AMS Sustainability Project – Stormwater Management in the UBC Botanical Garden

Phase II

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CIVL 202

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Executive Summary

This report discusses the practice of stormwater monitoring in the UBC Botanical Garden since August 2012, in response to the suggestions provided by the Phase I of the stormwater management project finished in May, 2012. The scope of the Phase II project is to obtain the on-site flow rates of the continuously flowing West Creek and Rock Creek, and to design a retention solution for stormwater reuse in the irrigation.

A flow rate tracking system was established by setting up weirs in West Creek and Rock Creek. A set of pressure sensitive HOBO dataloggers were placed at the weirs, and the related parameters (absolute barometric pressure, atmospheric pressure, temperature, etc) were regularly collected by site visits. The data collection started from August 2012 represented the characteristics of the Botanical Garden area in both dry and rainy season. Upon the hydrograph results, the baseflow results of both creeks were studied and compared with the actual monthly accumulative irrigation demand. A supply-demand model was established, and several scenarios have been considered in terms of percentage of capture and capture locations.

The baseflow at Weir #1 in West Creek is 0.8L/s. The total capture of the accumulated flow can satisfy the irrigation demand with additional potable water from July to October. On the other hand, the baseflow at Weir #2 in the merge of West Creek and Rock Creek is 2.4L/s. With a capture as low as 43 percent, it meets a total substitution of potable water irrigation for the whole year. The comparison concludes that the relatively ideal solution is to install retention device along the Old Marine Drive close to Weir #2 with a length of 220m and a volume of 150m^3. This retention storage provides a safety factor of 1.21 and is recommended to be constructed by modular matrix tanks.

Limitations in this project include data consistency and data availability. Incidents such as the weir foundation failure due to heavy rainfall occurred in October created discontinuity in data. Data correlation and interpolation were applied to achieve consistency, but inaccuracy can be introduced. The sediments carried from upstream also offset the actual water depth, leading to inaccurate data. The irrigation demand data were only available for less than one year, so this was not yet a good reference of the average annual irrigation demand.

Contents

Introduction

In January 2012, a group of 4th year civil engineering students participated in a research study of the stormwater management in the UBC Botanical Garden. The goal of the Phase I project was to seek for a feasible solution for stormwater collection in the Botanical and a distribution plan for potable water use for irrigation and emergency supply purposes. The results of Phase I project presented in May 2012 concluded that it was possible to collect the excess rainwater using different retention structures, such as storage tanks and underground water matrices. This outcome has brought the attention and interest amongst the stakeholders. In order to further prove this practice, the Phase II Project was launched in August 2012 upon the requests by the Director of the UBC Botanical Garden, and supported by faculty in Civil Engineering, UBC Campus Sustainability's SEEDS program and UBC Utilities. This project is sponsored by the AMS Sustainability Office.

Project Objective

The general objective for the Phase II Project is to study the on-site flow rates of West Creek and Rock Creek in the UBC Botanical Garden and to establish a correlation between the rainfall events and flow responses from the beginning of August to the end of October. The outcome of this project is expected to assist in a better estimation of the total amount of the resultant direct runoff after typical rain events. A prediction of the runoff volume from the entire season may be possible upon the projection of the runoff volume in a shorter experimental period to a longer time span. This report provides a reference in the stormwater management in the UBC Botanical Garden as well as an important factor in the decision making process for the stormwater collection.

Site Information

The project sites, West Creek and Rock Creek, are both located in the UBC Botanical Garden area. West Creek is a stream starting at the northwest end of the parking lot area and flows downstream along the Old Marine Drive until it merges with Rock Creek at the Trail 7 outfall. West Creek is a 300 m long open channel stream (except for a culvert passage under the northern boundary of the Botanical Garden). According to the UBC Watershed and Hydrology map provided by UBC Utilities, West creek is one of the receiver waters of the runoff from the West Side Catchment of the UBC region. This catchment covers an area of 49.3 ha as estimated from the map. The runoff collected in this catchment is mainly from the academic area and road traffic. It is expected that a part of local stormwater runoff is carried to a point where it converges to West Creek.

Rock Creek is located in the center of the Botanical Garden. Little over 100m of length, it runs across the Garden from the drainage pipe at the 16th Avenue Catchment to Trail 7. This catchment is relatively small with a gross area of 8.2 ha. It collects the surface runoff from mainly residential areas, sports fields and road traffic. Among the five creeks in the Botanical Garden region, West Creek and Rock Creek flow continuously. Thus, they are selected for analysis in this project because their baseflow in dry seasons may be a potential source to retain for irrigation.

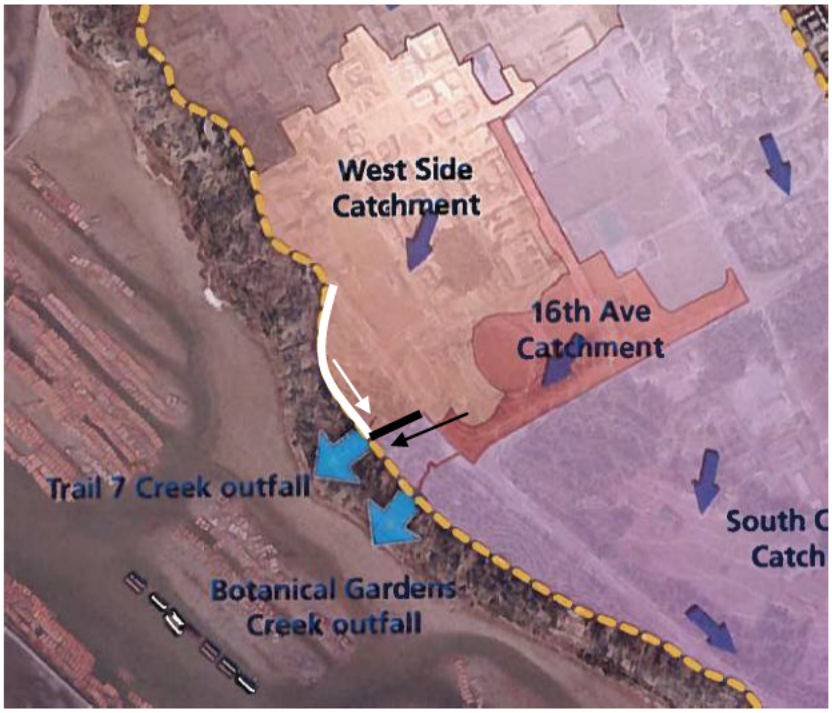


Figure 1: Project Site; West Creek in white collects runoff from West Side Catchment; Rock Creek in black collects runoff from 16th Ave. Catchment; Map Source: UBC Utilities

Concept and Method

The project consists of on-site measurements and data analysis. The scheme of this practice is to calculate the total runoff volume from the established hydrograph of the creek flows after the raw data are recorded. A demand-supply model is later constructed to evaluate the total collectible stormwater.

Measurement Method

In order to calculate the accurate flow rate, the V-notch method is used to measure the volumetric flow rate. As V-notch is relatively accurate in a small to medium streams, it is suitable to be used here to calculate the flow rates in West Creek and Rock Creek. The weirs were set up in each stream to measure the downstream flows as seen in Figure 2. The flow is designed to pass only over the V-notch except when the flow rate is large enough to flow over or bypass the whole weir structure. Both weirs have a ruler beside for convenient on-site V-notch head readings.

Figure 2: Weir #1 in West Creek

The two weirs have slightly different purposes. Weir #1 in West Creek was installed in front of the culvert outside the Botanical Garden to; Weir #2 in Rock Creek was installed in the downstream merge by Old Marine Dr, so that it collects the flows from all the upstream creeks including West Creek, Tzumu Creek and Rock Creek. This is to estimate the fraction of flow that each stream contributes in the downstream flow.

For both streams, data is continuously recorded using the HOBO dataloggers. Each logger is programmable to record different parameters, including barometric pressure, surrounding temperature and so on. Due to potential risks of the public tampering with the equipment, the data logger was placed in a concealed location.

On-site V-notch head readings are taken from the ruler on regular visits. Actual water depth data are recorded by the HOBO datalogger every 5 to 15 minutes. Since the loggers are pressure sensitive, the HOBOware program uses Equation 1 to calculate the actual depths. Equation 2 and Figure 3 show the calibration of V-notch head from the actual depths.

The exact location of the datalogger changes every time when it is removed from the stream to connect with a shuttle reader. The shuttle reader then transfers the data into the computer software. To ensure accurate readings, the head at the weir is recorded after the datalogger is replaced, and the date and time are noted. This measurement will correlate with the water level recorded by the datalogger of a similar date and time. Then all subsequent readings after this date and time will refer to this datum point. This procedure is repeated every time a reading is made at the weir.

$$D_{actual} = \frac{(P_{underwater} - P_{atm})}{\rho_T g} \qquad \text{Eq.1}$$

$$D_{V-notch} = D_{actual} - D_{calibration} \qquad \text{Eq.2}$$

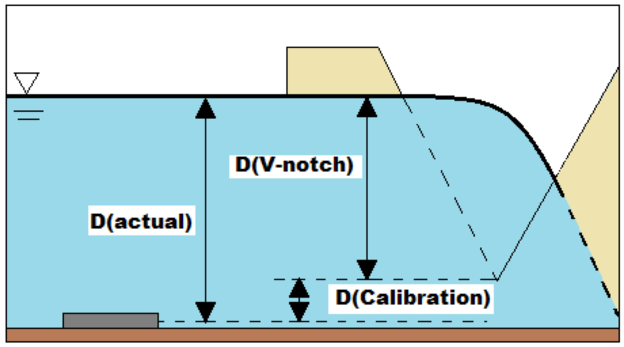


Figure 3 Calibration of V-notch Head Readings

The stage-discharge relationship is governed by the weir geometry. Provided by LMNO Engineering, the stage-discharge relationship is as follows for a V-notch weir:

$$Q = 4.28 \times C \times \tan\left(\frac{\theta}{2}\right) \times (h+k)^{2.5} \quad \text{Eq. 3}$$

$$C = 0.607165052 - 0.000874466963\theta + 6.10393334 \times 10^{-6}\theta^2$$

$$k = 0.0144902648 - 0.00033955535\theta + 3.29819003 \times 10^{-6}\theta^2 - 1.06215442 \times 10^{-8}\theta^3$$

Where $Q =$ discharge, in cubic feet per second
$C =$ discharge coefficient
$\theta =$ notch angle
$h =$ head, in feet
$k =$ head correction factor, in feet

A factor of $\left(\frac{0.3048m}{1ft}\right)^3 \times \left(\frac{1000L}{1m^3}\right) = 28.32\frac{L}{ft^3}$ can be applied to obtain units of liters per second. Given the notch angle of the weir, we can reformat the equation to be dependent on the head. Therefore:

53.2^o notch angle	$Q = 35.08(h + 0.004161)^{2.5}$
90^o notch angle	$Q = 70.05(h + 0.002903)^{2.5}$

Stage-Discharge Relationship

Baseflow - Weir #1

During the summer season, there is minimal precipitation, and this is reflected in the water level of the stream. The consistent and steady flow rate is maintained from August to September, indicating that this stream has a baseflow of 0.82 L/s. Abrupt changes in the flow rate attribute to the occasional rain storm event, and are omitted from calculating the baseflow. It was assumed that the baseflow calculation will become inaccurate at the start of October 1, because of increasing precipitation. The direct runoff from a previous rain event cannot be fully carried by the stream before the next rain event. As predicted, frequent rainfall in October is reflected by the varying water level, which validates our assumption. Also, it is reported that the base of weir #1 was destroyed in October, resulting bypass of flow. This creates discrepancy and inconsistency in data. Students take the usual flow ratio of West Creek and

Rock Creek and back calculate the data at this period to correct the readings. The results of baseflow from August 8th, 2012 to Oct. 25, 2012 are presented in Figure 4.

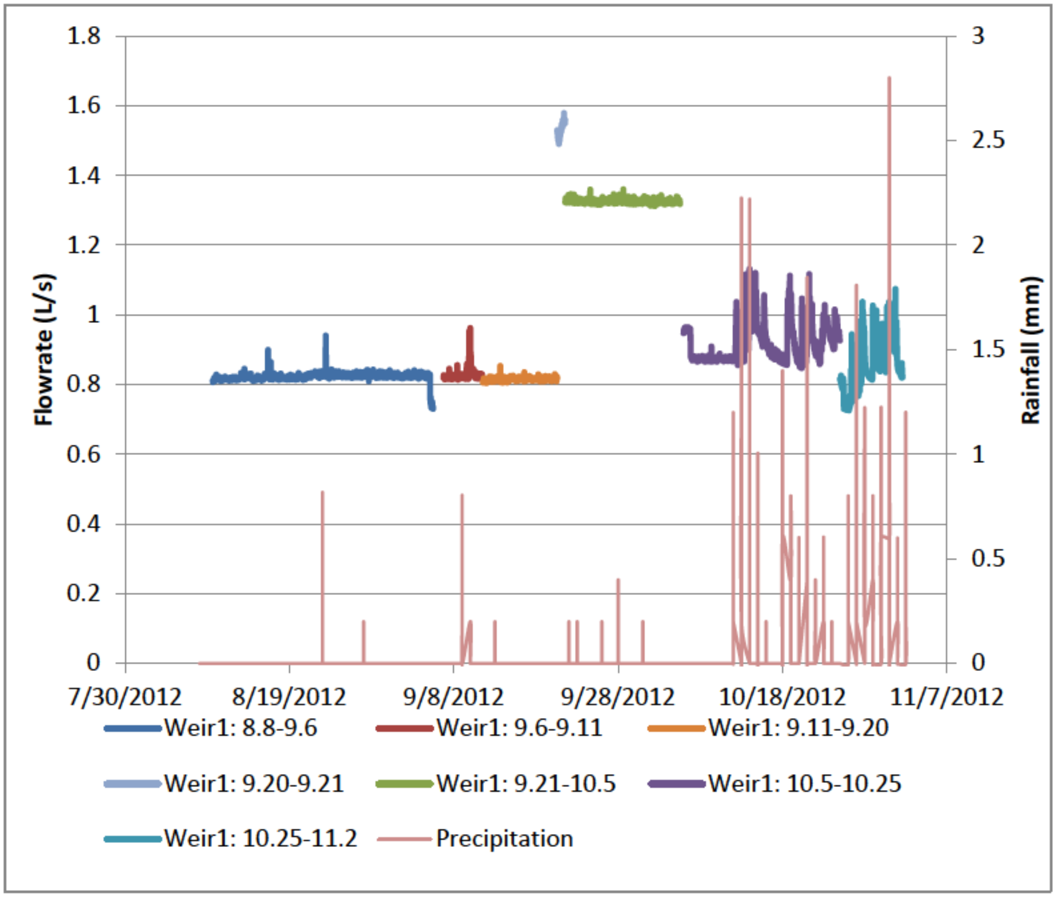


Figure 4 Baseflow Calculation - Weir #1

Baseflow - Weir #2

Similar to Weir #1, Weir #2 also exhibits a steady flow throughout September. Because this is the confluence of three streams, the baseflow is higher at 2.4 L/s. The unsteady flow rates through October suggest responses to rain storm events, and hence will not be used to calculate baseflow. The results of baseflow from September 6th, 2012 to November 2nd, 2012 are presented in Figure 5.

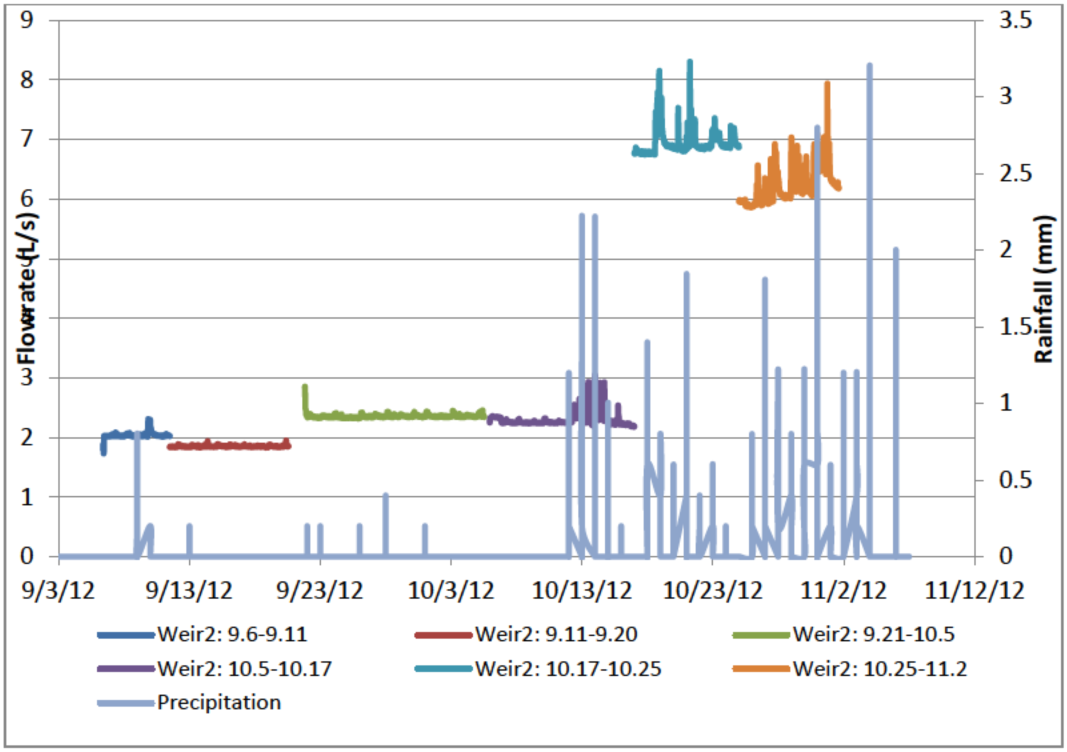


Figure 5 Baseflow Calculation - Weir #2

Water Supply and Demand

To determine the feasibility of stormwater collection, we require an assessment of supply and demand for water. We will define the supply for water as the available water generated purely on the baseflow, and the demand for water as required water for irrigation purposes in the Botanical Gardens. Table 1 below shows the cumulative water consumption for the Botanical Gardens. The meter reached its capacity 14005 m^3 in November 2011, which is also the rain season in Vancouver. Therefore, it is assumed the winter irrigation relies on frequent precipitation.

Date	Meter Reading (m^3)	Monthly Demand (m^3)
2011-Apr-21	100	100
2011-May-20	550	450
2011-Jun-21	3003	2453
2011-Jul-21	5840	2837
2011-Aug-22	9180	3340
2011-Sep-16	12270	3090
2011-Oct-24	13785	1515
2011-Nov-21	14005	220
2011-Dec-21	14005	0
2012-Jan-24	14005	0

Table 1: Cumulative water consumption of the Botanical Gardens

Methodology

A simple supply and demand balance model was used to determine the excess or deficit of water needed for irrigation. The supply and demand for water were calculated daily, and the excess or deficit was carried over to the next day. The days where supply exceeded demand will result in surplus of stored water, and vice versa for the days where demand exceeded supply.

Daily water supply was determined using the baseflow of a stream. By multiplying the baseflow with an equivalent time period to 24 hours, a daily inflow, or supply, is calculated. It is assumed that the baseflow is constant, and the daily inflow will also be constant.

Daily water demand was determined using the data in Table 1. Data between recorded points were interpolated, assuming the water consumption changes linearly as Figure 6. Summer irrigation (June – October) requires about 95% of the total demand. Therefore, the model will mainly compare the total baseflow at weir #2 with the summer demand.

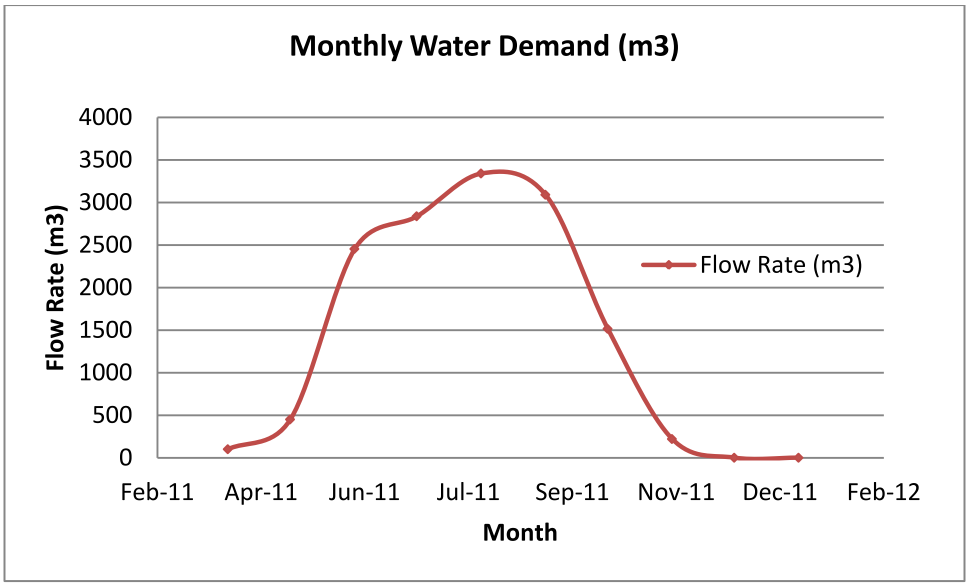


Figure 6 Monthly Water Demand

Results

The combined flow at Weir #2 (of 2.4 L/s) has enough water to potentially irrigate the Botanical Gardens from April through September. The net stored volume of water, if completely captured, will be 20.5 million litres by the end of September, with no deficit during this period. The daily collectible volume for West Creek is 69.4m^3. With a collection total flow, the accumulated volume can sustain the irrigation until mid of June, where a deficit shows and an additional amount of potable water is required to assist the irrigation. More additional potable water is needed if partial flow is collected. On the other hand, the baseflow of Rock Creek at weir #2 is three times the baseflow of West Creek. With a total collection, the accumulated volume increases without bound while satisfying the total irrigation demand. More realistically, if we consider losses in the system, it can run on 43% efficiency and still be able to meet the demands. Table 2 illustrates some scenarios that affect our supply. Therefore, it is more reasonable to install a retention structure at weir #2 if the Botanical Garden decides to reuse the stream flow for irrigation as much as possible.

Weir No.	Capture Efficiency	Percentage of Water Consumed	Net Stored Volume by 30-Sep (m^3)	Notes
1	100%	100%	-1737	Deficit starting 04-Jul
1	80%	100%	-4047	Deficit starting 03-Jun
2	100%	100%	20515	Surplus; increases without bound
2	80%	100%	13755	Surplus; increases without bound
2	42.5%	100%	1080	Breakeven on 03-Sep, overall surplus

Table 2: Scenarios with varying net stored water

Limitations and Discussion

As illustrated in Figure 5, the data show discontinuity at days where the datalogger was removed from the stream to obtain the recorded data. It is apparent that manually handling the datalogger can introduce continuity issues in the data. For determining baseflow, data discontinuity becomes a bigger issue at Weir #2 because the gap in the data introduces error in determining baseflow. A continuous record of flow data is ideal for determining flowrate accurately.

The assumptions made in the study cause other limitations. During the heavy rainy days, since the sites were visited weekly or bi-weekly, the effect of upstream sediments was not considered. Upstream sediments carried down to the V-notch can change the geometry of the channel, block the flow and raise the water level. This can overstate the water level, causing discontinuity of data and overestimate of the total stormwater collectible.

The baseflow value for both weirs signifies the minimum amount of water flowing in the streams. In order to account for total available water, additional information—precipitation, infiltration, frequency of precipitation, etc.—are required to predict the amount of water generated. The existing irrigation demand data cannot represent a historical average because they were collected within a year. The use of a continuous datalogger can provide this additional data without complicated formulas.

Recommendations

Considering the potential use of the captured water, we suggest the use of the Atlantis® Matrix Tank offered by the Layfield Group. It can be designed for use as a detention basin to delay stormwater runoff that discharges to Trail 7 Outfall. It can also be designed for use as a retention basin by installing a pump in the system.

This stormwater management system uses a modular design that can be tailored to site limitations. Assembly of tanks is performed on site, ensuring more efficient use of transportation. It uses mostly recycled polypropylene, making it more cost effective in terms of construction due to its lightweight property. See Appendix C for the product brochure.

Based on the water consumption data from the Botanical Gardens, the largest daily consumption is about 123.6 m^3 of water (on 2011-Aug-23). By sizing the system to hold at least that amount, the Botanical Gardens can potentially be irrigated by means of only stormwater.

Sample Design

A suggested location for the tank system is along Old Marine Drive, just west of the Botanical Gardens. Figure 7 shows the approximate location of the system. In order to collect as much runoff as possible, the aqua tanks should be installed close to its outlet close to the Old Marine Drive. This will also reduce the effect of installation to park visitors. The tank will be 2 boxes wide and 2 boxes deep and will span about 220 meters. Given 90% void space, this tank system can store 150 m^3 of water, with a safety factor of 1.21 to the largest daily consumption.

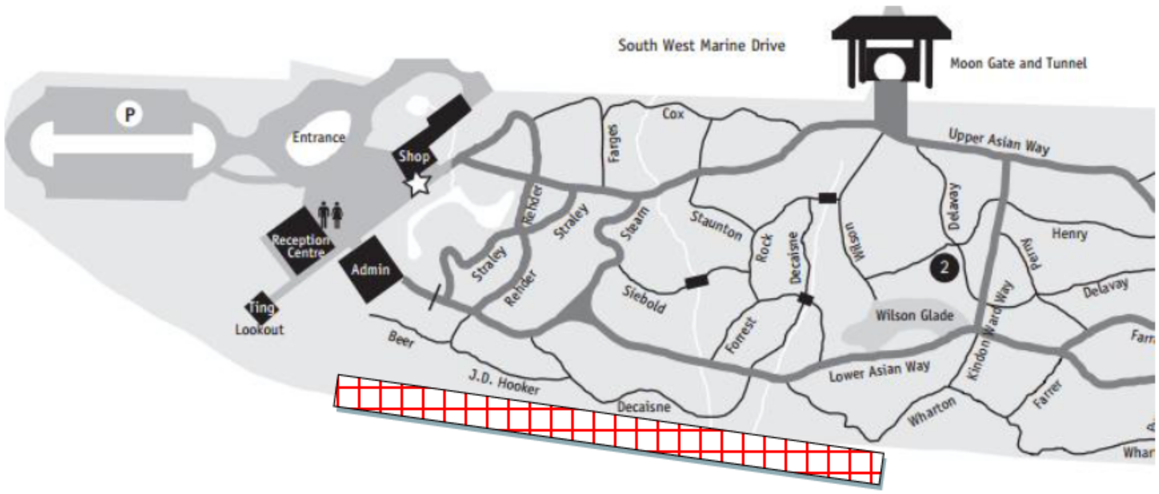


Figure 7: Location of Aqua Tanks

Economic Feasibility

Understanding the components of the system will help price the cost of the project. Table 3 shows a list of items—that are not exclusive—to include in a cost estimate. A defined scope of work and detailed design is required for a cost estimate.

Item	Description
Modular matrix tanks	To provide void space for water storage
Geotextile	To provide a barrier against the soil
Geomembrane	To contain water within the tanks
Upstream settling tank (or equivalent)	To reduce sediment from entering the tank system
Pump	For use as retention basin
General labour	Including excavation, equipment rental, bedding and backfill material, labour wages
Tank installation	Including tank assembly, field weld geomembrane
(Possible) upstream water treatment	To improve water quality (pollutants, BOD, bacteria and viruses...)
Investigations and studies	Including environmental impact assessment, water quality investigation, geotechnical report, etc.

Table 3: Items to include in a cost estimate

Conclusion

The outcome from this project proved that it is feasible to install a retention matrix system along the Old Marine Drive to collect baseflow and stormwater from West Creek and Rock Creek. The amount collected will satisfy the recorded irrigation demand. However, uncertainties and limitations exist in the course of this project due to natural channel modifications and data discontinuity. This report is recommended as a reference in the future research with more stream data collected.

Appendix A: Raw Data and Flow Rate Calculation

Correction of raw data (sample):

Date Time, GMT-07:00	Abs Pres, kPa	Abs Pres Barom., kPa	Sensor Depth, m	Batt, V	Corrected Depth (in)	Weir Flow (cfs)	Weir Flow (L/s)
9/6/2012 11:20	102.477		0.19	3.54	2.835	0.06918	1.959
9/6/2012 11:25	102.446		0.187	3.51	2.715	0.06217	1.761
9/6/2012 11:30	102.476	100.611	0.19	3.48	2.835	0.06918	1.959
9/6/2012 11:35	102.474		0.19	3.48	2.835	0.06918	1.959
9/6/2012 11:40	102.459		0.188	3.48	2.755	0.06446	1.825
9/6/2012 11:45	102.433	100.624	0.185	3.48	2.635	0.05775	1.635
9/6/2012 11:50	102.472		0.19	3.48	2.835	0.06918	1.959
9/6/2012 11:55	102.486		0.192	3.48	2.915	0.07410	2.098
9/6/2012 12:00	102.472	100.599	0.191	3.48	2.875	0.07162	2.028
9/6/2012 12:05	102.472		0.192	3.48	2.915	0.07410	2.098
9/6/2012 12:10	102.459		0.191	3.48	2.875	0.07162	2.028
9/6/2012 12:15	102.472	100.578	0.193	3.48	2.955	0.07664	2.170
9/6/2012 12:20	102.459		0.191	3.48	2.875	0.07162	2.028
9/6/2012 12:25	102.459		0.19	3.48	2.835	0.06918	1.959
9/6/2012 12:30	102.448	100.603	0.188	3.48	2.755	0.06446	1.825
9/6/2012 12:35	102.435		0.187	3.48	2.715	0.06217	1.761
9/6/2012 12:40	102.422		0.186	3.48	2.675	0.05994	1.697
9/6/2012 12:45	102.474	100.594	0.192	3.48	2.915	0.07410	2.098
9/6/2012 12:50	102.476		0.192	3.48	2.915	0.07410	2.098
9/6/2012 12:55	102.45		0.189	3.48	2.795	0.06680	1.891
9/6/2012 13:00	102.439	100.594	0.188	3.48	2.755	0.06446	1.825
9/6/2012 13:05	102.425		0.187	3.48	2.715	0.06217	1.761
9/6/2012 13:10	102.388		0.183	3.48	2.555	0.05352	1.516
9/6/2012 13:15	102.401	100.598	0.184	3.48	2.595	0.05561	1.575
9/6/2012 13:20	102.376		0.182	3.48	2.515	0.05148	1.458

On-site readings and V-notch calculation:

1. Correction of V-notch depth:

Recording Time	Sensor Depth (m)	V-Notch Height (in)
9/11/2012 11:00	0.191	2.875

Calibration depth = 0.191 – 2.875*2.5 = 0.119m

Corrected depth = sensor depth – 0.119m

2. Calculation of flow rate:

$$Q = 4.28 \times C \times \tan\left(\frac{\theta}{2}\right) \times (h + k)^{2.5}$$

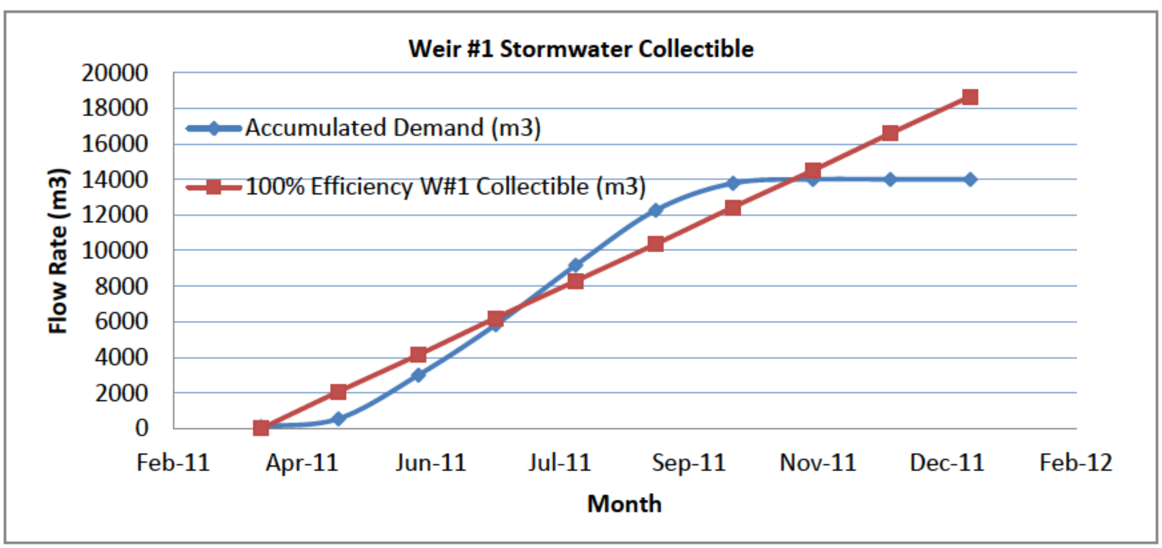
$$C = 0.607165052 - 0.000874466963\theta + 6.10393334 \times 10^{-6}\theta^2$$
$$k = 0.0144902648 - 0.000339555535\theta + 3.29819003 \times 10^{-6}\theta^2 - 1.06215442 \times 10^{-8}\theta^3$$

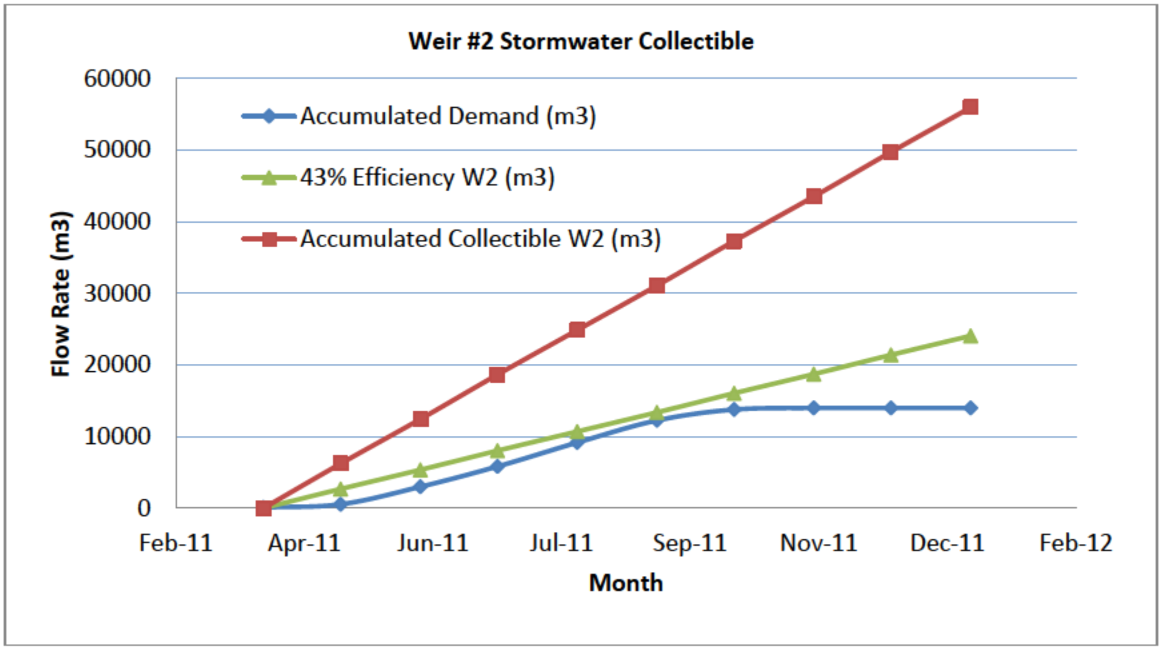
C = 0.578
K = 0.00417 (Weir #1); 0.0029 (Weir #2) ft

	Notch Θ	h (in)	h (ft)	Q (cfs)	Q (L/s)
1/31/2013	53.1	6.75	0.5625	0.29877	8.46
1/17/2013	53.1	4.375	0.364583	0.102059	2.89
1/8/2013	53.1	16.75	1.395833	2.866385	81.17
11/6/2012	53.1	15	1.25	2.177222	61.65
11/2/2013	53.1	5.9375	0.494792	0.21736	6.15
10/17/2012	53.1		0	1.39E-06	0.00
10/5/2012	53.1	2.625	0.21875	0.028999	0.82
9/21/2012	53.1	3.25	0.270833	0.049018	1.39
9/20/2012	53.1	3.375	0.28125	0.053792	1.52
9/11/2012	53.1	2.625	0.21875	0.028999	0.82
1/31/2013	90	3.25	0.270833	0.096968	2.75
1/17/2013	90	4.75	0.395833	0.248321	7.03
1/8/2013	90	-	-	-	-
11/6/2012	90	16	1.333333	5.105143	144.56
11/2/2013	90	17	1.416667	5.938702	168.17
10/17/2012	90	18	1.5	6.849	193.94
10/5/2012	90	19	1.583333	7.838258	221.96
9/21/2012	90	20	1.666667	8.908635	252.27
9/20/2012	90	21	1.75	10.06224	284.93
9/11/2012	90	22	1.833333	11.30111	320.01

Appendix B: Demand-Supply Model and Design Scenarios

Date	Meter Reading (m3)	Monthly Water Demand (m3)	100% W1	80% W1	Daily Collectible
Apr-11	100	100	**0**	**0**	69.12
May-11	550	450	**2074**	**1659**	
Jun-11	3003	2453	**4147**	**3318**	
Jul-11	5840	2837	**6221**	**4977**	
Aug-11	9180	3340	**8294**	**6636**	
Sep-11	12270	3090	**10368**	**8294**	
Oct-11	13785	1515	**12442**	**9953**	
Nov-11	14005	220	**14515**	**11612**	
Dec-11	14005	0	**16589**	**13271**	
Jan-12	14005	0	**18662**	**14930**	
Date	Meter Reading (m3)	Monthly Demand (m3)	100% W2	43% W2	Daily Collectible
Apr-11	100	100	0	0	207.36
May-11	550	450	6221	2675	
Jun-11	3003	2453	12442	5350	
Jul-11	5840	2837	18662	8025	
Aug-11	9180	3340	24883	10700	
Sep-11	12270	3090	31104	13375	
Oct-11	13785	1515	37325	16050	
Nov-11	14005	220	43546	18725	
Dec-11	14005	0	49766	21400	
Jan-12	14005	0	55987	24074	





Weir #2 Stormwater Collectible
Accumulated Demand (m3)
43% Efficiency W2 (m3)
Accumulated Collectible W2 (m3)
Flow Rate (m3)
60000
50000
40000
30000
20000
10000
0
Feb-11
Apr-11
Jun-11
Jul-11
Sep-11
Nov-11
Dec-11
Feb-12
Month

Appendix C: Retention Box Information

Infiltration • Detention • Rainwater Harvesting

The Atlantis underground tank system is a modular sub surface system that can be constructed to hold any volume required. The sub surface location of the tank frees up space for landscaping or driveway use while also ensuring optimal conditions for retaining water is always maintained. Macro and micro pollutants are completely kept out of the system through an Atlantis Filtration Unit.

Excavation

Installation of the Matrix® tank modules

Appendix D: Reference

Atlantis Modular Underground Tank System:

http://www.atlantiscorp.com.au/brochures/Atlantis_Matrix_Tank.pdf

Calculation aid:

LMNO Engineering, Research, and Software, Ltd.

http://www.lmnoeng.com/