UBC SEEDS: Botanical Gardens Project

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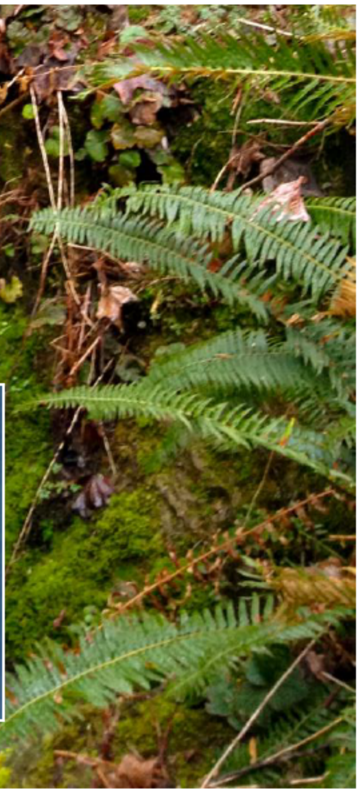

1 Disclaimer

2 Executive Summary

Working with UBC SEEDS and UBC Botanical Garden, our team was tasked with proposing an efficient and cost effective solution to the issue of seasonal flow rate variations in Rock Creek at the UBC Botanical Garden, which have raised concerns regarding flooding, erosion, and aesthetics of the stream. Through our three months endeavor, we have examined pre-existing information, conducted research on methods of flow rate control, and gathered other details regarding the stream as required. From this information, we have formulated a series of suggestions for mediating seasonal flow rate variations and controlling the associated problems.

We also conducted proper surveying for the stream and were able to map out the elevation profile for the stream; the total elevation drop across the stream is approximately 7.5m over a 93m length. Four locations of steep elevation drop in the stream were also identified. Through analysis of past local precipitation data, we have determined that there is indeed a very large seasonal fluctuation in expected flow rate in Rock Creek; precipitation rates are generally between 5mm to 15mm per day during the winter and spring months between October and June, while summer precipitation is negligible. Average flow rate for Rock Creek I was found to be 13.45L/s, and based on the data, the flow rate strongly correlates with the trend seen in precipitation.

After considering the characteristics of the stream, we have outlined four solutions, which are as follows: adding a permeable holding pond at the top of the stream, rock weir placement along the upper half of the stream, stream bed roughening along the lower half of the stream, and riprap installation along the sides of the stream. These proposed ideas are explored in detail in the following report, explaining the purpose, design, cost, drawbacks, and possible improvements of each.

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3 Introduction

We are a group of 2nd year UBC Civil Engineering students who have been selected to help UBC SEEDS and UBC Botanical Gardens discover solutions for Stormwater management. This introduction lists our project's objectives, scope, limitations, assumptions, and methodology.

3.1 Objectives

The water in Rock Creek, a rainwater runoff stream in UBC Botanical Gardens, is flowing at an undesirably fast rate. This has created problems for UBC as follows:

- At peak rain periods, the stream is at risk of flooding
- The stream is mostly empty during low rain periods, which is aesthetically unappealing
- There has been no attempt made to store this water for use in irrigation or emergency situations
- The bank around the culvert at the bottom of the stream suffers considerable erosion during peak rain periods
- The water flows through the bottom culvert and down the cliff at a critically fast rate, impinging on the City of Vancouver's property and causing extensive erosion

Our role is to propose sustainable, economical, and aesthetically pleasing solutions to the above problems, while keeping each solution as feasible and unintrusive as possible.

3.2 Project Scope

The official commencement of this project was on February 6th, 2013. We took 1.5 months compiling existing data, contacting important advocates for further guidance, researching relevant topics relating to civil engineering, and conducting data acquisition ourselves for any outlying data. The remaining time was spent using our data and findings in collaboration with our own creativity and knowledge to finalize our solution to the above issues.

The deliverables consisted of a poster, which visually presented our solution to our peers, mentors, professors, and clients, a project documentation assignment, which noted all team and client meetings, client emails, and the progression of our solution, and a final report, which presents our solution in full detail. In addition, our team wrote 6 bi-weekly blog posts to note any significant decisions or discoveries throughout our project's development.

Our project is just a small piece in the tapestry of UBC's sustainability objectives and the development of the Botanical Gardens, but we are nevertheless honored to partake in the process. A similar project was conducted in 2010, the report of which resides in the UBC SEEDS library. We frequently referred to this report to utilize the data previously collected and expand upon the solutions presented. We anticipate that the data and information presented in this report will feed into other SEEDS projects underway, and in the future, with related goals.

3.3 Limitations

With this project, we needed to consider what we could control and what we could not. Firstly, the current conditions of UBC Botanical Gardens presented us with some unavoidable constraints. The garden is home to many plants and some wildlife, so we could not provide a solution that was too invasive that would disrupt this local ecology. Also, the garden staff was not interested in a costly solution or a solution that involved extensive labour.

Secondly, we realized that we could not impinge on property outside of the Botanical Gardens. This issue was of deep concern to us because many outside sources affect Rock Creek, and inversely, Rock Creek affects the property owned by UBC and the City of Vancouver. Because of this issue, we realized that our solution would have minimal affect on the stream activity located outside of the Botanical Gardens. For example, we cannot significantly affect the erosion across Old Marine Drive down the cliff to the ocean.

Thirdly, we realized that there were many aspects of this project outside of our knowledge base as 2nd year students, such as *Surveying* and, a vital topic, *Open-Channel flow*. We conducted as much research as possible on these topics in the short amount of time we were given, but our solution is still not as advanced and extensive as it could be in a few years. As a result, our solution is mainly qualitative, with as many calculations as we were able to accurately and confidently complete. For further exactitude, we recommend contacting a 4th year Civil Engineering student and/or a civil engineer specialized in Fluid Mechanics or Open-Channel Flow.

3.4 Assumptions

The flow rate data displayed below is collected at a weir located just outside of Rock Creek. It is also slightly affected by another runoff stream: West Creek. Another weir located in West Creek collects the flow rate in that stream. We assume that the flow rate in Rock Creek is approximately equal to the flow rate in the weir minus the flow rate in rock creek.

As well, we only have flow rate data collected from Sept. 2012 to Nov. 2012. However, as seen in section 4.3 Precipitation, September to November showed a good range of minimum to maximum rainfall. Since rock creek is a rainfall runoff stream, the maximum and minimum precipitation is directly related to the maximum and minimum flow rates. Therefore, we can assume that this data is a good representative of flow rates over the entire year.

In addition, in order to calculate the volume of the pond at the beginning of the stream, we assume that it is rectangular in shape. The edges are slightly rounded, but this will not affect our overall volume significantly. Lastly, we assume that the affect that Tzumu Creek has on the weir is negligible.

4 Current Conditions

4.1 Elevation

We conducted a survey of the stream with a stadia and builder's level by recording the elevation every 10 feet, as well as at every abrupt change in elevation. We plotted the stream elevation vs. the stream length in the following chart:

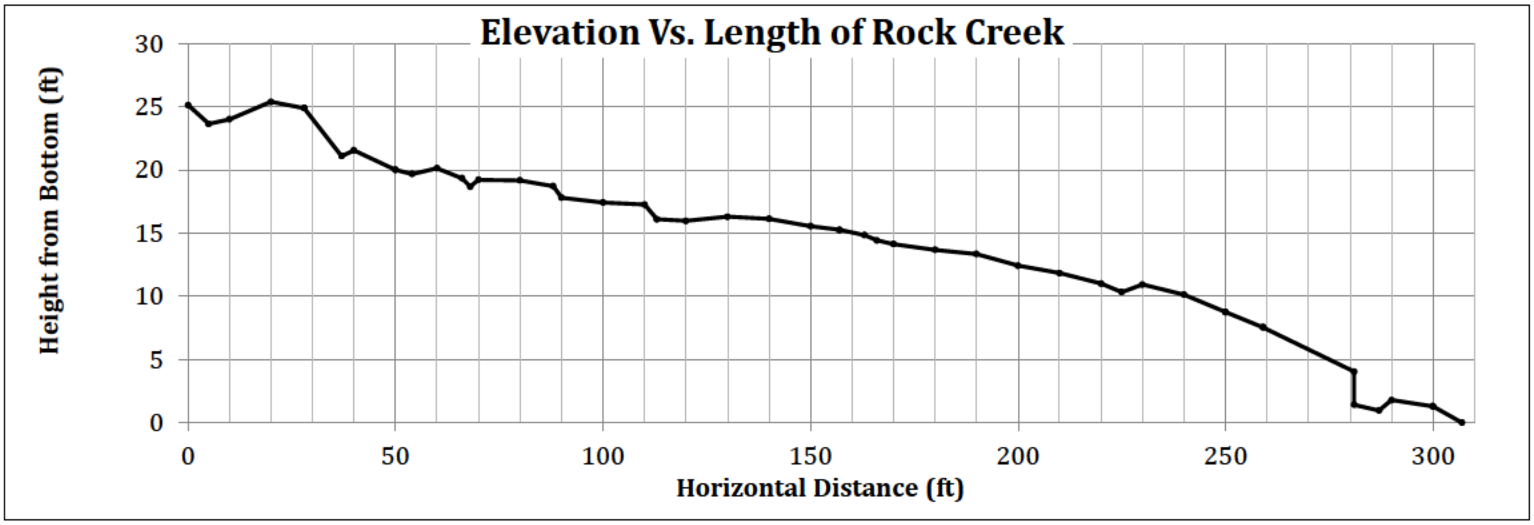

Figure 1: Elevation Vs. Length of Rock Creek

A detailed table of elevation vs. length, including bridge height off of the water and bridge locations can be found in Appendix A. Our data collected states that Rock Creek drops from 25 ft. to 0 ft. over a length of 307 ft., meaning our average gradient is $i = \frac{-25}{307} = \ 0.08143$, or a downhill grade of 8.14%. The steepest elevation drops occur at 28 to 37 ft., with a downhill grade of 42.1%, at 88 to 90 ft., with a downhill grade of 45.8%, at 110 to 113 ft., with a downhill grade of 38.9%, and from 240 to 281 ft., with a downhill grade of 14.8%. There is an immediate drop of 2.63 m. at 281 ft. due to the water cascading out of the culvert into the stream below, (distance is measured from the bottom of the culvert to the bottom of the stream bed). See the following figure for the labeled points of steepest gradients:

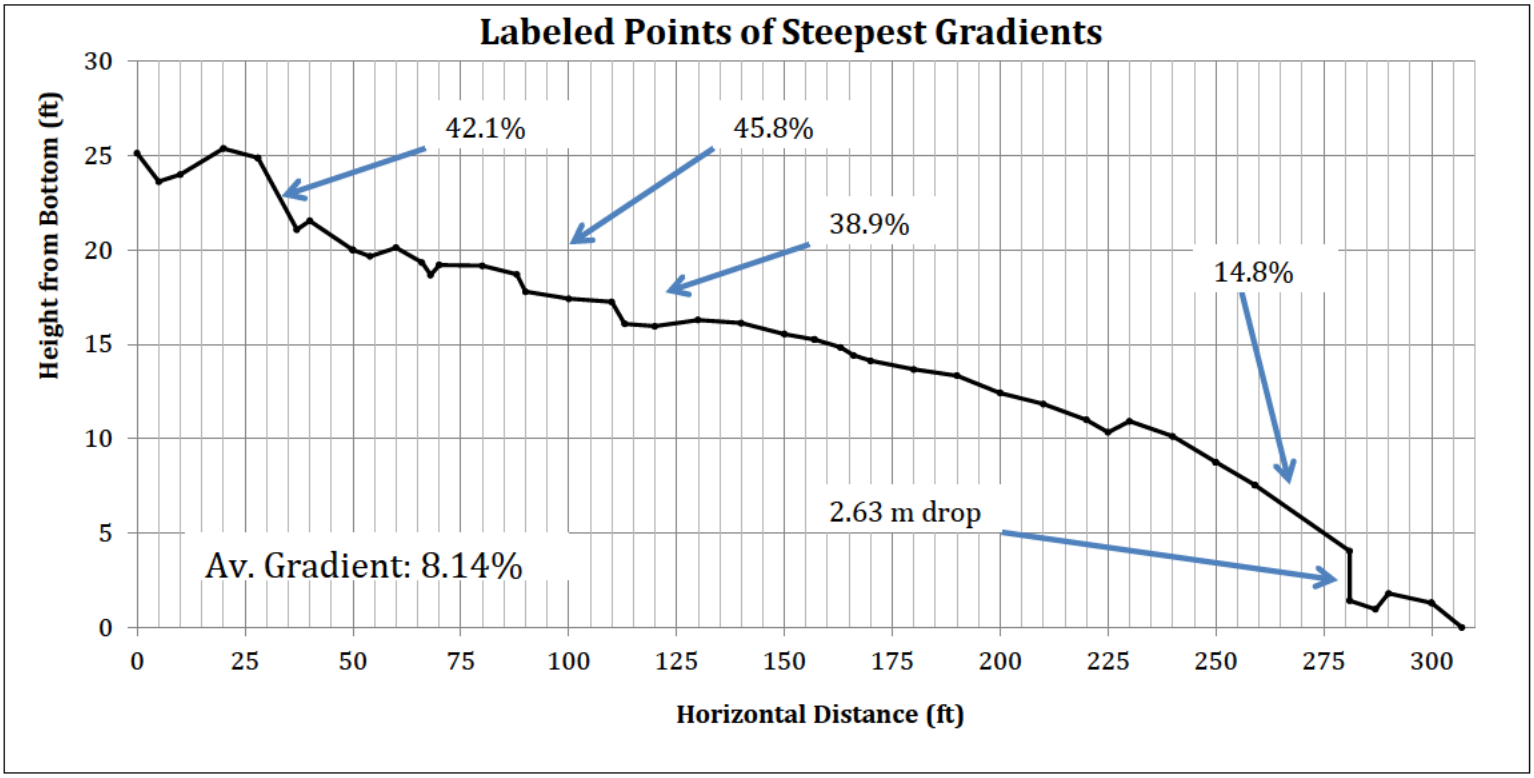

Figure 2: Labeled Points of Steepest Gradients Along Stream Length

Also, we noted the critical locations of bridges and culverts along Rock Creek that cannot be moved. There are 3 culverts located at 0 ft., at 259 to 281 ft, and at 307 ft. There are 3 bridges located at 28 to 37 ft., at 157 to 163 ft., and at approximately 259 to 272 ft. See the following figure for detailed labeling:

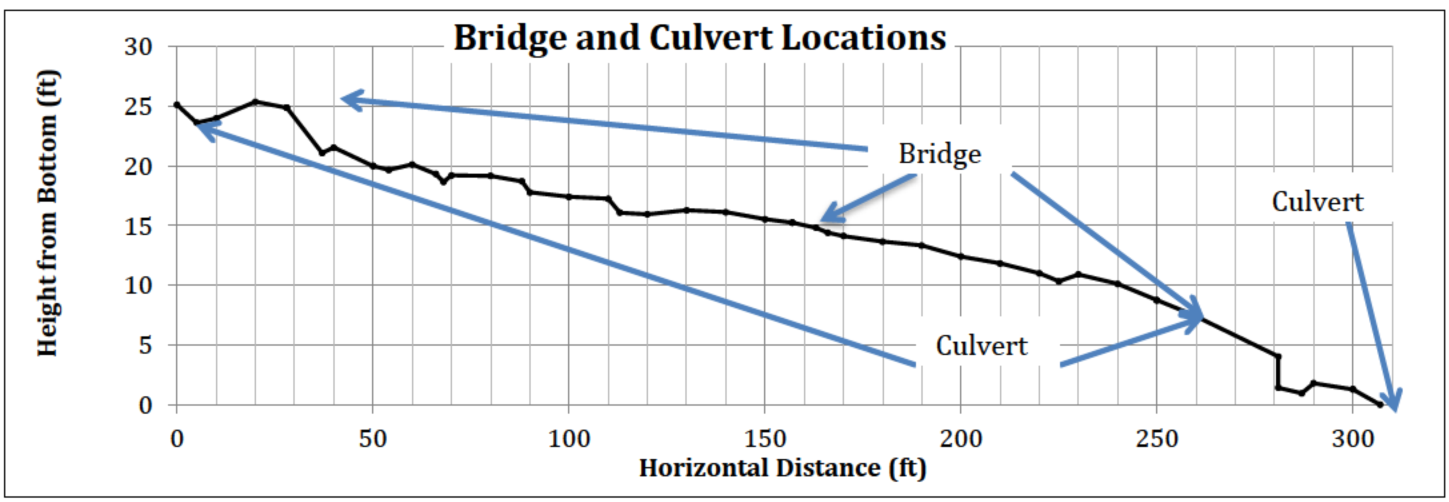

Figure 3: Bridge and Culvert Locations Along Stream Length

4.2 Flow Rate

The flow rate is collected from weirs in the following locations:

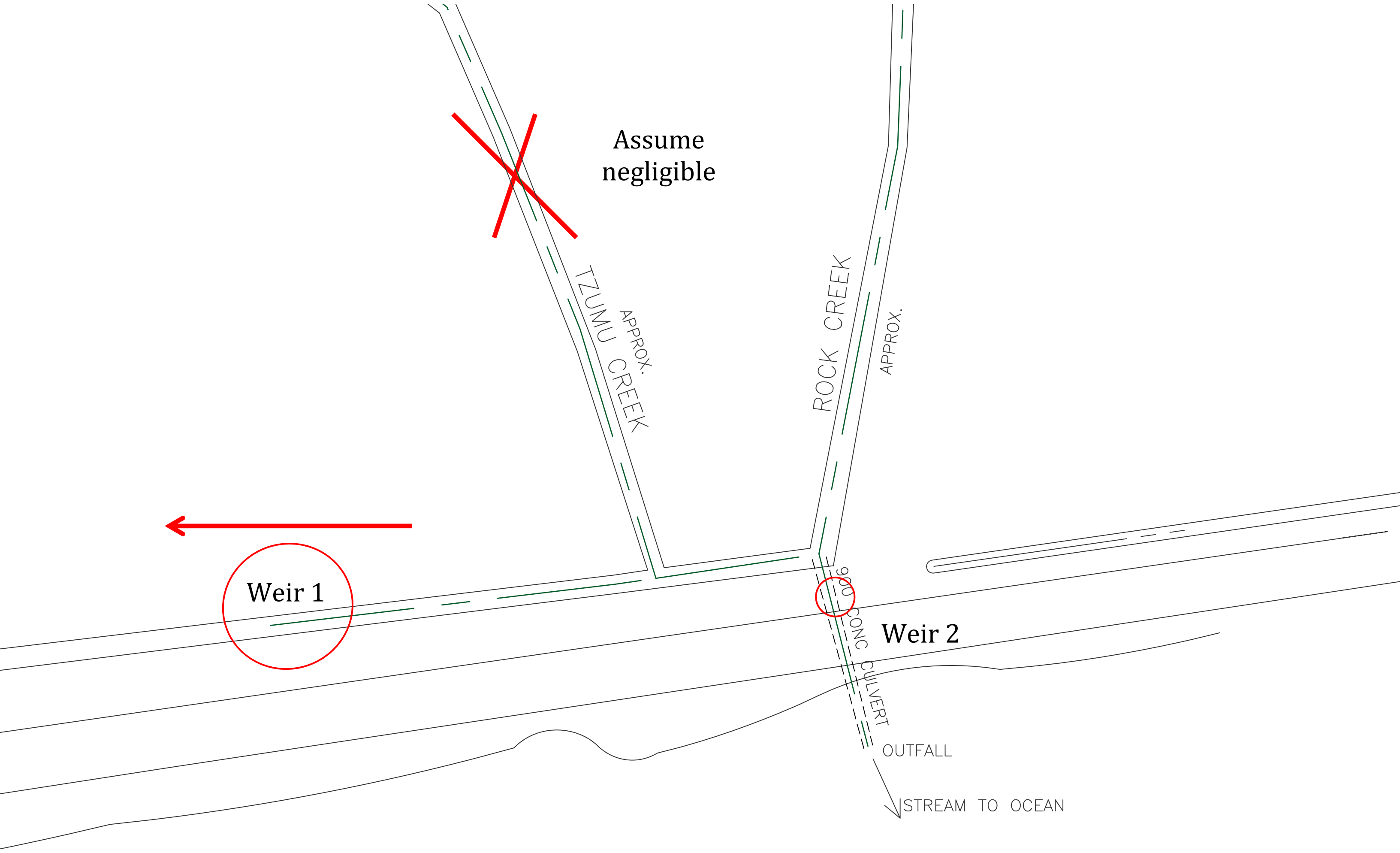

Figure 4: Weir Locations, Circled in Red. Note: Weir 1 is located further up West Creek.

Since we need the flow rate in Rock Creek, we take Q in weir 1 and subtract it from Q in weir 2, as follows:

Date	W 1 Flow Rate (L/s)	W 2 Flow Rate (L/s)	Rock Creek Flow Rate (L/s)
11-Sep	0.821	2.028	1.207
20-Sep	1.523	2.746	1.223
21-Sep	1.388	3.298	1.910
05-Oct	1.027	2.253	1.226
17-Oct		6.804	6.804
25-Oct	0.729	4.592	3.863
02-Nov	6.155	14.605	8.450
06-Nov	61.65	144.56	82.910
Average Flow rate in Rock Creek (L/s)		13.449	

Figure 5: Flow Rate In Weirs and in Rock Creek

Therefore, our average flow rate is 13.45 L/s or 0.01345 m^3/s.

4.3 Precipitation

The following is a plot of the mm of daily precipitation versus the months the year from Mar. 1st, 2012 to Dec. 31st, 2013:

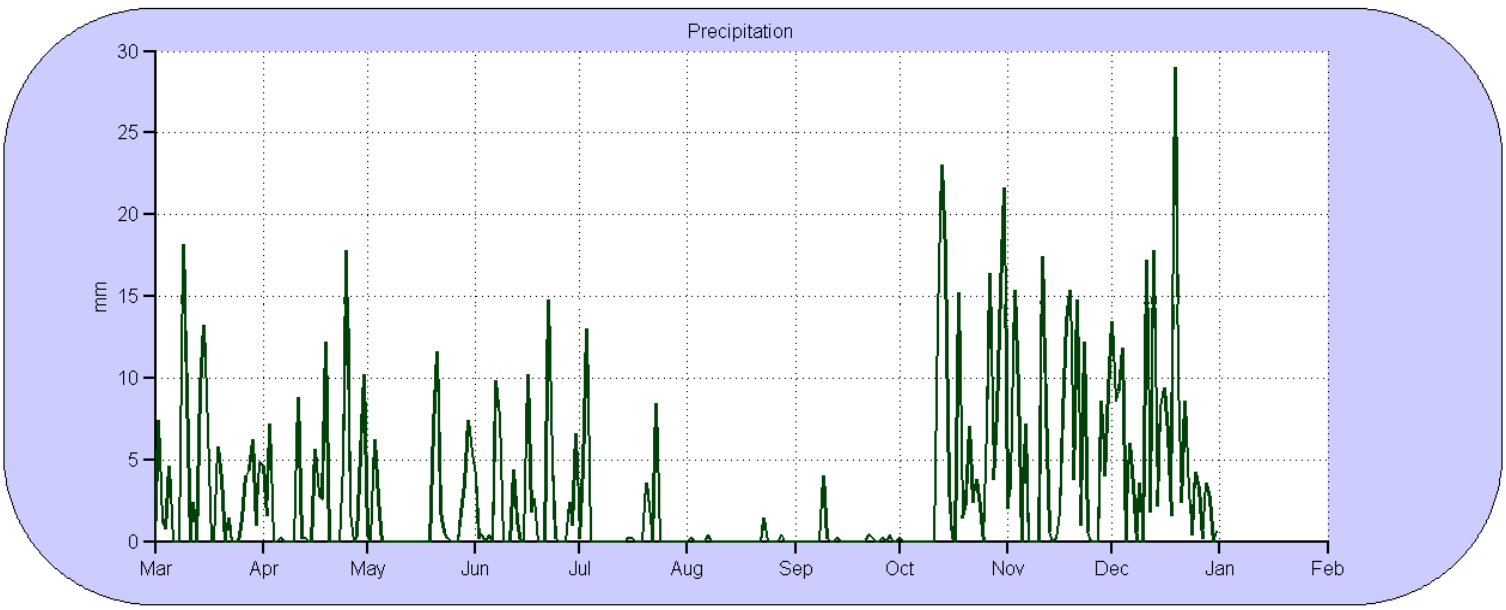

Figure 6: Daily Precipitation at UBC from Mar. 2012 to Dec. 2013

This plot shows that autumn and winter months are particularly rain heavy, the summer months are considerably dry, and the spring months are about average. The amount of precipitation directly correlates with the flow rate in our stream due to the fact that Rock Creek is a runoff stream. Therefore, we want our solution to make the stream fuller in the summer months and reduce flooding/store water in the fall and winter months.

4.4 Pond Volume

At the beginning of the stream, the channel is wider and deeper than in the rest of the stream. The depth of the pond changes periodically with the varying precipitation and flow rate.

What we will consider the depth of the pond will be the average length from the bottom of the pond to the opening of the continuing stream. This represents the maximum volume that the pond can hold before the water will start to flow down the stream. For clarity, this is shown below:

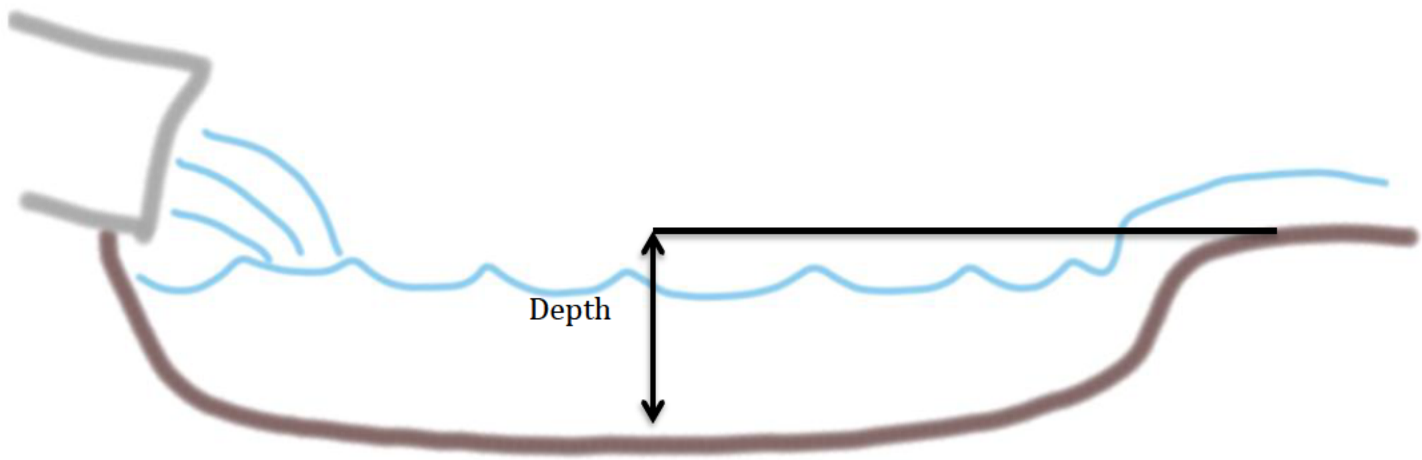

Figure 7: Depth of the pond

According to our measurements, the stream was 30 ft. long, 11 ft. wide, and 3 ft. deep. Which means our current pond volume is 990 ft^3 (or 28.03 m^3 or 28,030 L). Therefore, the pond as it currently stands will fill for 35 minutes before it begins to flow down the stream.

4.5 Qualitative Observations

Many plants and trees surround the stream. Because of this, there is an excessive amount of debris and fallen trees in the stream that could be contributing to flooding. This debris will have to be dealt with if our solutions are indeed implemented, because it could hinder its success.

In addition, we noticed that the east wall of the stream is made of soft silty-sands, while the west stream wall is composed of hard rock. This means that any digging we suggest must be conducted on the east side.

Lastly, a large tree has grown right on the edge of the bank at the north end of the stream. The roots of the tree are exposed and surround the bottom stream bank. We observed that the structural integrity of both the bank and the tree depend on one another. Furthermore, we speculate that extensive further erosion around this area could lead to catastrophic events for either the tree or the bank.

5 5.0 Proposed Solution

5.1 Pond and Drainage Weir System

5.1.1 What is it

We recommend widening the stream at the top into a pond, and immediately following, we suggest adding a weir that is impervious on the surface, but very permeable near the streambed. This will accomplish a controlled flow rate out of the pond, which reduces erosion, slows down the stream, and reduces the risk of flooding near the bottom of the stream.

During average pond depth, the water will flow into the pond and out the bottom of the weir as usual:

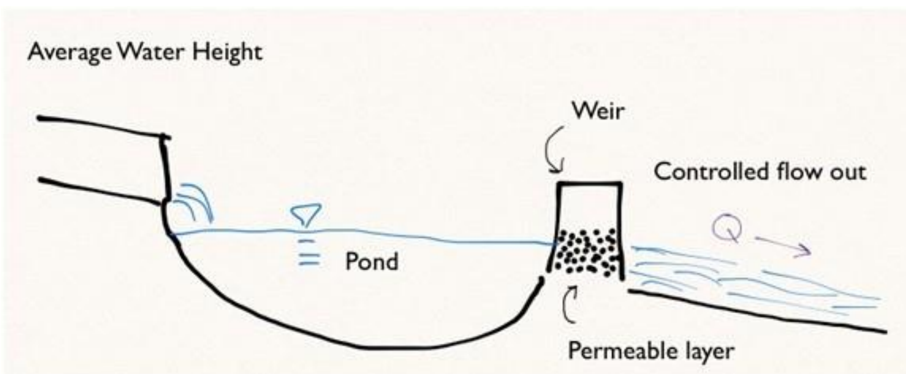

Figure 8: Pond/Weir System with Average Water Height

During peak pond depth, the weir will allow the water in the pond to flow out at a controlled rate due to the downward drainage in the pond:

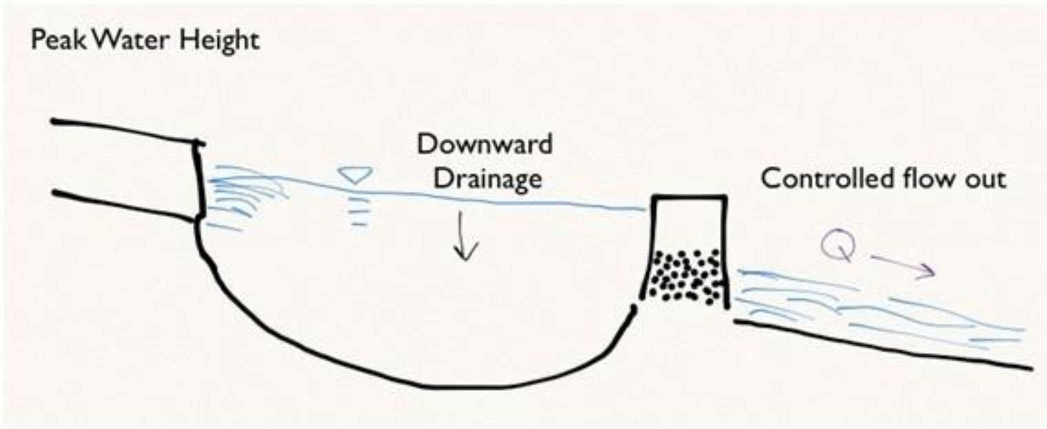

Figure 9: Pond/Weir System at Peak Water Height

If the pond were to reach a height that over-tops the weir, the flow rate would no longer be controlled. However, the energy in the pond will still be dissipated, which will still help reduce the erosion in the stream:

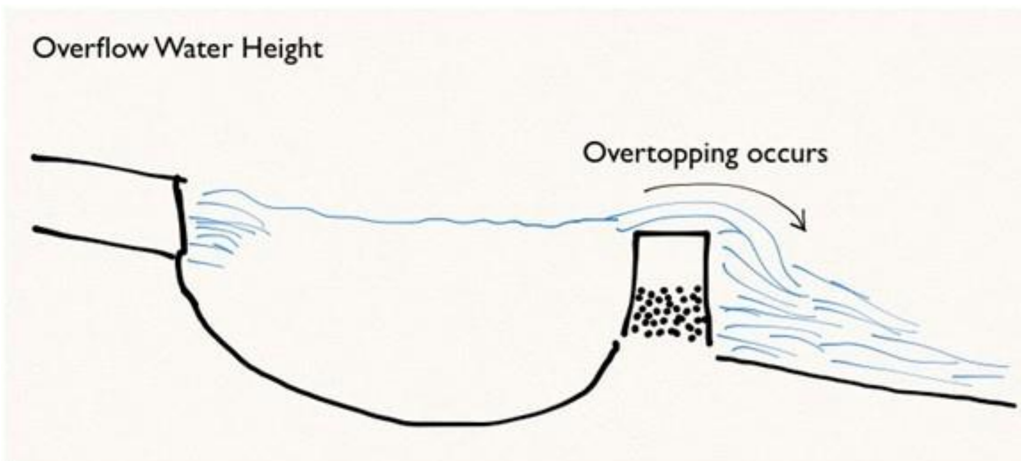

Figure 10: Pond/Weir System at Overflow Water Height

5.1.2 What is the Ideal Design for Rock Creek?

The pond should be designed with a volume based on the desired amount of water to be stored. Currently, the pond holds up to approximately 28,000 L, which at an average flow rate of 13.45 L/s, will take 35 minutes to fill before it begins to flow down stream. The minimum pond volume we recommend based on the pond/weir drainage system is 50,000 L. This can be obtained by widening the current pond another 3 m. See the table below for other options:

Desired Pond Volume (L)	Amount that the stream must be widened by (m)	Amount that the stream must be deepened by (m)
50,000	3	0
75,000	3	0.5
100,000	3	1
150,000	3.5	1.5

The weir should be placed immediately before the first bridge, right when the pond transitions into a stream. The weir should be constructed out of rocks that are 4 to 8 inches in diameter (Porter, 2013). The impervious layer at the top of the weir can be achieved in many ways. One solution would be to lay plastic between the rocks. Secondly, there could be a sprayable sealant sprayed between the rocks. However, an experienced professional should check exact requirements for the rock weir.

5.1.3 How will it Help Achieve the Objectives?

A pond and weir system will help in achieving our objectives by:

- Slowing down the stream
- Controlling the flow rate, which will reduce the erosion along the stream,
- Allowing for maximum water storage in the pond,
- And reducing flooding at peak rainfall periods.

5.1.4 What is the Estimated Price?

The cost of the weir would be minimal since most of the materials can be readily obtained from the Botanical Gardens. Also, the cost of widening the stream would be minimal as well since the staff of the gardens can easily complete this task in a few hours. Most of the cost would go to the installation of the special drainage weir since it needs to be properly installed (Castro, 2000). The price of this will vary depending on the company that the staff decides to hire,

5.1.5 Are There Any Drawbacks?

This pond/weir system is very intricate and must be constructed properly in order for it to work. It is vital that an experienced professional be present during installation, which unfortunately, will increase the cost of this solution (Castro, 2000).

5.1.6 Can This Solution be Improved in the Future?

A pipe could be installed in place of the pervious rock layer, which could be controlled with a valve. This would allow for maximum storage, greater control over the stream flow rate, and allow for the possibility to stop the stream for a short period of time if need be. Material specifications require further investigation.

5.2 Rock Weirs

5.2.1 What is it?

According to Porter (2013), the purpose of the rock weir is to control the water flow, which reduces erosion of the gully, as well as to store water and make the stream more full. The weir is constructed out of small sized boulders. Proper size must be selected for the boulders so that they are immune to movement from the strongest expected water current.

5.2.2 What is the Ideal Design for Rock Creek?

The rocks should be higher on the sides and lower in the center (Porter, 2013). The side facing the direction of water flow should be C – shaped (Bureau of Reclamation, 2013). Higher rock accumulations on the sides of the weir encourage water to travel through the center, thus preventing further erosion of the gully. The sketch below outlines the C-shape and the lowered height in the center:

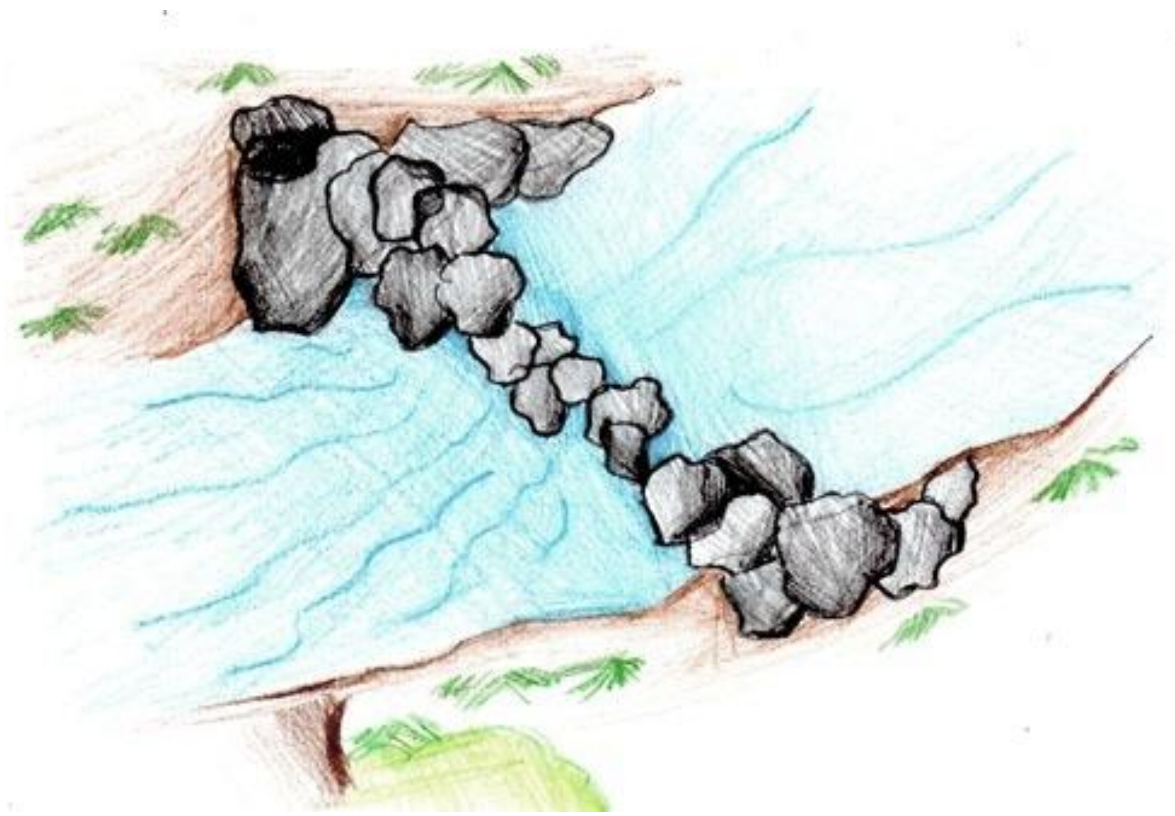

Figure 11: Sketch of the Rock Weir Design

In order to capture the most water, weirs are to be placed right before a sudden drop in gradient:

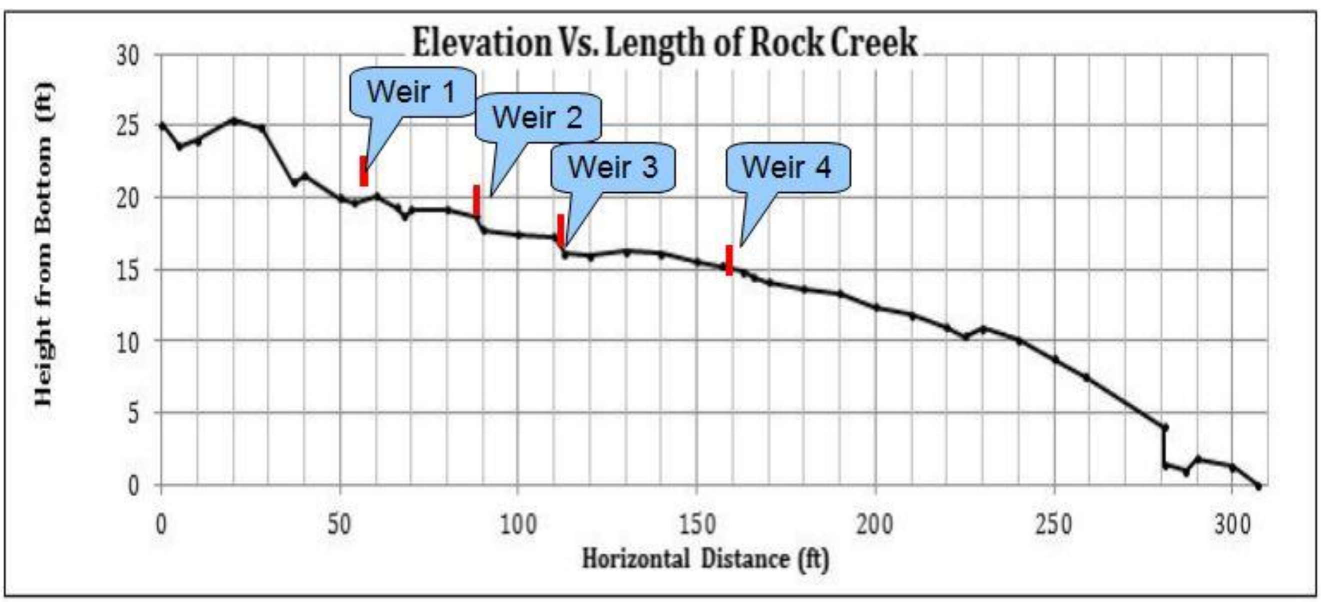

Figure 12: Location of the Weirs Along the Stream Length

5.2.3 How will it Help Achieve the Objectives?

During times of heavy rainfall, excess water flow will be controlled through the weir. During dry seasons, the weir can keep excess water that accumulated during rainfall seasons in the stream and add an aesthetic touch to the Botanical Garden. During rare excessive rainfall periods, the rock weirs will be low enough to allow for the water to overtop, but still not cause the stream to flood. In addition, since the weirs will help control the flow rate, this also reduces erosion of the stream walls.

5.2.4 What is the Estimated Price?

The specific gravity of boulders is normally 3 times than that of water. Density of boulders can be assumed to be 3000 kg/m^3. The height of each weir is around 0.5 m. The width of the stream is on average 1.6 meters. Given the flow rate and weir height conditions, the weir thickness at base should be at least 1.5 m in order to maintain stability. However, higher up the weir, thickness can be smaller. For a total of 4 weirs, about 7.2 tons of boulders are required. According to the pricings listed on homewyse (2013), the total costs will be $1127, $1663, or $2203 for basic, better, or best quality boulders. For the longest lasting weir, we recommend best quality boulders. However, this price can be reduced or eliminated completely if the weirs are built with existing boulders located in the gardens. It may, however, take some manual labour and knowledge to relocate the rocks and properly install the weirs.

5.2.5 Are There Any Drawbacks?

Debris can accumulate at the weir. However, due to the stream being very narrow, workers can easily reach into the stream with the aid of a tool and remove any debris that may accumulate in there. Due to the sudden reduction of cross sectional area and increase in velocity of the water, white water often forms at the exit side of the weir. This phenomenon can add oxygen content into any water that passes through the weir, and may harm the local ecology system. Fortunately, other than a small population of insects, there is no other visible aquatic life present in the stream.

5.2.6 Can This Solution be Improved Upon in the Future?

Although rock weirs are a low cost solution, once constructed, the garden staff has little control over the weir system and the stream. When more funding is available in the future, the weir system can perhaps be replaced by a system of mini dams. Garden staff can directly influence the flow rate in the stream by opening and closing multiple pipes installed in the dams. In addition, pipe controls, water level sensors, and water flow sensors can be directly connected to the dam via an underground cable network or wireless communications. What's more, turbines can be installed in the dams to generate electricity for powering the garden's offices or other recreational uses.

5.3 Roughening the Stream Bed

5.3.1 What is it?

Simply by adding rocks or rip rap to the creek bed, the velocity of the stream could be reduced by about 5-15%. The rocks will create a rougher surface for the water to traverse, absorbing some of the kinetic energy. This will then lower the velocity of the water in the creek. Manning's equation: $V = \frac{1}{n} R_n^{\frac{2}{3}} S_e^{\frac{1}{2}}$ governs the velocity of the water (Houghtalen, Osman Akan and Hwnag, 2010). With only changing the roughness coefficient, n, the formula can be simplified to an inversely proportional relationship between the stream velocity and roughness coefficient, $V \propto \frac{1}{n}$. Some values of n for various methods of roughing the stream bed are shown below.

Channel Surface	n
Natural Channel stones or weeds	0.030-0.040
Riprap lined channel	0.035-0.045
Mountain streams gravel and cobble	0.030-0.050

Figure 13: Typical Values of n

5.3.2 What is the Ideal Design for Rock Creek?

The ideal location for roughening is between the second and third bridge. This particular section of the stream is relatively shallow with minimal bank height, but a wider cross section. This wide and flatter cross section maximizes the surface area in contact with the water. The effectiveness of roughening a stream is directly related to the amount of surface area of the stream base in contact with flowing water. Therefore, roughening the stream is well suited for this particular section and will be more effective in this area than other conventional methods. This is a relatively simple method to implement and effective use of materials readily available in the garden.

5.3.3 How will it Help Achieve the Objectives?

Due to the highly dynamic flow of the stream during the changing seasons of the British Columbia west coast, erosion is a primary concern of maintaining the integrity stream. Erosion is ultimately due to the high velocity of the stream loosening and carrying away soils on the streambed. By lowering the velocity of the water in the creek, the degree of erosion inside the creek will be lowered. It can be expected that with proper roughening of the stream, erosion of local soils can be minimized.

5.3.4 What is the Estimated Price?

The methods of roughening the stream previously mentioned in table [[]] utilize natural and economically abundant materials of gravel and stone. Furthermore, various sizes of rocks are available in the garden, which may be utilized. Larger deposits of rock and gravel are purchasable from local quarries and gravel delivery services if the gardens supply is depleted. The cost for appropriate stones can range from 38-60 dollars (btygravelmart, 2013), and it is expected that 3 cubic yards will be required to suitably roughen the stream. While it is expected that the garden has a large enough supply of gravel to roughen the stream – leaving the total investment of managing this section of the stream free of material costs – purchasing additional gravel is still relatively cheap and a economically preferable option.

5.3.5 Are There Any Drawbacks?

At present, several large cobbles can be seen within the stream. The addition of smaller aggregates and gravels will provide a uniform and natural texture of the streambed. Nevertheless, a streambed comprised of only various sizing of rock will not be consistent with the stream banks, local landscape, or with other sections of the stream. The drawback of roughening the stream through the addition of gravel is merely from an aesthetic inconsistency noticeable to a watchful eye.

5.3.6 Can This Solution be Improved Upon in the Future?

While roughening of the stream is preferable for the lower water levels during the summer and fall seasons, it is less effective as the water level rises. If roughening the stream does not suitably lower the stream velocity during the rainy seasons of winter and spring, other methods implemented in other sections of the stream can be extended to this section.

5.4 Stream Wall Reinforcement

5.4.1 What is it?

In the downstream of the third bridge, there is obvious bank erosion around the culvert. The banks on both sides of the culvert are damaged significantly, and the soil of the banks has become loose. The unstable bank condition will lead negative effects on the plants around the area, and it will also lead potential dangers to the travelers in Botanical Garden. At the same time, bank erosion will cause a large amount of soil precipitation in the water. The increasing water level in the area will cause flooding in heavy rainy days. Therefore, to strengthen the soil condition, reduce precipitation, and protect both plants and travelers, we recommend stream bank reinforcement in the area.

5.4.2 What is the Ideal Design for Rock Creek?

The ideal design for the stream wall reinforcement is a combination of riprap and live stakes. Riprap is simply a sturdy rock layer constructed on the contours of the bank, while live stakes are woody plants that are introduced along the bank, which will form roots and aboveground brushes (IDNR, 2006). The configurations of the two solutions are shown below.

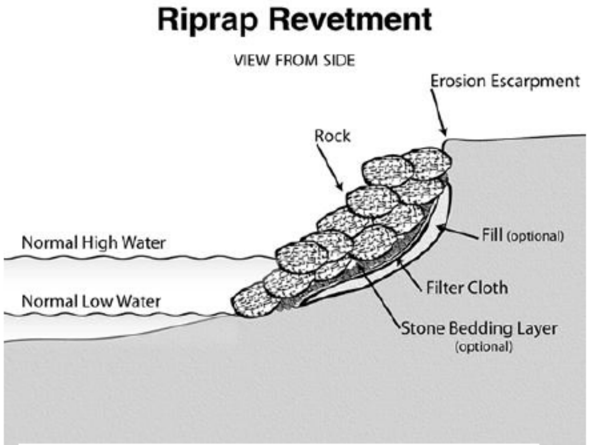

Figure.5.4.1. Riprap Revetment (NCDENR)

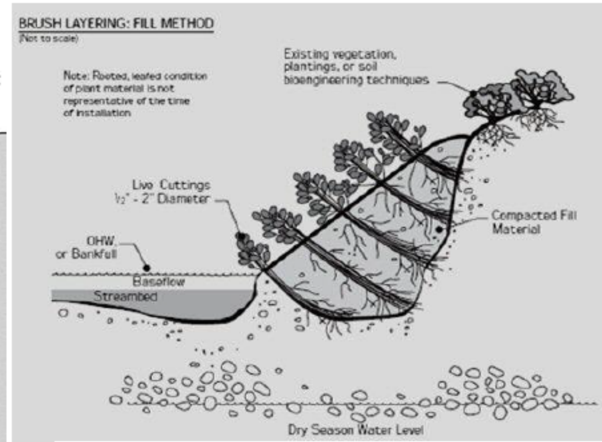

Figure.5.4.2. Live Stakes (IGA)

Our specific design for the bank around the culvert in Rock Creek is shown below.

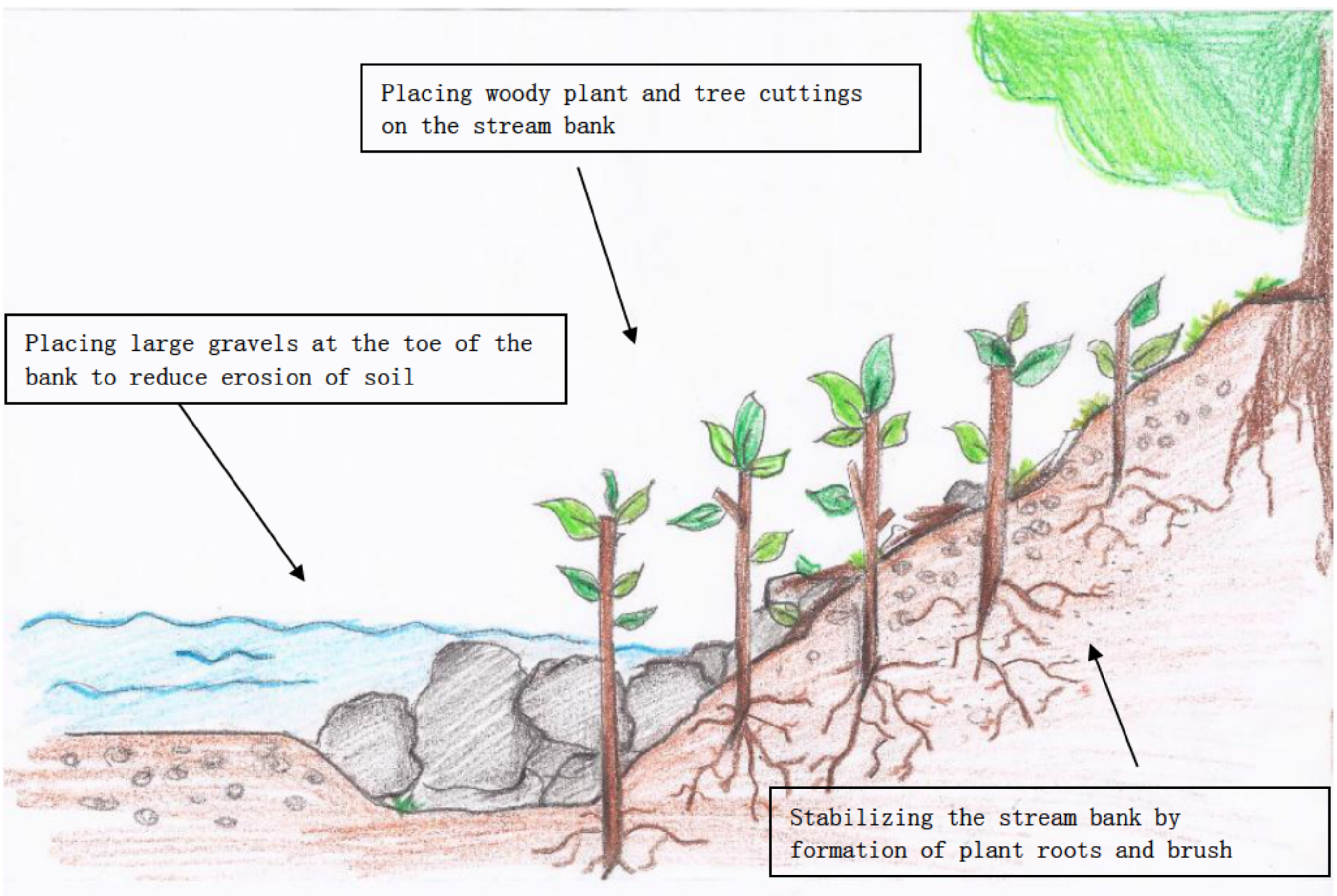

Figure.5.4.3. Live Stakes

5.4.3 How will it Help Achieve the Objectives?

Both of the riprap and live stakes can work very effectively to strengthen the bank and reduce erosion around the area.

When a rock layer, such as riprap, is constructed, the heavy rocks on the surface of the bank will protect the land underneath from eroding and weakening. With the formation of live stakes, the roots will help dry and strengthen the soil by forming a protective net and using the surrounding water as nourishment. In addition, because there is disturbance in the stream caused by the bushes and rocks on the bank, the flow rate will also be decreased (IDNR, 2006).

There are many advantages for using the two methods for bank reinforcement. Both of them have a natural appearance, and they also have no negative effects on the environment (Doyle, 1992). Therefore, the design is an environmentally friendly choice which is suitable for being used in Botanical Garden. More importantly, both of the methods are easy to be constructed and repaired so that it saves much work (IDNR, 2006).

5.4.4 What is the Estimated Price?

The preferred materials used for riprap are broken limestone, dolomite, or quartzite. The more angular and rough the rocks are, the better the rocks fit together. In addition, as the speed and height of the stream changes frequently under different weather conditions, heavy and large rocks are required to prevent the movement of the rock layer. At the same time, we also need some small-size rocks which can fulfill the void spaces between large rocks (IDNR, 2006). Based on the data provided by the Lakeside Land Company, the price of riprap is $25 per ton (LLC).

The material used for live stakes can be young willows or shrub dogwoods (IDNR, 2006). Some other species which root easily and has straight branches can also be used (ERNST). Based on the prices provided by Foggy Mountain Nursery, the average price of live stakes is around $0.42 per stake (FMN).

However, the total cost can be reduced because most of the material listed above can be obtained directly from Botanical Garden.

5.4.5 Are There Any Drawbacks?

Even though we are planning to use heavy and large rocks for riprap, a heavy rainfall or a high flow event may also lead displacement and deterioration of the rocks (IDNR, 2006). Therefore, it is essential for us to inspect the condition of the area to maintain high working efficiency of the riprap. More labor cost is required for regular inspection and repair.

5.4.6 Can This Solution be Improved Upon in the Future?

The design can be improved if we add some erosion control fabric around the plants. However, the measurement will lead a higher cost (IDNR, 2006). For instance, a Curlex Net Free Erosion Control Fabric Natural is around $0.10 per square foot (CNFECFN).

6 Conclusion

After considering the characteristics of the stream, we have outlined four solutions, which are, as stated above, adding a holding pond at the top of the stream, rock weir placement along the upper half of the stream, stream bed roughening along the lower half of the stream, and riprap installation along the sides of the stream. These proposed ideas are aimed to control flow rates during the winter and spring seasons, increase flow rates during the summer seasons, and to mediate erosion problems within the stream.

7 Appendix A: Data and Calculations

7.1 Elevation Data

Distance (ft.)	Relative Height (ft.)	Height of Bridge above water (ft.)
0	25.125	
5	23.625	
10	24.000	
20	25.375	
28	24.875	
28	24.875	2.1667
37	21.083	
40	21.542	
50	20.000	
50	20.000	
54	19.667	
60	20.125	
66	19.333	
68	18.667	
70	19.208	
80	19.167	
88	18.708	
90	17.792	
100	17.417	
110	17.250	
113	16.083	
120	15.958	
130	16.292	
140	16.125	
150	15.542	
157	15.250	
157	15.250	2.3125
163	14.833	
166	14.417	
170	14.125	
180	13.667	
190	13.333	
200	12.417	
210	11.833	
220	11.000	
225	10.333	
230	10.917	
240	10.125	
250	8.750	
250	8.750	

259	7.542	
259	7.542	3.5417
281	4.042	2.6250
281	1.417	
287	0.958	
290	1.792	
300	1.292	
300	1.292	
307	0.000	

7.2 Sample Calculations

Pond Volume

$$\left[Average\ Flow\ Rate\ \left(in\,\frac{L}{s}\right)\right] \times [Days\ that\ flow\ rate\ will\ be\ maintained\ (in\ s)]$$

Pond fill time

$$[Volume\ of\ Pond\ (in\ L)] \div \left[Flow\ Rate\ \left(in\,\frac{L}{s}\right)\right]$$

Manning's Equation

$$V = \frac{1}{n} R_n^{\frac{2}{3}} S_e^{\frac{1}{2}}\ \mathrm{g}$$

8 Appendix B: References

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