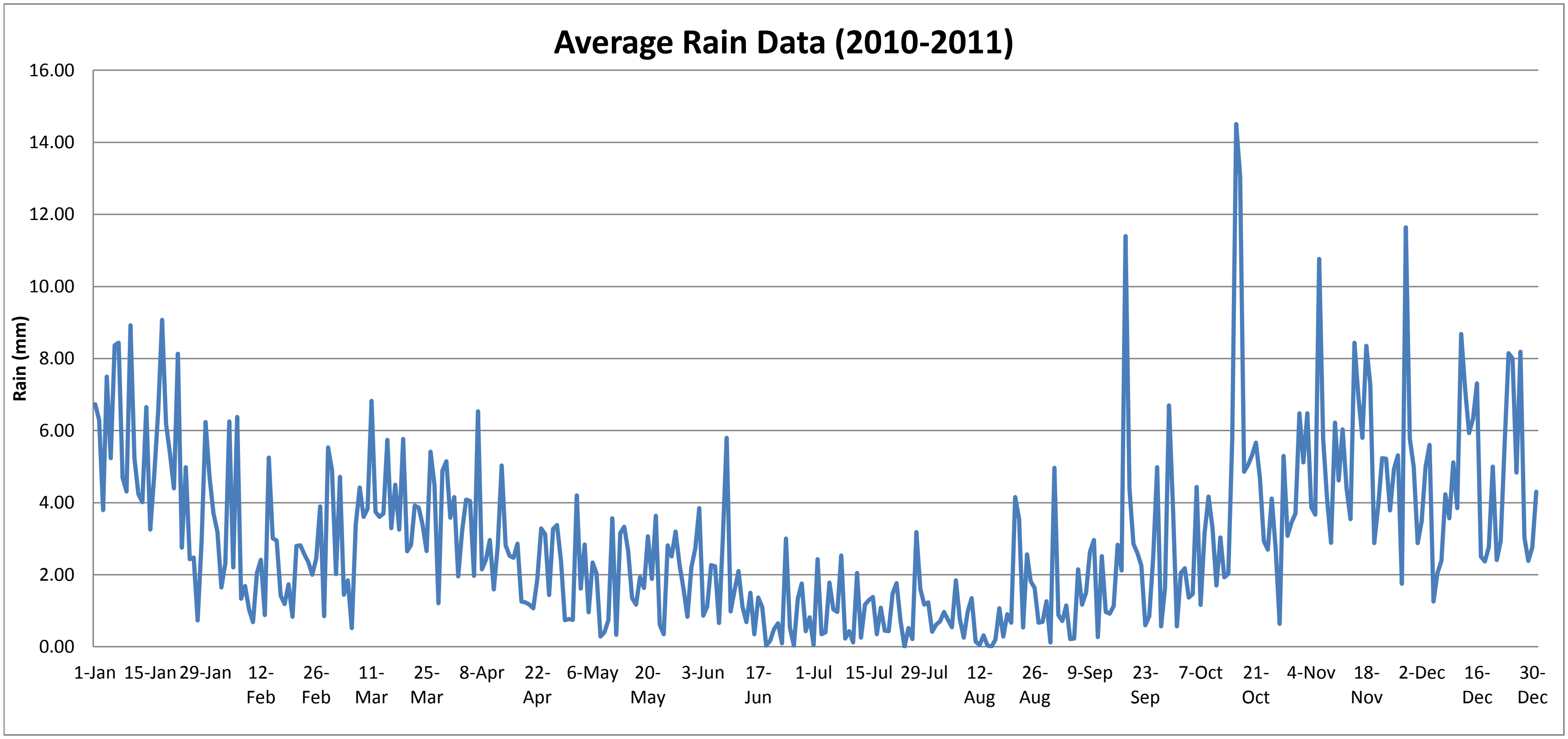
22-Mar	7	0	0	10.6	0.2	0	8.4	20.4	0	0	0.2	0.2	3.92
23-Mar	3.2	0	0	3.8	2.4	0	1.2	23.4	6.4	6	0	0	3.87
24-Mar	0	1.6	0	0.3	5.6	0	9.8	15.8	0	7.4	0	0	3.38
25-Mar	0	4.9	0	2	12.8	0	0	0	3.4	0	8	0.8	2.66
26-Mar	0	4	1	8.2	5.2	33	4.2	0	3.2	0	5.4	0.8	5.42
27-Mar	2.8	18.6	7.2	4.4	5.8	9	0	0	0	0	0	6	4.48
28-Mar	0.8	1.5	0.2	0	0	3.4	0.4	0	1.8	0.8	4.4	1.2	1.21
29-Mar	0	5.8	0.7	0.3	0	17.6	0	0	4	0	20.6	9.6	4.88
30-Mar	0	0	0	8.4	11.4	0	3.4	1.2	2.4	9.8	1.6	23.6	5.15
31-Mar	0	10.2	1	1.6	0	9.8	4	0.4	0	5.6	0	10.4	3.58
1-Apr	0	0.2	0	0.2	0	6.2	10.6	0	0	25.4	1	6.2	4.15
2-Apr	0	0	0	1.8	0	5.6	0.2	1.6	0	8.6	5.6	0	1.95
3-Apr	0	0	0	15.4	0	10.6	8	0	0	0	1.8	3	3.23
4-Apr	1.6	0	0	5.6	0	0	0.6	1.8	6.6	0	2	30.8	4.08
5-Apr	1	14.4	1.4	7.9	0	13.8	0	0	1	0	9	0	4.04
6-Apr	0.2	6.6	2	1.4	0	6	0	0	3.6	0	3.2	0.6	1.97
7-Apr	0	7.6	0	28.8	1.2	9	0	0	20.4	0	11.4	0	6.53
8-Apr	0	0	0	7.2	0	0	0.8	8.6	1	0	8.2	0	2.15
9-Apr	0	0	7.4	3.2	0	0	11.6	3	1.2	2.6	0	0	2.42
10-Apr	0	7.6	5.2	0.2	0	10	3.6	0.2	0.4	0.4	0	8	2.97
11-Apr	0	0	5	1.5	0	7.8	0	0	0	4.8	0	0	1.59
12-Apr	0	2.1	5.2	0	0	3.4	1.6	1	0	20.2	0	0	2.79
13-Apr	0.4	5.2	20.2	9.6	0.8	0.2	11.2	11.2	0.8	0	0.2	0.6	5.03
14-Apr	0.6	0	5.2	2.4	2.4	0	2.4	1.4	0	0	0.4	19	2.82
15-Apr	2.8	0	7.3	2.4	0.8	7.6	7.2	0	0.2	0	1.6	0.4	2.53
16-Apr	0	0	7.8	0.2	0	8.8	0.4	11.6	0	0.4	0.2	0.2	2.47
17-Apr	0	13.1	0.6	1.4	0.2	1	0	2.6	0	11.2	4.2	0	2.86
18-Apr	0	10.1	0	3.2	0	0	0.6	0	1.2	0	0	0	1.26
19-Apr	0.4	0.2	0	1.4	4.2	0	0.6	0	4.8	3.2	0	0	1.23
20-Apr	0	0	0	1	1.6	0	1.6	0	0	0.4	7.8	1.6	1.17
21-Apr	9.2	0	0	1	0	0	1.6	0	0.2	0.4	0	0.4	1.07
22-Apr	5.8	13.4	0.4	0	0	0	0	2.8	0	0	0	0	1.87
23-Apr	1.6	9.6	0	19.4	3.6	0.2	0	0	0	0	5	0	3.28
24-Apr	0	1.2	0	24.4	0	0	0	5.4	0	0	2	4.4	3.12
25-Apr	4	0	0	0	0	0	0	2	0	0	3.6	7.6	1.43
26-Apr	0.2	0	14.6	0	0	0	0.2	11.4	0	0	9	3.8	3.27
27-Apr	9.7	4	0	0	0.2	0	0.6	11.6	2	0	8.2	4.2	3.38
28-Apr	0	9.3	0	0	0	0	0	0	13.2	0	1.4	4.8	2.39
29-Apr	0.6	1.5	0	0	0	0	6.6	0	0.2	0	0	0	0.74
30-Apr	5.4	1.6	0	0	0	0	0	0	0	0	2.2	0	0.77
1-May	4.2	1.6	0	0	0	0	1.2	1.4	0	0	0.6	0	0.75
2-May	1.8	0	1	0	2.8	2.6	0	7.4	1	5.8	11	17	4.20
3-May	5.8	0.8	0	0	1	0	0	4.4	6.6	0	0.8	0	1.62
4-May	8.2	9.8	0.2	6.7	0.6	0.4	0	0	0	8.2	0	0	2.84
5-May	2.9	0	1	0	0.4	0	0	0	0	2.4	0	4.8	0.96
6-May	3.8	0	2.6	0	0	0	2.6	4.4	0	8.6	0	6	2.33
7-May	0	0.4	0	0	1.4	0	8.4	0.4	0	0.4	0	13.4	2.03
8-May	0.4	0.2	0	0	0.2	2.6	0	0	0	0	0	0	0.28
9-May	0.4	0	0	0	2.6	1.8	0	0	0	0	0	0	0.40
10-May	5.3	0	0	0	1.4	0	0	0	1	0.8	0	0.4	0.74
11-May	5.8	0	0	0	1.4	0	0	0	1.8	11.2	0	22.6	3.57
12-May	0.2	0	0	0	0	0	0	0	0	3.6	0	0.2	0.33
13-May	0	0	11.4	0	0	0.2	0	0	17	9.2	0	0	3.15
14-May	0	16	1	3.2	0	3.8	0	0	10.2	3	0	2.8	3.33
15-May	0	11.8	0	1.4	0	10.4	0	0	0	0	0	8.4	2.67
16-May	0	2	7.6	4.2	0	2.4	0	0	0	0	0	0	1.35
17-May	0	0	3	11	0	0	0	0	0	0	0	0	1.17
18-May	5.2	0	0	0	0	9.2	0	1.4	0	5.6	1.8	0	1.93
19-May	3	0.8	0.6	0	0	8.6	0	2.8	1.4	0.2	2.2	0	1.63
20-May	11.8	0	3.8	2	0	1	0	13.6	3.8	0	0.8	0	3.07
21-May	10.2	0	0	1.6	0	3.8	3.8	1.2	0	0	0.2	1.8	1.88
22-May	0	0	0.2	12.8	10.8	7.8	10.6	0	0	0	1	0.4	3.63
23-May	0	0	1.2	0.2	0	1.4	4.6	0	0	0	0	0	0.62
24-May	0	0	0	3.6	0	0	0.6	0	0	0	0	0	0.35
25-May	0	0	1.4	2.6	12.8	0	4.2	0	0	0	1.6	11.2	2.82
26-May	6.6	0	1.1	0	0	0	1.2	0	0.4	12.8	6.2	1.8	2.51
27-May	19	0	2.2	0	14.2	0	0.8	0	0	0	0.4	1.8	3.20
28-May	4.2	3.4	11.2	0	0.2	0	1.6	0	0	0	6.8	0	2.28
29-May	4	0	2	0	8.6	0	0	0	0	0	4.8	0	1.62
30-May	0.2	0.8	0	0	0.6	0	0	0	0	0	8.4	0	0.83
31-May	0	0	0	0	1.8	12.6	3.2	0	0	0	7.6	1.2	2.20
1-Jun	1.8	15	0	0	1	5	6.6	0	0	0	3.4	0	2.73
2-Jun	2	12	0	0	0	0	2.8	0	0	0	14	15.4	3.85
3-Jun	0	0.4	0	0	0	0	0	0.4	9.6	0	0	0	0.87
4-Jun	0	0	0.2	0	0	0	3.4	7.6	0.6	0	1.6	0	1.12
5-Jun	6.2	0	2.4	0	3.2	2.4	0	1.2	11.8	0	0	0	2.27
6-Jun	7.6	1.2	0	0	0	0	0	10	4.6	0	3.4	0	2.23
7-Jun	0	0.3	0	0	1	1.8	0	4.4	0.4	0	0	0	0.66
8-Jun	0	0	0	0	0	8	25.8	0	1.4	0	0	0	2.93
9-Jun	1.6	11.4	0	0	0	0	12.8	18.6	14.4	0	10.8	0	5.80
10-Jun	0.6	6	0	0	2.2	0	0	0.2	0	0	2.8	0	0.98
11-Jun	10.8	0.6	0	0	3.6	3.6	0	0	0	0	0.2	0	1.57
12-Jun	15.8	2.2	0	0.4	5	1.6	0	0.2	0	0	0	0	2.10
13-Jun	3.4	0	0	0.8	6.8	1.4	0.6	0.2	0	0	0	0.2	1.12
14-Jun	7.2	0	0	0.4	0	0.2	0	0.2	0	0	0.2	0	0.68
15-Jun	0	0.4	0	0.2	0	0	0.4	3.8	0	0	11	2.2	1.50

16-Jun	0	0	0	0	0	0	2	2.2	0	0	0	0	0.35
17-Jun	0	0	5	0	0	9.6	0	1.8	0	0	0	0	1.37
18-Jun	0	0	0	0	0	1.6	0	0.4	0	0	0	11.2	1.10
19-Jun	0	0	0	0	0	0	0	0	0	0	0	0.4	0.03
20-Jun	0	0	0	2	0	0	0	0	0	0	0	0	0.17
21-Jun	0	0	0	0.4	0	5	0	0.6	0	0	0	0	0.50
22-Jun	0	0	0	1.8	0	3.6	0	2.2	0.2	0	0	0	0.65
23-Jun	0	0.2	0	0.4	0	0	0	0	0	0	0	0.6	0.10
24-Jun	0	0.4	0	0	0	0	0	20.6	0	7.6	0	7.4	3.00
25-Jun	0	0	0	0	0	0	0	0.8	0	2	0	3.6	0.53
26-Jun	0	0	0	0	0	0.2	0	0.2	0	0	0	0	0.03
27-Jun	0	8.2	4.2	0	0	1.8	0	0	0	1.2	0.6	0	1.33
28-Jun	0	2.1	17	0	0	0	0	1.6	0	0	0.4	0	1.76
29-Jun	0	0	2	0.4	0	0	0	2.8	0	0	0	0	0.43
30-Jun	0	0	0	6	0	3.8	0	0	0	0	0	0	0.82
1-Jul	0	0	0.2	0	0	0	0	0	0	0	0.4	0	0.05
2-Jul	25.8	0	0	0	2.4	0.2	0	0	0	0	0	0.8	2.43
3-Jul	0	0	0	0	0	0	0	0.2	0.2	0	0.2	3.6	0.35
4-Jul	2.4	0	2	0.2	0	0.2	0	0	0	0	0	0	0.40
5-Jul	1.6	0	0	0	0	19.6	0	0	0.2	0	0	0	1.78
6-Jul	0	0	0	0	9	3	0	0	0	0.4	0	0	1.03
7-Jul	0	0	1.6	0	0	0	0	0	0	7.6	0	2.4	0.97
8-Jul	0	0	10.6	0	0	14.2	0	0	0	5.4	0	0.2	2.53
9-Jul	2.4	0	0	0	0	0	0.4	0	0	0	0	0	0.23
10-Jul	0	0	0	0	5.2	0	0	0	0	0	0	0	0.43
11-Jul	0	0	0	0	0	1.4	0	0	0	0	0	0	0.12
12-Jul	0	0	0	12	0	2.4	10.2	0	0	0	0	0	2.05
13-Jul	0	0	0	2.8	0	0	0.2	0	0	0	0	0	0.25
14-Jul	0	0	0	4.2	0	0	0.4	0	0	0	0	9.4	1.17
15-Jul	0	13.9	0	0	0	1.6	0	0	0	0	0	0	1.29
16-Jul	0	3	0	0	0	1	0	0	0	0	0	12.6	1.38
17-Jul	0	0	0	0	0	0	0	3.6	0	0	0	0.6	0.35
18-Jul	0	0	0	0	0	0	0	13	0	0	0	0	1.08
19-Jul	0	4	0	0	0	0	0	1.4	0	0	0	0	0.45
20-Jul	0	0	0	0.6	0	0	0	4.6	0	0	0	0	0.43
21-Jul	0	0	0	0	0	0	0	12.6	0	0	0	5.2	1.48
22-Jul	9.6	0	0	0	0	0	0	11.6	0	0	0	0	1.77
23-Jul	3.4	0	0	0	0	0	0	5.2	0	0	0	0	0.72
24-Jul	0	0	0	0	0	0	0	0	0	0	0	0	0.00
25-Jul	0	0	0	0	0	0	0	0	0	6.2	0	0	0.52
26-Jul	2.2	0	0	0	0	0	0	0	0	0.4	0	0	0.22
27-Jul	26.2	12	0	0	0	0	0	0	0	0	0	0	3.18
28-Jul	12.9	6.4	0	0	0	0	0	0	0	0	0	0	1.61
29-Jul	0	0	0	0	0	0	0	0.8	13.2	0	0	0	1.17
30-Jul	0	0	0.8	0	0	0	14	0	0	0	0	0	1.23
31-Jul	0	0	0	0	0	0	0	0	2.2	0	0	2.8	0.42
1-Aug	0	0	0	0	0	0	0	0	7.4	0	0	0	0.62
2-Aug	0	8.3	0.2	0	0	0	0	0	0	0	0	0	0.71
3-Aug	0	8	0	0	3.6	0	0	0	0	0	0	0	0.97
4-Aug	0	6.6	2.2	0	0.2	0	0	0	0	0	0	0	0.75
5-Aug	0	5.5	0	0	0	0	0	0	0	0	1	0	0.54
6-Aug	0	1.7	2	3.2	15.2	0	0	0	0	0	0	0	1.84
7-Aug	0	0	0	0	0	0	0	0	0	0	9.2	0	0.77
8-Aug	0	0	0	0.4	0	0	2	0	0	0	0.6	0	0.25
9-Aug	0	0	0	0.2	0	0	1.2	0	2.2	7.2	1	0	0.98
10-Aug	0	0	0	0	0	0	1.6	0	0	14.6	0	0	1.35
11-Aug	0	0	0	0.3	0	0	0	1.2	0	0.2	0	0	0.14
12-Aug	0	0	0	0	0	0	0	0.6	0	0	0	0	0.05
13-Aug	0	0	0	0	0	0	0	0	0	3.8	0	0	0.32
14-Aug	0	0	0	0	0	0	0	0	0	0.4	0	0	0.03
15-Aug	0	0	0	0	0	0	0	0	0	0	0	0	0.00
16-Aug	0	0	0	0	0	1.2	0	1.2	0	0	0	0	0.20
17-Aug	0	0	0	0	0.8	11.8	0	0	0.2	0	0	0	1.07
18-Aug	3	0	0	0	0	0	0	0	0.4	0	0	0	0.28
19-Aug	1.6	0	0	0	0	0	0	1.4	7.8	0	0	0	0.90
20-Aug	0	0	0	0	0	0	0	0.4	7.6	0	0	0	0.67
21-Aug	0	23.4	0	0	19.8	0	0	0.8	5.8	0	0	0	4.15
22-Aug	0	22	0	0	1	0	0	0	0	0	0	19.6	3.55
23-Aug	0	6.4	0	0	0	0	0	0	0	0	0	0	0.53
24-Aug	0	0	0	0	13.2	0	0	0	17.6	0	0	0	2.57
25-Aug	0	0	1.4	0	19.2	0	0	0.8	0	0.4	0	0	1.82
26-Aug	0	0	0	0	0.2	0	0	2	16.4	0	1	0	1.63
27-Aug	0	1	0	0	1.8	0	0	0	4.2	0	1	0	0.67
28-Aug	0	1.7	0	0	0	0.8	0	0	5.8	0	0	0	0.69
29-Aug	1.4	0	0	0	0	13.4	0	0	0.4	0	0	0	1.27
30-Aug	0	0	0	0	0	1.4	0	0	0	0	0	0	0.12
31-Aug	0	3.8	0	0	0	0	0	0	0	0	55.8	0	4.97
1-Sep	0.4	7	0	0	3.2	0	0	0	0	0	0	0	0.88
2-Sep	0	0	6.8	0	0.2	0	0	1	0.6	0	0	0	0.72
3-Sep	0	2.4	0	0	0	0.4	0	2.6	0	8.4	0	0	1.15
4-Sep	0.2	0	0	0	1	0.6	0	0.8	0	0	0	0	0.22
5-Sep	0	0	0	0	0	0	0	0	0	2.8	0	0	0.23
6-Sep	0	0	0	4.2	0	0	0	0	0	6	15.6	0	2.15
7-Sep	4.4	0	0	9	0	0	0	0	0	0	0.6	0	1.17
8-Sep	0.8	0	11	0	6.2	0	0	0	0	0	0	0	1.50
9-Sep	6.4	0	4.8	0	0	0	4.6	0	0	15.8	0	0	2.63

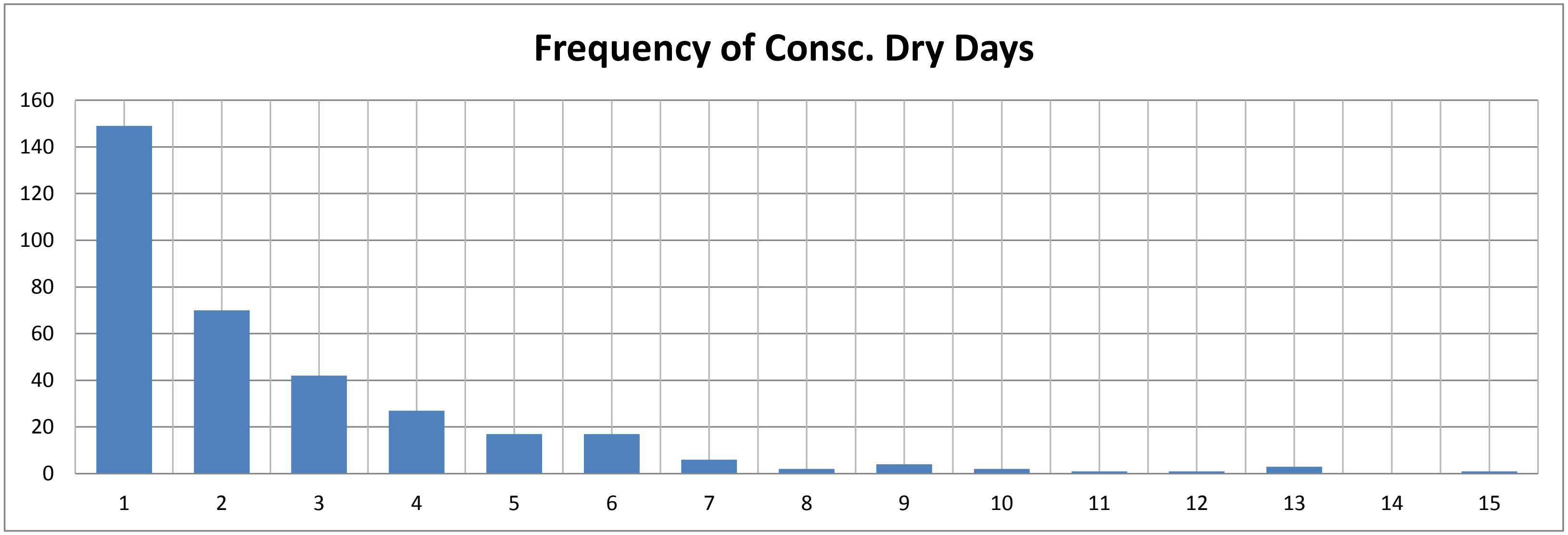
10-Sep	2.4	0	0	6.8	26.4	0	0	0	0	0	0	0	2.97
11-Sep	0	0	0	0	0	0	0	0	0	0	3.2	0	0.27
12-Sep	0	0	0	0	0	0	0	0	0	0	30.2	0	2.52
13-Sep	0	0	0	0	6.8	0	3.8	0	0	0	1	0	0.97
14-Sep	0.2	0	0	3.8	6	0	1	0	0	0	0	0	0.92
15-Sep	0	0	4.4	0	7	0	0.6	0	0	0	0.2	1.4	1.13
16-Sep	0	0	7.4	0.2	7	4.8	0	3.2	0	6.6	4.8	0	2.83
17-Sep	0	0	0	8.2	4.6	0	2.4	0	0	0	0.6	9.6	2.12
18-Sep	0	1.6	0	8	91.6	0	8.2	0.4	0	0.6	21.6	4.8	11.40
19-Sep	0	0	0.2	0	3.4	0	1.2	0	0	13.6	34.2	0	4.38
20-Sep	1	0.2	0	0	0	0	17.4	2.6	5.8	0	7.2	0	2.85
21-Sep	0	14.6	0	0	0.4	0	0	6.4	7.2	0	0	2.6	2.60
22-Sep	0	0	0	0	5.2	0	0	0	0	0	0	21.8	2.25
23-Sep	0	0	0	0	0.4	0	0	0	0.2	0	6.6	0	0.60
24-Sep	0	0	0	0	0	0	0	1.8	5.4	0	3	0	0.85
25-Sep	0	2.2	0	0	0	0	0	1	11.2	0	7.6	7.6	2.47
26-Sep	0	13.6	0	0	0	0	0	0	0.2	0	24.6	21.4	4.98
27-Sep	0	0	0	0	0	0	0	1.4	0	0	5	0.4	0.57
28-Sep	6.6	1.8	0	0	0	8.6	0	0	0	2.4	0.4	0	1.65
29-Sep	23.2	0.2	0	0	0	39.2	0	8.4	0	9.4	0	0	6.70
30-Sep	2.4	0	0	0	0	0	0.2	44	0	0	0	0	3.88
1-Oct	0	0	0	0	0	0	0	1.4	0	5.4	0	0	0.57
2-Oct	0	0	3.6	0	0	9.6	0	5.2	5.8	0.2	0	0.2	2.05
3-Oct	0	0	8.8	0	0	0.4	0	1.4	8.8	0	0	6.8	2.18
4-Oct	0	0	0.2	0	0	0	0	0.8	11.8	0	2.4	1.2	1.37
5-Oct	0	0	0.6	0	9.2	1	0	0	1.2	0	0	5.6	1.47
6-Oct	0	0	0	18	6.2	16.4	0	8.4	4.2	0	0	0	4.43
7-Oct	0	1.7	0	1.2	0	1.8	0	5.8	0.2	0	0	3.2	1.16
8-Oct	3.2	1.4	0.2	4	21	0	3.8	0	0	0	4.2	0	3.15
9-Oct	13.4	0	1.2	0.8	10	0.2	0	2.2	0	0	22	0.2	4.17
10-Oct	0	17.5	0.2	0.4	0.2	7.6	0	5	0	0	3.2	5.6	3.31
11-Oct	0	0	0	12.2	0.4	0	0	0	0	0	0.8	7	1.70
12-Oct	0	16.2	0	7	0	13.2	0	0	0	0	0	0	3.03
13-Oct	0.8	7.6	0	0	0	0	0	0	14.6	0.2	0	0	1.93
14-Oct	0	3.9	0	0	0	11.6	2.4	0	0	5.6	0.8	0	2.03
15-Oct	1.6	0	0	12.8	0	18	31.6	1.8	0.8	2.6	0	0	5.77
16-Oct	23	5.7	0	85	1.6	20.2	1.2	6.6	13.2	17.6	0	0	14.51
17-Oct	12	0	0	55.8	22.8	8.8	0.2	14.6	12.8	29.6	0	0	13.05
18-Oct	1.6	22.3	0	0.6	5	0	2.6	24.4	0	1.8	0	0	4.86
19-Oct	11	0	1.6	6	1.8	6.6	5.4	27.2	0	0	0	1	5.05
20-Oct	27.4	0	0	25.4	0.8	0	0	2	5	0	0	3.2	5.32
21-Oct	0	19.4	0	4.4	0.4	0	0	25.6	0	7.8	1.4	9	5.67
22-Oct	0	9.8	0	4.2	14.6	0	0	12.2	0	3	1.6	10.8	4.68
23-Oct	0	0	0	0	3.6	0.2	0	0	2	26.6	2.8	0	2.93
24-Oct	0.6	10	0	0	1.8	0	5.4	3.2	0.4	0	11	0	2.70
25-Oct	0	1.4	0	0	9.6	5.2	2	0	0.2	13.6	17.4	0	4.12
26-Oct	0	11.3	0	0	0	0	1.4	0	0	15.8	2.4	1.6	2.71
27-Oct	5.8	0.3	1.3	0	0	0	0	0.2	0	0	0	0	0.63
28-Oct	18	0	0.6	10.4	2.4	5.2	0.2	4.2	0	7.8	2.4	12.4	5.30
29-Oct	1.8	0	0	0	5.4	2.4	1.6	2.6	0	21	2.2	0	3.08
30-Oct	0	10	0	0	0	12.8	0	0	3.4	9	0.4	5.8	3.45
31-Oct	5	7.6	0	0	0.4	14.2	0	0.4	15.2	0.4	1.2	0	3.70
1-Nov	0	4.4	0	0	35	18.6	0	1.2	1.8	0	16.8	0	6.48
2-Nov	0	0	0	0	17.2	16	14.4	1.8	6.4	2	0	3.6	5.12
3-Nov	0.6	0	0	0	0	11.4	44.6	10.8	10.4	0	0	0	6.48
4-Nov	4.2	12.6	0	0	0	4	22.4	0.8	2.6	0	0	0	3.88
5-Nov	1.4	3	3.8	0	0	10.8	16.6	0	0	7.8	0.6	0	3.67
6-Nov	0.4	0	10.6	0	43.2	2	35.8	8	22.4	3.8	3	0	10.77
7-Nov	0.4	0	6	0	10.6	3.4	0.2	4	20.4	16.6	0.8	7	5.78
8-Nov	7.6	0	13.2	0.2	0	11.6	0	5.6	6	4.6	0	0.4	4.10
9-Nov	0	0	8.4	0	0.6	2	0	5.6	4.6	7	5.8	0.6	2.88
10-Nov	0	0	7.5	6	0	6.4	30	8.8	4.4	11.6	0	0	6.23
11-Nov	0	2.6	6.4	0	0	8.4	2.6	2.6	21.2	0.6	1.4	9.6	4.62
12-Nov	0	5.1	14.3	0	1.4	6.2	24.4	7.6	3.6	0.6	0.4	8.8	6.03
13-Nov	0.4	19.4	5	0	3.2	6.2	7	0	0	4.2	7.4	0	4.40
14-Nov	0	16.1	6.2	0.2	10.6	0	0	1.4	1.2	4.6	2.2	0	3.54
15-Nov	0	6.5	2.2	8.8	13.8	0.4	38.8	11	0.4	12.8	6.6	0	8.44
16-Nov	0	3.2	6	14.2	3.4	2	0.8	3.2	0	38.6	0	11.8	6.93
17-Nov	0	0	1	19	0	0	21.2	12.4	0	7.8	5.8	2.4	5.80
18-Nov	0	0	25.8	37	5	0	2	0	0	14.8	13.4	2.2	8.35
19-Nov	0	11.3	30.6	7.2	0	0.2	4.6	4.2	0	24	5.2	0	7.28
20-Nov	0	9	0.3	0	0	0	2.6	0	5.6	17	0	0	2.88
21-Nov	0	3.2	0	0	0.8	0	15.8	0	6.8	15	0	5.2	3.90
22-Nov	0	4	0.4	0	3.4	0	14.4	0	0	22.4	0	18.2	5.23
23-Nov	11	0.4	0	4.2	11.6	0	8	0	0	7.8	0	19.6	5.22
24-Nov	1.2	0	0	4.4	27.6	2	1.2	0	0	4	0	5	3.78
25-Nov	16.2	0.6	0	3.2	0.4	7.4	0.6	0	3.2	26.4	1.2	0	4.93
26-Nov	12.8	0	0	0	4.8	0.2	0	21	0	6.6	7.4	11	5.32
27-Nov	0	0	0	0.4	1.4	2.6	0	0	1	0	2.4	13.2	1.75
28-Nov	0	18.5	0	62.6	0	0	0	5.8	34.6	17.6	0.6	0	11.64
29-Nov	13	8.6	0	0	5.6	8.4	0	0.4	19.2	1.2	8.4	4.6	5.78
30-Nov	4.8	13.4	0	0	0	0.4	0	0	1.2	2.6	37	0.4	4.98
1-Dec	11.4	13.3	0	3	0	0	0.2	0	6.6	0	0	0	2.88
2-Dec	12	3	0	10.8	1.2	0	0	10.6	0.6	0	3.6	0	3.48
3-Dec	0	7	0	0	6	0	0.6	46.4	0	0	0	0	5.00
4-Dec	0	4.6	2.6	4.2	35.4	2.6	6.2	11.6	0	0	0	0	5.60

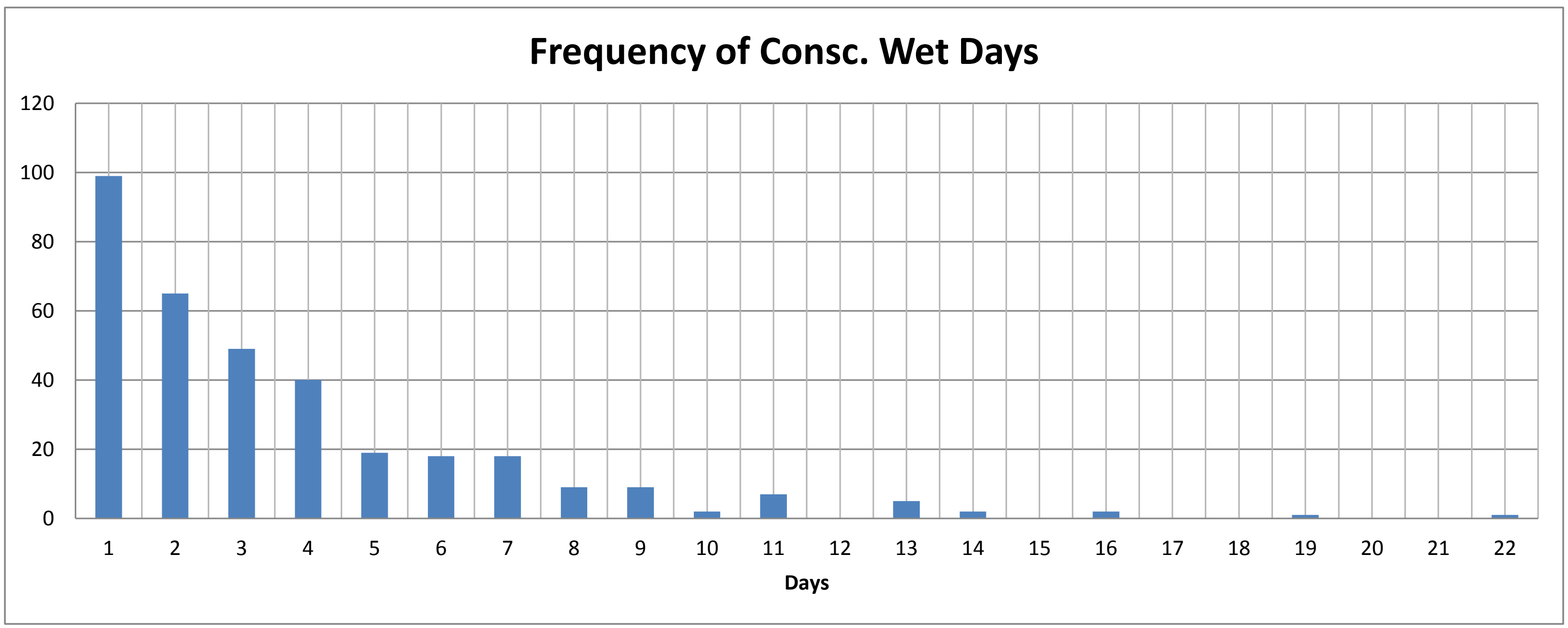
5-Dec	0	5.9	0	6.6	0.4	0.4	1.6	0	0.2	0	0	0	1.26
6-Dec	0	5.8	0	5	4.8	0	0	0	9	0	0	0	2.05
7-Dec	0	1.4	0	1.4	7.8	0	1	0	2.2	0	14.8	0	2.38
8-Dec	1	14.2	0	1	7.8	0	2	0	0.8	0	24	0	4.23
9-Dec	0	3.4	1.6	0	7.8	0	3	0	13.6	0	13.4	0	3.57
10-Dec	1	13.4	10.6	0	26.2	0	3.6	0	2.6	0	3.8	0.2	5.12
11-Dec	0	4	13.2	4.6	0	0.8	16.6	1.8	0	0	5.2	0	3.85
12-Dec	0	22.4	8	7.6	0.4	0.6	6.4	0.4	31.6	0	26.8	0	8.68
13-Dec	0	38	9.2	3.4	5.8	0	15.4	14	0	0	0	0	7.15
14-Dec	1.4	0	16.6	2.4	11.6	0	15.2	7.2	0	1.8	13.6	1.4	5.93
15-Dec	0.4	36.2	10.2	0	0.6	0	6.6	4.8	0	11.8	2.6	2.8	6.33
16-Dec	28.1	18	6.4	12.8	1.2	0	1.2	1.8	0	9.8	0	8.4	7.31
17-Dec	0.2	5.2	11.8	0	6.8	0	0	1.4	0	1.4	0	3.2	2.50
18-Dec	0.2	1.2	4	0	1.2	0	0.8	12.8	0	2.8	4.4	1	2.37
19-Dec	1	0.8	0.2	1.8	0	4	8.4	12.2	0	3	1.4	0.4	2.77
20-Dec	0	0	0	6	0	23.6	5.2	0	0	24.2	0.2	0.8	5.00
21-Dec	0.5	0	0	0	0	6.8	10.2	2.6	0	8.4	0.4	0	2.41
22-Dec	10.6	0	1.6	0	0	12	0	10.4	0	0	0.6	0	2.93
23-Dec	15.8	0	0	4.2	0	7.6	12.2	10.6	0	0	16.6	0.6	5.63
24-Dec	2.4	0	5	8.8	1	17.8	24.4	0	0	0	17.8	20.6	8.15
25-Dec	8.8	0	14.8	0.2	33.4	14.6	0.8	11.2	3	0	7.8	1.4	8.00
26-Dec	15.6	0	0.6	0.8	14.8	4.6	0.4	0.6	10	0	3.2	7.4	4.83
27-Dec	5.4	0.8	9.6	10	0	13.6	0.8	13.8	12.8	0	5.2	26.2	8.18
28-Dec	0	7.8	0.2	0	0	13.2	0	4.6	0.6	0	2	8	3.03
29-Dec	0	0	1.2	0	7.8	1.8	1.8	2.8	8.8	0.2	0	4.2	2.38
30-Dec	1.2	0	10.5	0	4.2	11	0	0	0.6	5.4	0	0.2	2.76
31-Dec	6	4.6	1.6	2.6	2	22.4	1.4	0	6.6	4.4	0	0	4.30

B.6 Precipitation Graph

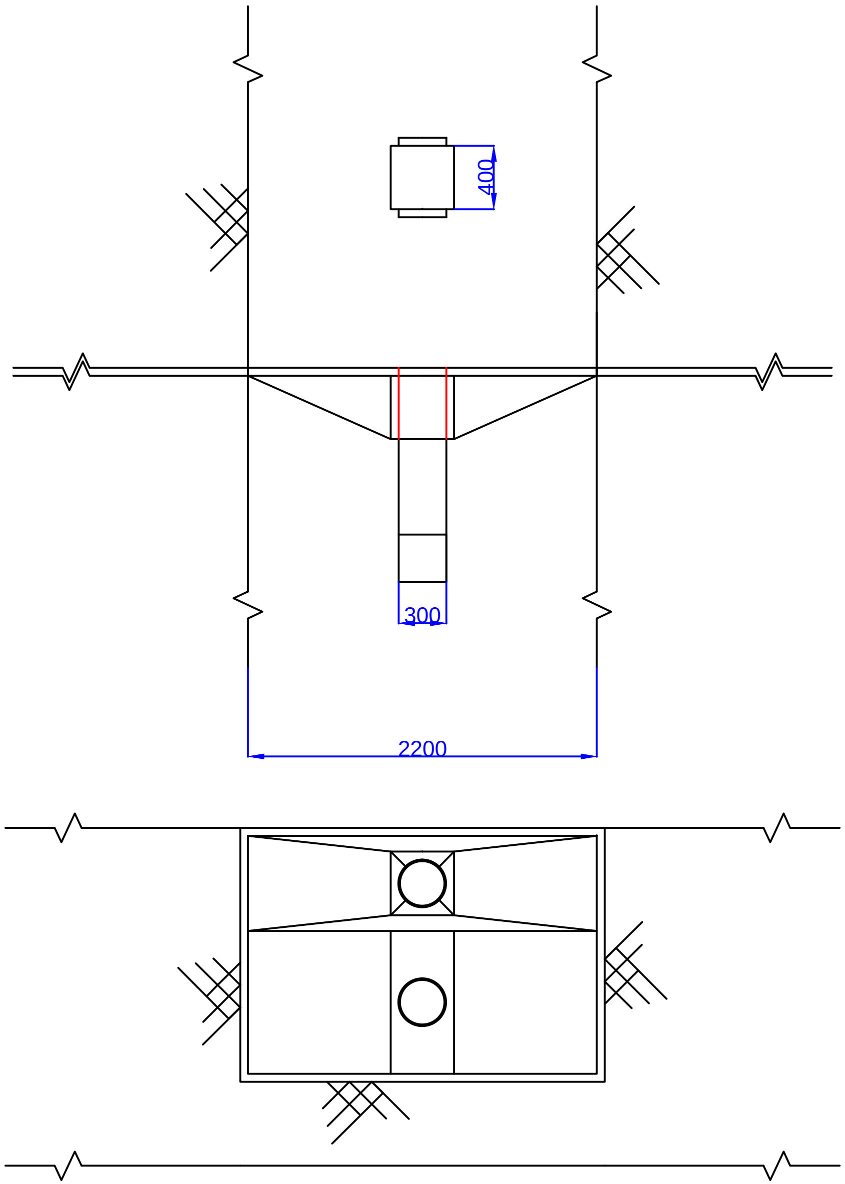


B.7 Frequency of Consecutive Dry/Wet Days



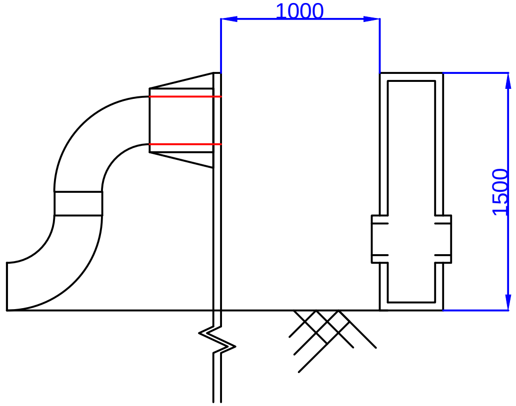


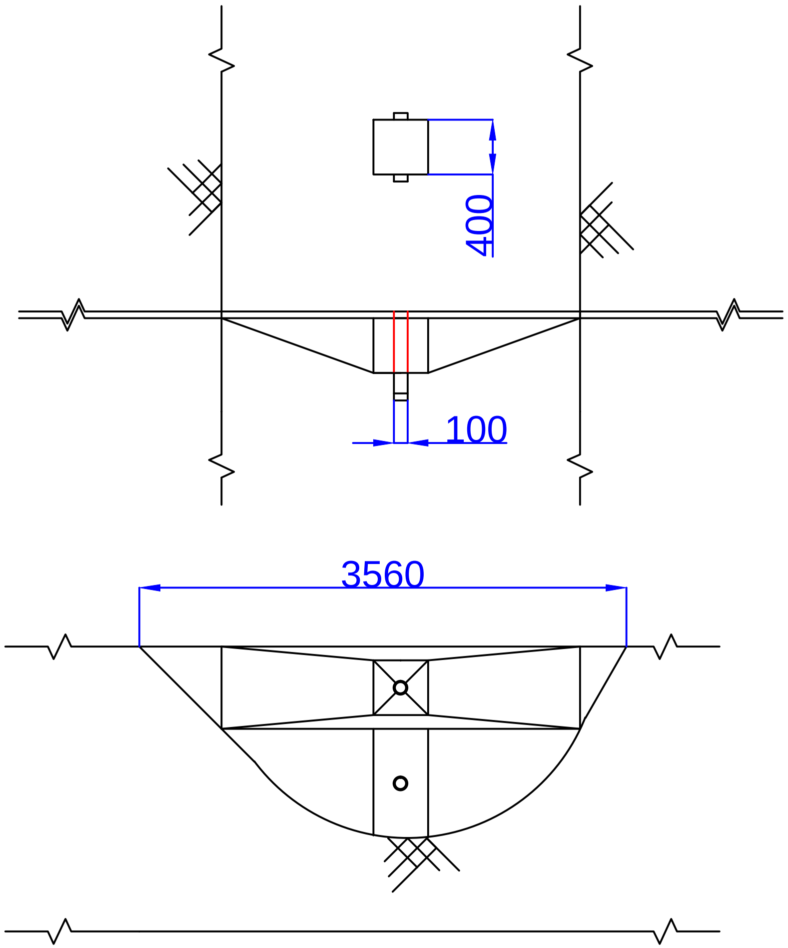
APPENDIX C – AUTOCAD DRAWINGS



Drawing C.1
Dam & Outfall Design
Garden Stream

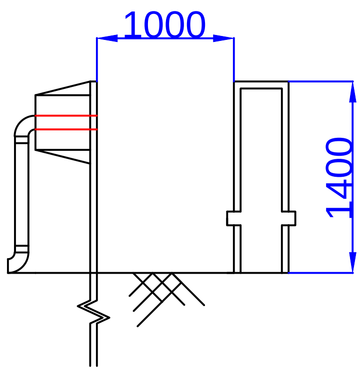
Dimensions are in mm.





Drawing C.2
Dam & Outfall Design
Parking Lot Stream

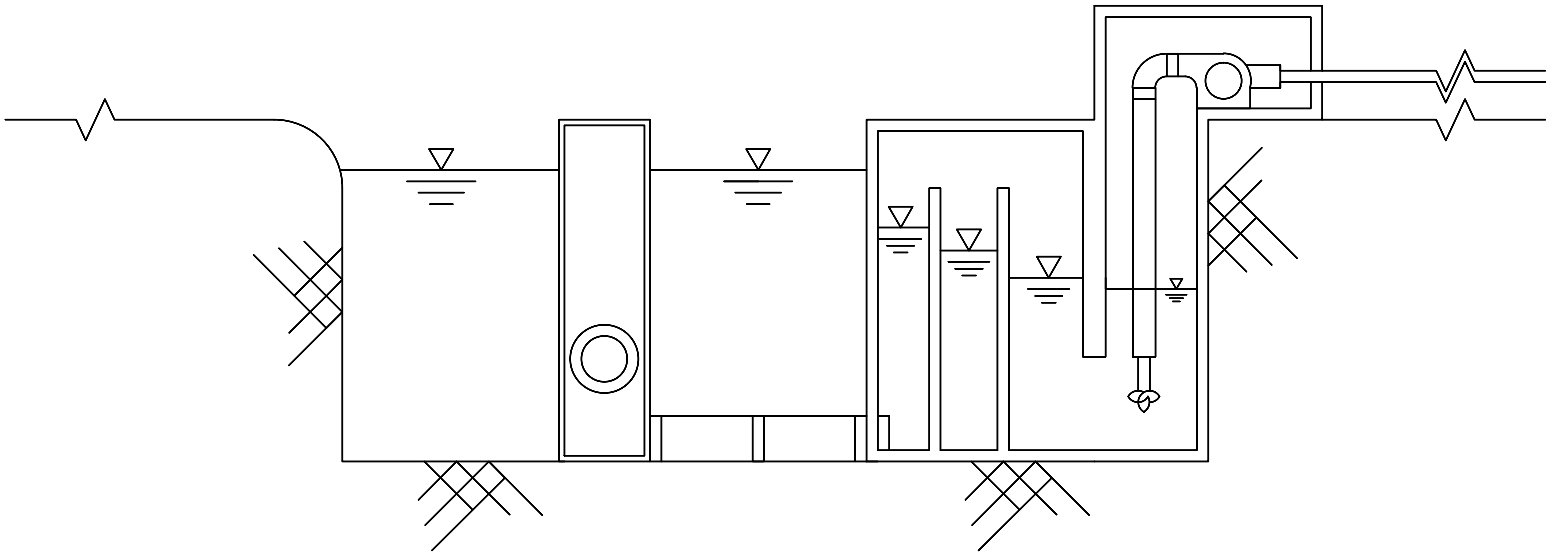
Dimensions are in mm.



PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

Drawing C.3

Typical Pumping System

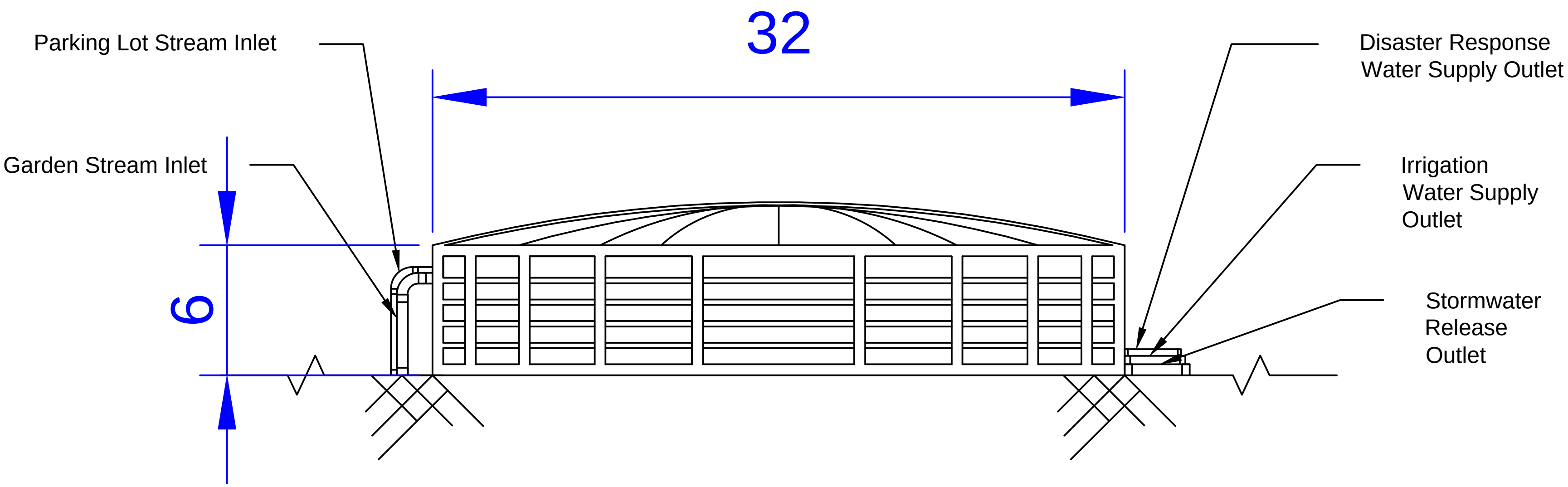


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

Drawing C.4
Storage Tank Connectivity

Dimensions are in m.



APPENDIX D - PROJECT DESCRIPTION FORM

DRAFT

Date: February 2011 Patrick Lewis, Doug Justice, revised Nov 2011, Brenda Sawada

PART 1: STAFF INFORMATION

Anticipated Staff Commitment:

- *Define project clearly using this form*
- *Meet initially with student(s)*
- *Meet bi-weekly with students (or as agreed) to determine progress and provide guidance and support throughout the project*
- *Hold final meeting for presentation of research/recommendations*

Principal Staff Name: Patrick Lewis

Position: Director Department: UBC Botanical Garden and Centre for Plant Research

Address: 6804 Southwest Marine Drive, Vancouver BC, V6T 1Z4

Phone: 604-862-5805 Fax: Email: patrick.lewis@ubc.ca

Additional Staff Names:

Name:	Position/Department:	Phone/Email:
Douglas Justice	Associate Director	douglas.justice@ubc.ca
Iain Taylor	Professor Emeritus	iepiep@interchange.ubc.ca
Alek Paderewski	Manager, Mechanical Utilities, UBC Utilities	
Jenny Liu	Mechanical Utilities Engineer, UBC Utilities	
Waleed Giratalla	Water and Waste Engineer, Campus Sustainability	
Siu Tse	Associate Director, Infrastructure and Services Planning, Campus and Community Planning	

PART 2: PROJECT INFORMATION

Topic:	Stormwater Management in the Botanical Garden	Category: Please x those that apply	CLIMATE AND ATMOSPHERE TRANSPORTATION FOOD SYSTEMS	**X** FINANCIAL MATERIALS **X** COMMUNITY	**X** WATER ENERGY **X** LAND

Working Title: Stormwater Management and Retention in the Botanical Garden

Overall Purpose:

A) To propose implementable stormwater management practices in the Botanical Garden to reduce 1) erosion and periodic flooding within the Garden, and 2) erosion of cliffs and subsequent damage to the Fraser River estuary to the immediate west of the Garden.

B) To propose implementable methods for retaining seasonal runoff for irrigating the Garden in periods of low rainfall and reduce the use of potable water.

Contribution to Sustainability at UBC:

A) Lower maintenance and repair costs

B) Reduced municipal potable water consumption

C) Improved foreshore habitat

D) Creation of a working water sustainability demonstration project

Outline of Project Details:

Working with Garden staff and faculty, students will:

- Gather data from records and anecdotal comments from staff to gain an overall sense of how water is used throughout the entire Botanical Garden

- Assess how much water has historically been used and is needed for future irrigation in the Botanical Gardens taking into account potential climate shifts and including the proposed expansion of irrigated areas (the se corner of the lower garden). Identify areas of interest and concern
- track water courses in the Garden including up-stream water sources, and gather records and anecdotal information about seasonal water flows including such things as volume, nature and volume of particulate matter, infiltration patterns and erosion in the Garden and on the sand cliffs and estuary to the west of the Garden
- Use data collected both up- and down-stream of the Garden, and in the Garden, to propose implementable methods for managing storm water flows to control erosion and flooding and to retain water for irrigation purposes. Proposals and recommendations should include but not be limited to:
  - examining the potential for irrigation from the Trail 7 creek that has a flow monitoring system and could potential have a pump installed by UBC Utilities
  - installing under pathway storage tanks, see www.watermanagementsolutions.ca or http://www.rainxchange.com/products/aquablox.php
  - installing a water retention system on the bank above Creek 3 (southeast of the intersection of 16th Ave and Southwest Marine Drive) designed to collect storm water during winter flows
  - installing weirs in the streams in the lower garden

Anticipated Dates for Initiation and Completion of Project:

- Winter term 2012

NEXT STEPS

- Jim to review draft 4, use track changes to make changes and seditions as necessary
- Jim to post internally as SEEDS Directed Studies project
- Jim to select students with potential to be involved
- Brenda and Jim to meet with students in mid-December to orient students to project and SEEDS
- Brenda to arrange meeting first week of January with all parties to provide student orientation

Report D:

Emergency Water Supply Plan

Prepared by: Patti Shen

May 6th, 2012

Contents

Figures and Tables

Executive Summary

The objective of this report is to propose the emergency water supply plan as requested by Aleksander Paderewski from UBC. The reason of this plan is to provide a solution of survival for the on-campus residents during a disaster event such as an earthquake. In response to that, an emergency water supply system is designed with two major components: the disinfection facility and the distribution network. The stormwater quality analysis report from CARO Analytical Services provides the plan with a set of background information that suggests the main disinfection goal in order to meet the Metro Vancouver Guideline for drinking water standard. The water samples show high concentration of coliforms that needs to be removed, and UV disinfection system is recommended for the treatment for its effectiveness and minimal health effects. A small scale UV disinfection model—Upstream System NC 10-75 is selected for the design. The distribution network consists of emergency storage, pump, disinfection facility and pipeline. The emergency storage is originally designed to be $36m^3$ with a scenario of 4000 on-campus residents, 2 liters of supply per person per day and 3 days of supply period. This design is later modified since the irrigation storage tank has an extra $300m^3$ to accommodate the emergency supply with a flexibility to reach a 24-hour supply with an extra $140m^3$. The pump used for the emergency supply is the stormwater releasing pump of the storage tank. Proper coordination of pump operation ensures the performance for either purpose. The disinfection system is located adjacent to the pump to maintain a suitable pressure head. The distribution area is proposed to be the Totem Field at the intersection of SW Marine Dr and Stadium Rd which provides an open space for both gathering and multiple outlets. Thus the pipeline extends to the northeast of the tank across SW Marine Dr. The economic analysis show the emergency water supply system itself will not be profitable based on the fact that disasters are unpredictable and the savings from electricity and water cannot cover for the expense even with the extreme scenario. However one can consider this system as a part of the entire stormwater retention project, in which the emergency supply will occupy a small amount and thus has neglect impact on the payback period, which is estimated to be 29 years. This design is still in the conceptual stage because many assumptions, uncertainties and limitations apply during the computation process. Disaster prediction and lack of data mainly contribute to the feasibility of the design. The cost of labor, excavation and traffic management also require this proposal to be further studied and evaluated.

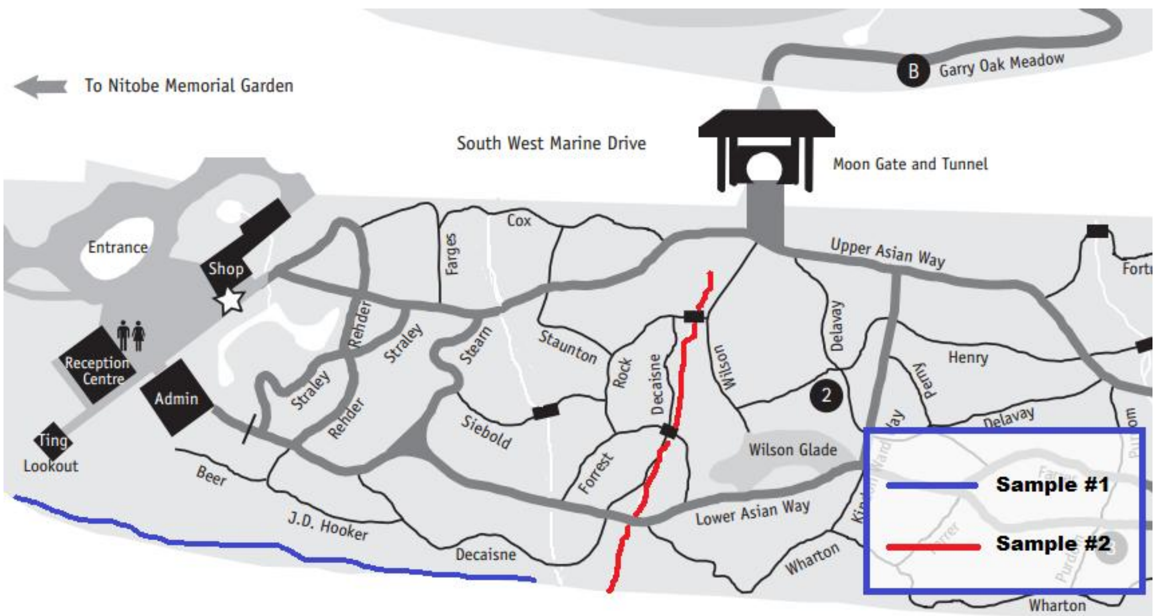
1.0. Introduction

The primary goal of this report is to establish a conceptual model of the emergency water supply for the on-campus residents during a disaster event. The emergency water supply system consists of two parts: disinfection and distribution. This report starts with the sampling test from CARO Analytical which determines the contents of the water in order to recommend the proper treatment method. UV disinfection is selected for its effectiveness and minimal health effects. The report then introduces and describes the components of the distribution, mainly the system components and supply strategy. Moreover, the report discusses the economic analysis and the uncertainties and limitations that apply in this project.

2.0. Stormwater Quality

In order for the stormwater collected in the Botanical Garden to be a potential source of emergency water supply during disaster periods, it is crucial for the collected water to satisfy the Metro Vancouver Guideline as a potable water source. To achieve this objective, water quality has to be examined and a set of treatment facility needs to be installed to remove contaminants of concern.

A set of stormwater sampling test was conducted by CARO Analytical Services on January 11th, 2012. The complete set of laboratory report (Work Order: CA20185) was received on January 26th 2012 by UBC Utilities. The purpose of this sampling test is to provide a scientific study on the existing streams in the UBC Botanical Garden so that further treatment methods can be proposed. In this test, CARO examined samples from two locations: the stream by Trail 7 (Sample #1) and the stream located at the intersection of Rock Trail and Wilson Trail (Sample #2). Each sample was tested mainly in four categories: general parameters (BOD_5 and TSS), field parameters (pH), total recoverable metals (e.g., As, Cu, Mn, Zn) and microbiological parameters (total and fecal coliforms) (Certificate of Analysis, 2012) (UBC Botanical Garden



Map).

Figure 1 Sample Locations Source: http://www.botanicalgarden.ubc.ca/sites/default/files/ubc-botanical-garden-map.pdf

Samples from different locations have slightly different characteristics. Nonetheless, both samples show high concentration of coliforms and the existence of some heavy metals. Specifically, the total coliforms and fecal coliforms of these samples exceed far from the Guideline, which requires zero total and fecal coliforms in the water body. Moreover, both samples have shown existence of copper, iron and manganese. Sample #2 also shows the existence of molybdenum. A summary of the concentration of aforementioned is listed below.

Table 1 Existing contents in samples

Parameters	Stream by Trail 7	Stream by Botanical Gardens	Metro Vancouver Guideline	Reported Detection Limit	unit
Copper	0.0084	0.0107	2	0.002	mg/L
Iron	0.39	0.58	10	0.1	mg/L
Manganese	0.0752	0.14	0.0752	0.002	mg/L
Molybdenum	<0.001	0.0011	1	0.001	mg/L
Total Coliforms	930	230	-	3	MPN/100mL
Fecal Coliforms	9.1	9.1	-	3	MPN/100mL

The listed metal contents are confirmed existence by comparing the tested concentration with the reported detection limit, which is the lowest concentration of the analytes that can be detected and reported with relatively accurate and precise analyses. The metal contents can be retained in the soil naturally and from traffic runoff. In order to determine whether the metal contents come from traffic runoff or not, tests of typical organic substances such as gasoline and diesel should also be performed. As this is not included in the report, this possibility is unknown. Nevertheless, even though samples show existence of listed heavy metals, the concentration of all detected metals is below guideline, and therefore they do not contribute to the water quality concern (DETECTION LIMITS: Definition and Explanation of Terms, 2005).

The main concerns of water quality from the two streams are however not only total and fecal coliforms. As the original objective of the testing report was not to examine the water for potable water purpose, there were no tests on viruses and pathogens such as Giardia and Cryptosporidium. Thus, with their potential existence in water, the disinfection system need to achieve 4-log removal of viruses, 3-log removal of Giardia and Cryptosporidium, and zero coliforms in the water. This requires the disinfection system to be highly effective and have minimum effects on water consumers. Also, the scale and complexity of the system must be considered so that the plan is feasible within cost and time constraints.

Furthermore, there is a possibility for harmful chemicals such as herbicides ingredients that need to be removed. Because it is not included in the conventional drinking water treatment objectives, this factor is considered to have negligent health effects provided that the intake amount during the disaster event is minimal. Thus, chemical contaminants are treated as one of the uncertainties in the later section.

3.0. Ultraviolet Disinfection

From the previous discussion, ultraviolet disinfection is selected to treat the collected stormwater for potable water purpose. Ultraviolet disinfection is highly effective, and since UV light is the only disinfectant, it leaves no health concerns to human. It is also economically efficient at a small scale, such as the scale for this emergency water supply. As a minimum of 3-

log removal is required, we need to ensure that a typical UV disinfection facility provides adequate UV dose to remove 99.9 percent of the pathogens.

Table 2 UV dose for 3-log removal and typical UV disinfection facility

3-Log Removal	E.Coli	Cryptosporidium	Giardia	Typical UV Disinfection Facility
UV Dose (mJ/cm2)	4.1~7.3	12	11	40

It is shown here that a 3-log removal of pathogens will require the UV dose up to 12 mJ/cm^2, while typical small scale UV disinfection equipment provides a minimum dose of 40 mJ/cm^2 with specified flow rate. Thus, an equipment of this kind is sufficient to remove most of the mentioned pathogens. Here, an example model is referred to for demonstration and design purpose. The Upstream System NC 10-75 in the left of Figure 1 is an innovative and highly effective ultraviolet disinfection system with external light. Unlike the ordinary systems (right of Figure 1) in which the UV lamp locates in the center of the sleeve, the NC 10-75 design with external lamps and elliptical reflector provide redundancy and enhance contact area. Water flowing inside the sleeve is treated by UV light through the quartz sleeve from the external UV lamps. This ensures isolation of the treated water from light source to prevent any potential contamination while treating the water with higher efficiency. Moreover, the built-in smart sensors attached with the UV lamps monitor the water quality as well as the lamp output. The stainless steel wiper constantly rotates inside the quartz sleeve to uphold the transmittance of light, which is 75%. Therefore, the NC 10-75 significantly reduces the maintenance effort in the comparison with the ordinary systems. Despite the unique design, with a specified flow rate of $2.3m^3/hr$, NC 10-75 produces a minimum UV dose of $40mJ/cm^2$, which gives adequate disinfection to the water (Total Coliforms - 9.0 Treatment Technology, 2008) (Small-Scale UV (Ultraviolet) Water Purification, 2011).

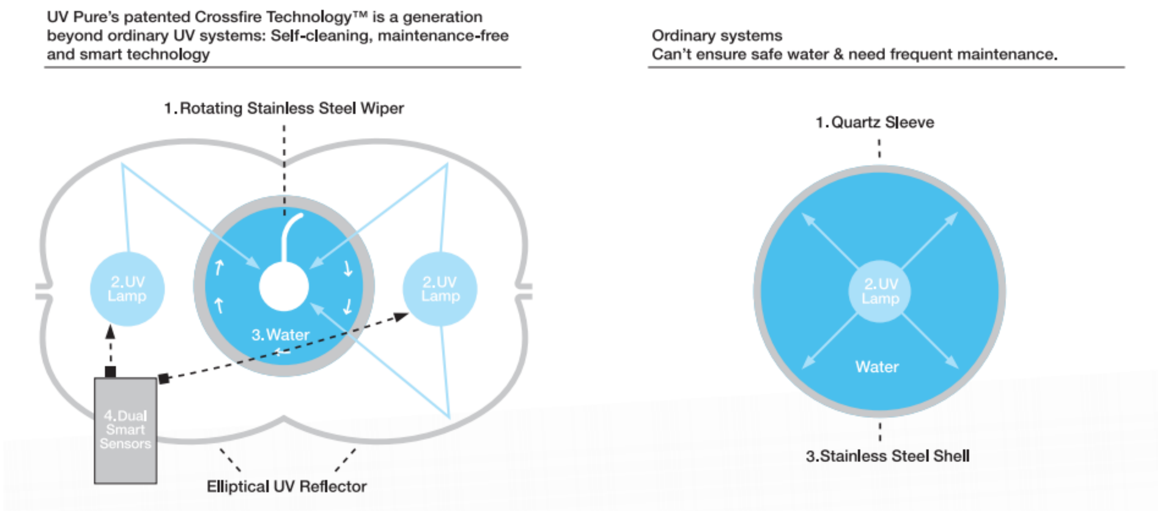


Figure 2 Upstream System NC 10-75 vs. Ordinary Systems Source: http://www.gongol.net/assets/store/uvpure/upstream.pdf

There are some limitations in using any of the UV disinfection system. As it is an advance treatment, UV disinfection system requires pre-treatment so that the water has low hardness, low dissolved solids, turbidity and so on. The effectiveness also depends on pH range, which is preferably 6 to 9. Having these criteria met not only assists in better treatment, but also for a prolonged equipment life. The water samples in the Garden satisfy hardness by iron and manganese contents, pH and water temperature, but their total dissolved solids and turbidity are unknown. Thus, in order to proceed with calculation, it is assumed that the collected water in the stormwater is qualified for the effective treatment, and that the pump system provides suitable pressure for the treatment (Upstream System, 2007).

Table 3 Sample Quality vs. Effective Treatment Range

Water Conditions	Minimum	Maximum	Sample #1	Sample #2	Unit
Hardness	0	855	-	-	mg/L
Iron	0	3	0.39	0.58	mg/L
Manganese	0	0.5	0.0752	0.14	mg/L
% UV Transmittance	75% or 50%	100%	-	-	
pH	6.00	9.00	7.77	7.24	
Total Dissolved Solids	0	1000	-	-	mg/L
Water Temperature	1	40	4	4	◦C
Air Temperature	1	40	-	-	◦C
Turbidity	1	1	-	-	NTU
Water Pressure	69	690	-	-	KPa

4.0. Distribution Strategy

This section introduces and explains the design details of the emergency water supply distribution strategy. The supply system consists of storage space, solar panel, pumps, disinfection facility and pipe network connecting with the distribution point. The coordination between the components determines the performance of the emergency system. The strategy involved in supply pattern and supply area is also discussed. Two designs are proposed based on the disaster scenario and the existing design of the stormwater storage tank. The latter design is the modified design that is proved to be flexible and feasible to achieve.

4.1. Storage Tank

Two designs are involved in the storage volume. The first design is based on one disaster scenario of 4000 on-campus residents, 2 liters of supply per person per day and 3 days of supply period. A safety factor of 1.5 is considered. This yields a volume of 36m^3 for adequate supply for one event. According to the tank design in Report C, the irrigation demand for the entire dry season is estimated at 4700m^3, and the tank capacity allows 5000m^3 of storage, which means an extra volume of approximately 300m^3 can be used for other purposes. In this case, this space is sufficient to accommodate the emergency supply as well as being a safety margin for the irrigation demand. Therefore, the storage tank is the source for both irrigation water and emergency water supply (Chand, Hsieh, & Mamorafshord, 2012).

4.2. Solar Panels

Solar panels are considered in this project as a power source specifically for the emergency water supply. In order to avoid conflicts with UBC Hospital in using the emergency power source, the Garden should equip an individual source that provides enough electricity to operate the pumps and disinfection system. The solar panels can be installed on top of the storage tank to collect sunlight in a short period of time. Given the power consumption of these two components, an optimum model can be selected from the suppliers. In our design, NC 10-75 consumes 118W and the two pumps consume approximately 6KW each. Therefore, a set of 36 commercial 200W solar panels can be selected. In terms of the selection between panel materials, mono-crystalline surface is preferred since less crystal faces creates stronger penetration and generates energy faster. Although it is more expensive in terms of manufacturing, the supply is required to be available as early as possible after the disaster, which overweighs the cost concern (Canadian Solar Panel Prices, 2010).

4.3. Pumps and Pipe System

The pump used in the emergency water supply system is the stormwater releasing pump. The pipe connecting to the distribution area starts from the pump. A valve is installed close to the pump in order to switch for stormwater releasing or emergency water supply purposes. The pump operates normally for stormwater releasing when no disaster occurs. This design can significantly reduce extra related costs. The coordination between stormwater release and emergency water supply in both dry and wet seasons is proved to be feasible. During the dry seasons when the storage tank is mainly discharging for irrigation, the stormwater releasing pumps are shut down. When a disaster occurs, the pumps can be turned on to transport emergency supply. In wet seasons when the storage tank is mainly charging, the pumps are usually turned on to drain overflows. Thus, emergency supply is almost immediately available by switching the valve. As in Report C, two stormwater releasing pumps are designed. In this report, only one pump is considered. A parallel system is possible, but the later calculation confirms that using one pump is sufficient.

4.4. Disinfection Facility

The NC10-75 can be installed adjacent to the tank just after the pumps. The reason is that the operation of NC 10-75 needs the electricity generated by the solar panel. Additionally, enough pressure head is required for effective disinfection.

4.5. Distribution Area

The selection distribution area has three criteria. The area needs to be easily accessible, spacious and close to the storage tank. Meeting these criteria means reduced hazard potential. In this project, the distribution area is determined to be the Totem Field at the intersection of SW Marine Dr and Stadium Rd. Over 3000m^2 of area is located just south of the campus, which is accessible by major streets. Besides, a shelter can be set up for temporary relief in this place. The large area provides enough space for multiple outlets that shortens the lineup time. Moreover, a shorter distance from the storage tank can reduce the risk of pipe damage during the disaster, as well as the pathogens re-growth after UV disinfection.

Although the proposed area meets all three criteria, uncertainties lie in the practicality of the plan since the installation involves traffic interruption and high excavation and labor costs. An improvement of the solution is needed in further studies.

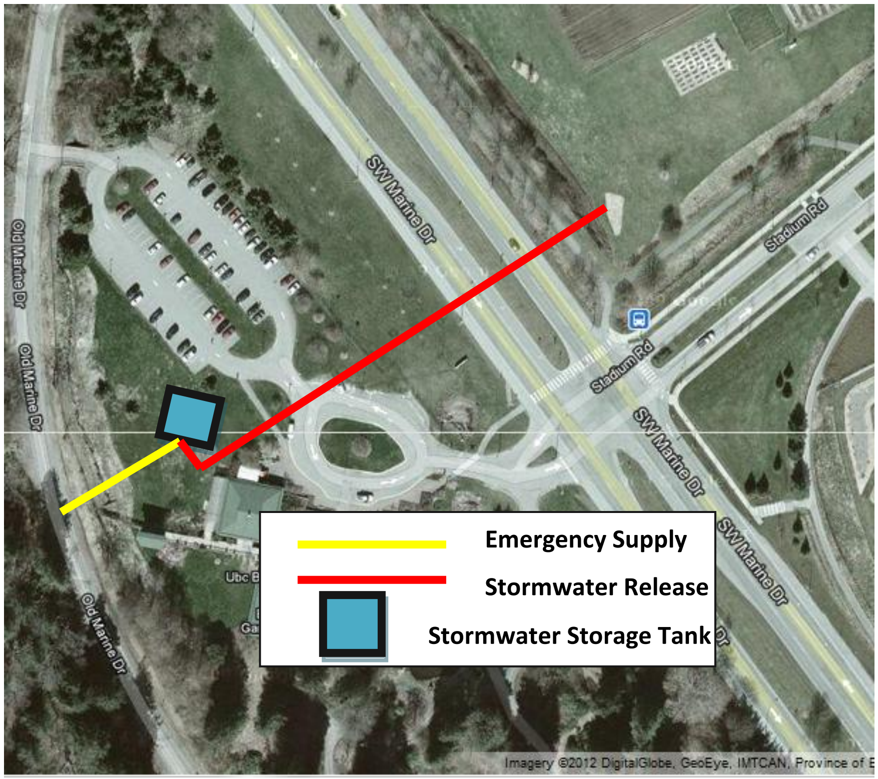


Figure 3 Distribution Area

4.6. Modified 24-Hour Supply

The aforementioned design volume is 36m^3. In order to reach effective disinfection with a specified flow rate of 2.3m^3/hr, the daily supply hour shrinks to only 5.2 hours. On the other hand, the extra 300m^3 of space provides a great flexibility in the adjustments of daily supply hours, daily supply amount, actual population and actual period. A 24-hour supply is considered, *ceteris paribus*, and the resulted daily supply volume is 55.2m^3 and a total of 166m^3 is required, which is feasible within the existing circumstance. Therefore, this modified design is preferred. Furthermore, the additional 140m^3 left can be used to accommodate extra supply demands.

5.0. Economic Analysis

The economic analysis of the emergency water supply is quite different from the ordinary cases where payback period and savings can be expected. As a solution to disaster events that provides pure social benefits, the saving from the amount of tap water that could have been consumed solely depends on the frequency and severity of the event. Even in the extreme case where disasters are assumed to occur annually, the saving of electricity and water cannot breakeven. Considering the emergency water supply as an independent case, only the installation and operation can be determined with certainty. The total installation cost is $42193 as of 2012, considering 36 200W solar panels, 1 NC 10-75 and 180 meters of 200mm PVC pipe (one complete system) at current price; the operation fee of an event with 24-hour supply is $205 in total. Annual saving and payback period is only computable by assumption. At an optimistic MARR of 2%, depreciation rate of 20%, annual maintenance of $2000/year with 10% increase each year after, the replacement of system is 13 years. With this extreme case, one can see that the saving is far from breakeven. Therefore, the emergency water supply system itself is not profitable. Its real dollar cash flow diagram is shown in Figure 4 (U.S. & Canada City Pipe Price Averages - Feb. 07, 2007).

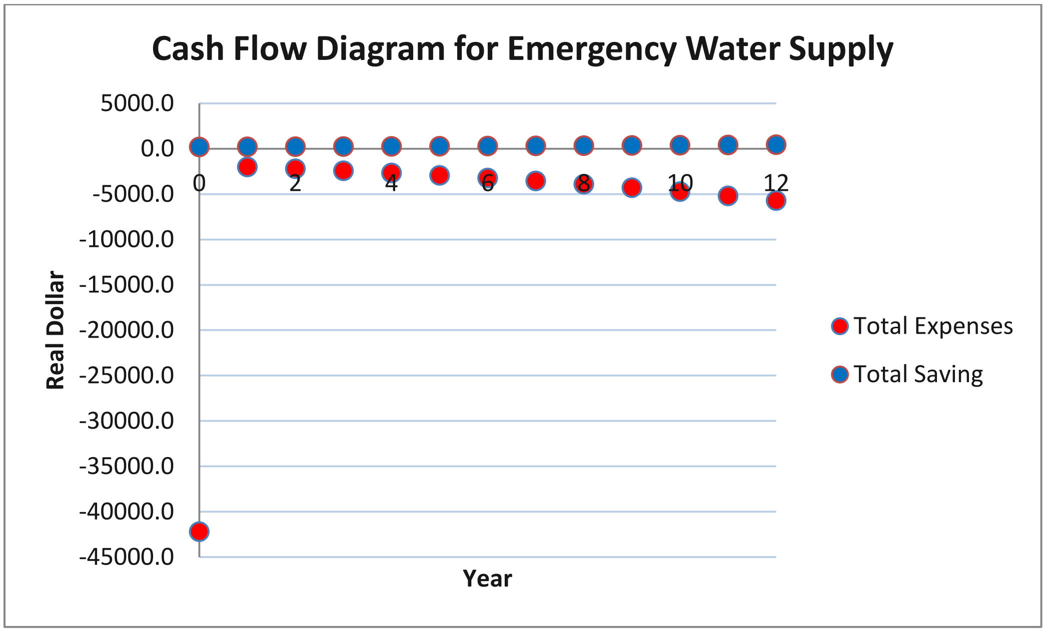


Figure 4 Cash Flow Diagram for Emergency Water Supply

Alternatively, one can also consider the emergency water supply a part of the entire SEEDS project, so that the expenses can be recovered from total water expense saved. In this case, the expense and saving of the emergency water supply will be small enough to be neglected and the payback period will be around 29 years as calculated in Report C. Another thing to notice is that the expenses of excavation and labor are not included since further studies are needed to estimate these costs (Chand, Hsieh, & Mamorafshord, 2012).

6.0. Uncertainties and Limitations

The design of the emergency water supply involves many uncertainties and limitations. Calculation and recommendations in this report are based on a series of assumptions based on industrial average and extreme cases. In order to validate this proposed plan, extensive studies as well as sufficient data support are needed.

The uncertainties are in three major aspects: climate and water conditions, system operation requirements and economic analysis. The climate conditions directly affect stormwater quality as well as the actual emergency supply amount. Not only does the fluctuating rainfall level introduces various types of contents in water, but also the fact that the CARO report did not cover more on microbiological and chemical test gives an uncertainty of the actual pathogen level that needs to be treated. Moreover, as the current meter was installed less than a year ago, lack of data from consecutive years creates obstacles in summarizing the data trend and establishing the model. One example is the base flow in summer, which is obtained from an empirical approach by assuming 10% of the winter flow. In terms of system operating, assumptions are made in the collected stormwater quality so that the stored water is immediately ready for UV disinfection. Specifically, assumptions such as total dissolved solids, hardness and turbidity are made to satisfy the effective treatment range of NC10-75. The aforementioned economic analysis has high level of uncertainty because the actual saving in energy and water bills come from the use of the emergency water supply during a disaster event, which is unpredictable with current technology level. At this stage, only the installation and operation fee can be calculated with certainty. The depreciation model and replacement schedule are computed based on an extreme case which is expected to yield the least payback period, and even this model does not give a breakeven point. Thus the only approach of breakeven analysis is to go through the emergency water supply as a part of the entire SEEDS project, in which the emergency water supply is accounted only as a small percentage of the total expense and saving. The approximate result will be similar as calculated in Report C (Certificate of Analysis, 2012).

The limitations of the emergency water supply are similar to the uncertainties because most of the uncertainties in this report are from the extent of information that students can utilize from the current materials. One of the major limitations is that disasters are difficult to predict as their frequency and locations are the main problems for prediction. As this report proposes a solution for survival in the disaster, this limitation makes it difficult to determine whether the system will be able to function in its service life, and how well it actually performs. Another effect of this limitation is whether this plan is worth proceeding giving such condition since the expense of this project will not be covered even with the assumption of frequent disasters. With the massive effort in the excavation across SW Marine Dr and traffic detouring, the feasibility study of this plan needs to be further conducted. The other limitation is the data acquisition which is restricted by the current measuring equipments in use for less than a year. However, this limitation can be solved once a series of data of major streams though consecutive years are obtained, and this will help establish a stream level model for the Garden independently. The design results based on this model should be more convincing. Overall, the emergency water supply plan in this report is still a conceptual model that is expected to be modified and further developed.

7.0. Conclusion

The report presents the conceptual model of emergency water supply for the Botanical Garden as a part of the SEEDS stormwater management project. The design of disinfection system and distribution is based on existing CARO analytical report, storage tank design from Report C and educated assumptions. Many uncertainties and limitations have prevented the design to be more accurate and practical, but the concept has been successfully established. Further research and developments can be built on this conceptual model. The current economic analysis can also be improved and modified for the project to be more feasible.

8.0. Bibliography

Canadian Solar Panel Prices. (2010, August 25). Retrieved May 5, 2012, from Canadian Solar Panel Prices: http://solarpanelprices.org/canadian-solar-solar-panel-prices

(2012). *Certificate of Analysis.* Richmond: CARO Analytical Services.

Chand, K., Hsieh, W. C., & Mamorafshord, M. (2012). *Report C: Sustainable Design for Irrigation and Stormwater Management in the UBC Botanical Garden.* Vancouver.

DETECTION LIMITS: Definition and Explanation of Terms. (2005, March 18). Retrieved May 4, 2012, from California Department of Public Health: http://www.cdph.ca.gov/certlic/drinkingwater/Documents/Drinkingwaterlabs/detectionlimitsdefinition.pdf

Small-Scale UV (Ultraviolet) Water Purification. (2011, March). Retrieved May 3, 2012, from DJ Gongol & Associates, Inc.: http://www.gongol.net/store/uvfilters/

Total Coliforms - 9.0 Treatment Technology. (2008, January 7). Retrieved May 1, 2012, from Health Canada: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/coliforms-coliformes/treatment-traitement-eng.php

U.S. & Canada City Pipe Price Averages - Feb. 07. (2007, Feburary). Retrieved May 4, 2012, from PVC Insight: http://www.pvcinsight.com/subscribers/2007/PVCINSIGHT_Feb07_Report01.pdf

UBC Botanical Garden Map. (n.d.). Retrieved April 25, 2012, from UBC Botanical Garden: http://www.botanicalgarden.ubc.ca/sites/default/files/ubc-botanical-garden-map.pdf

Upstream System. (2007). Retrieved May 4, 2012, from UV Pure: http://www.gongol.net/assets/store/uvpure/upstream.pdf

9.0. Appendix D

Asset Depreciation Model

Period, N	Capital costs		Maintenance costs				Total costs
	Salvage Value, S	EAC	Cost each year	Component PW	Cumulative PW	EAC	EAC
0	$ 42,193.24						
1	$ 33,754.59	$ 9,282.51	$ 2,000.00	$ 1,960.78	$ 1,960.78	$ 2,000.00	$ 11,282.51
2	$ 27,003.67	$ 8,363.45	$ 2,200.00	$ 2,114.57	$ 4,075.36	$ 2,099.01	$ 10,462.46
3	$ 21,602.94	$ 7,571.84	$ 2,420.00	$ 2,280.42	$ 6,355.78	$ 2,203.89	$ 9,775.74
4	$ 17,282.35	$ 6,887.84	$ 2,662.00	$ 2,459.28	$ 8,815.05	$ 2,315.04	$ 9,202.88
5	$ 13,825.88	$ 6,294.89	$ 2,928.20	$ 2,652.16	$ 11,467.21	$ 2,432.87	$ 8,727.76
6	$ 11,060.70	$ 5,779.18	$ 3,221.02	$ 2,860.17	$ 14,327.39	$ 2,557.81	$ 8,336.98
7	$ 8,848.56	$ 5,329.12	$ 3,543.12	$ 3,084.50	$ 17,411.89	$ 2,690.34	$ 8,019.47
8	$ 7,078.85	$ 4,935.04	$ 3,897.43	$ 3,326.42	$ 20,738.31	$ 2,830.98	$ 7,766.02
9	$ 5,663.08	$ 4,588.77	$ 4,287.18	$ 3,587.32	$ 24,325.63	$ 2,980.27	$ 7,569.04
10	$ 4,530.46	$ 4,283.48	$ 4,715.90	$ 3,868.68	$ 28,194.31	$ 3,138.77	$ 7,422.25
11	$ 3,624.37	$ 4,013.38	$ 5,187.48	$ 4,172.10	$ 32,366.41	$ 3,307.13	$ 7,320.51
12	$ 2,899.50	$ 3,773.59	$ 5,706.23	$ 4,499.33	$ 36,865.73	$ 3,486.01	$ 7,259.60
13	$ 2,319.60	$ 3,559.99	$ 6,276.86	$ 4,852.21	$ 41,717.95	$ 3,676.12	$ 7,236.11
14	$ 1,855.68	$ 3,369.08	$ 6,904.54	$ 5,232.78	$ 46,950.73	$ 3,878.22	$ 7,247.30
15	$ 1,484.54	$ 3,197.86	$ 7,595.00	$ 5,643.19	$ 52,593.92	$ 4,093.15	$ 7,291.01
16	$ 1,187.63	$ 3,043.82	$ 8,354.50	$ 6,085.80	$ 58,679.72	$ 4,321.77	$ 7,365.59
17	$ 950.11	$ 2,904.78	$ 9,189.95	$ 6,563.12	$ 65,242.84	$ 4,565.03	$ 7,469.81
18	$ 760.09	$ 2,778.88	$ 10,108.94	$ 7,077.87	$ 72,320.71	$ 4,823.94	$ 7,602.82
19	$ 608.07	$ 2,664.54	$ 11,119.83	$ 7,633.00	$ 79,953.70	$ 5,099.59	$ 7,764.13
20	$ 486.45	$ 2,560.38	$ 12,231.82	$ 8,231.66	$ 88,185.37	$ 5,393.13	$ 7,953.51

Installation Fee

Installation		Unit Price	Quantity	Subtotal
Disinfection System		$ 999.00	1	$ 999.00
Solar Panel		$ 599.95	36	$ 21,598.20
Pipe System		$ 70.33	180	$ 12,659.40
		Before Tax Total		$ 35,256.60
Tax	12%	After Tax Total (2012)		$ 39,487.39
		After Tax Total (2010)		$ 41,324.70

Saving During One Event	Power Use (W)	Duration (days)	Total Power Saved (KWh)	Unit Price ($/KWh)	Saving ($)
Solar Panel	172.8	3	447.8976	$ 0.09	$ 40.98
	Volume Use (m3)	Duration (days)	Total Volume Saved(M3)	Unit Price ($/m3)	
Water	55.2	3	165.6	$ 0.99	$ 163.94
				Total Saving ($)	$ 204.93

Supply Strategy

Original Design

On-campus Residents	=	4000	ppl
Daily Supply	=	2	L/ppl/day
Period	=	3	days
Safety Factor	=	1.5	
Design Supply	=	12	m3/day
Specified Flow Rate	=	2.3	m3/hr
Daily Supply Hour	=	5.22	hour

Modified Design

Specified Flow Rate	=	2.3	m3/hr
Daily Supply Hour	=	24	hour
Modified Supply	=	55.2	m3/day
Extra Storage Tank Space	=	300	m3
Total Supply	=	165.6	m3
Unused Space	=	134.4	m3
Safety Factor	=	1.81	