Influence of Engineered Soil Media Composition to the Hydraulic Performance in Rain Garden System

by

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Dissertation submitted in partial fulfilment of
the requirement for the
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CERTIFICATION OF APPROVAL

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Approved by,

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December 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD IDZWAN BIN RAZALI

ABSTRACT

Stormwater had been identified as one of the factor that causes surface runoff on the ground. The runoff is caused by the inability of the water to infiltrate into the soil, causing the water to stay on the ground and causes major problems such as flooding and water ponds. Rain garden is one of the best management practice approach in handling this matter. A rain garden promotes infiltration to the soil beneath, reducing the surface runoff thus solving floods problems. The objective of this study is to investigate the effects of soil media composition to the hydraulic performance in a rain garden system. Three types of soil media composition is used, which are fine river sand, coarse river sand, and leaf composts, which are made up of shredded dry leaves. The study is done by using sand column to represent a bioretention system, which are divided into three layers; the drainage layer, soil filter layer and ponding layer at the top. In order to analyse the hydraulic performance of the system, a few parameters had been identified as indicators in this study, which are the flow of water, soil hydraulic conductivity, water removal efficiency, and water holding capacity. A coarser grain material had been known to give a greater flow and hydraulic conductivity, however, an addition of fine sand and leaf composts helps in water removal and water drainage, which is also a good parameter for a better rain garden system.

Keywords: rain garden, best management practice, hydraulic conductivity, soil media composition, water removal efficiency.

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CHAPTER 1: INTRODUCTION

1.1 Project Background

Rain garden, is a bioretention system that function to catch and hold storm water runoff to promote water infiltration underground and evaporation to the atmosphere. The idea started back in 1990 in Prince George's County, Maryland during the time where the stormwater specialists had the idea of replacing the traditional idea of water retention system, which is by using retention pond. The idea of replacing retention pond with rain garden was found to be more effective in terms of cost, water quality and stormwater handling system.

The term "rain garden" emerged in 1993 as it is found more attractive. The concept had been implemented by other states especially Minnesota, Michigan and Wisconsin since then.

The idea of creating the rain garden is classified under low impact development (LID) which had been implemented in a lot of countries as a "green infrastructure" strategy. LID is an environmental philosophy that includes a focus on controlling urban rainfall and stormwater runoff at the source (Davis, 2008).

As the word bioretention suggests, the primary function of the rain garden is to hold and infiltrate stormwater and surface runoff before it is discharged to the local drain. Previously, the world is covered with mostly soil that allows the rainwater to infiltrate into the soil or flows into the lower region. However, when urbanization takes place, the roads are majorly covered with pavements, thus reducing the permeable area for the water to seep into the ground. This will result in the decreasing base flow and an increase in flood frequency (Wang, *et.al*, 2001), especially during rainy season. With rain garden installation, the soil area for the surface water to infiltrate will increase thus reducing the amount of surface discharge.

Besides that, rain garden also have potential in removing particles in the rainwater such as solids and bacteria. This occurs as the runoff water is allow to infiltrates through soil grains and sometimes roots of plant which act as a trap to these particles. Under proper care and maintenance, a high number of bacteria such as Escherichia Coli (E.Coli) can be removed via rain garden infiltration (Bright et.al, 2010). A study in North Carolina has shown that about 35% of nitrogen, 45% of total phosphorus and 85% of total suspended solid (TSS) can be removed by using bioretention method (Brown et.al, 2010). The reduction of bacteria and organic matter could improve the quality of water that will be discharged into the local drains, and into river.

From a landscape point of view, rain garden can be a new concept in home gardening and beautification. Bioretention will produce a good soil for gardening and planting. Several plants can be planted on the garden such as grasses, ferns and shrubs. Plants do not only enhance the look of the garden, but can also improve the performance of the rain garden in terms of hydraulic conductivity (Asleson et.al, 2009).

A typical rain garden consists of water inlet, mulch layer, excavated basin area, filters, retaining wall and outlet. Other features can also be included such as riprap and monitoring equipment. **Figure 1** shows the cross section example of a typical rain garden system.

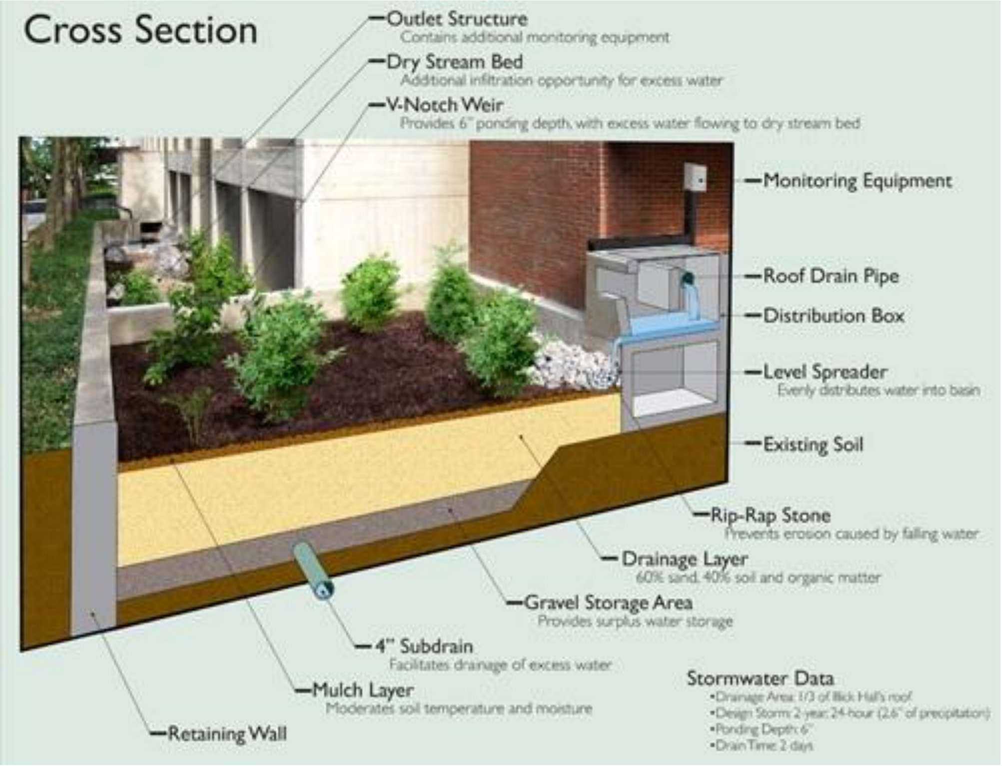


Figure 1: Cross Section of a Rain Garden (SUNY-ESF, 2012)

One of the methods to collect the rainwater directly is from the gutter. Usually the rainwater that is collected in the gutter will flow into the local drain, and causes accumulation of untreated water into the main drainage and river. By collecting the rainwater from the gutter, a huge amount of water can be collected and treated just after the storm event.

Maintenance is a must in ensuring the rain garden can function effectively and to prevent problems from occurring. A simple check for the rain garden effectiveness is by visual monitoring. Usually, monitoring is done 48 hours after storm event. There are several ways to identify that the rain garden is no longer capable to function as bioretention basin. Firstly, when a water 'pond' is form within the basin area. This shows that the infiltrated water is unable to flow out due to clogging or ineffective filtration media.

Another signs that the rain garden is ineffective is the presence of wetland plane species such as cattail and arrowheads (Asleson et.al, 2009). If they does appear, it show a prolong period of saturation, as a result of the presence of hydric soil.

1.2 Problem Statement

In well-developed areas such as the urban areas, the increase in pavements and high rise buildings will cause the permeable areas on land to reduce, hence causing a problem when it comes to water-related situation such as raining and flooding. Since the land floor had been covered, the movement of water from surface into underground becomes slower and if the storm duration is longer, the surface runoff will increase and flooding will occur.

Therefore, to prevent this from continuing to occur, rain garden can be implemented as to increase permeable areas at urban areas, hence promoting infiltration of water into the ground. A rain garden system must not only able to infiltrate stormwater at a faster rate, but also must have a capacity enough to retain the ponded water before the next storm event.

In terms of infiltration, the effectiveness of a rain garden system is largely governed by the type of soil used and how is it prepared. The primary function of the rain garden is to act as bioretention that can hold a certain amount of water underground as to prevent increment in surface runoff. A good mixture of soil, known as engineered soil, will cause a rain garden to work smoothly and effectively thus eliminating most of major problems related to flooding.

According to Urban Stormwater Management Manual for Malaysia (MSMA) by Department of Irrigation and Drainage (DID), the mixture of soil media had been determined according to table below;

Table 1: Contents of the Soil Mixture by Volume (DID, 2012)

Soil Mixture	Contents by Volume (%)
Top soil (sandy / silt loam)	20-25
Medium sand	50-60
Organic leaf composts	12-20

Every types of the soil mixture will give different impact to the hydraulic performance of the rain garden. This raised a question of how well the system will perform is all the parameters are being varied? Plus, with the additional of organic material such as the leaf compost, this will surely alter the hydraulic properties of the soil itself, since it has relatively different characteristics with the soil, physically.

1.3 Objective

The objective of the study is to investigate the effects of different engineered soil composition to the hydraulic performance of rain garden. The engineered soil consists of fine sand, coarse sand and leaf compost. The hydraulic performance of the rain garden includes the outflow, hydraulic conductivity, and the efficiency in terms of water removal by the soil mixture.

1.4 Scope of Study

The scopes of this study are as follows:

i. Usage of river sand as soil mix
ii. Usage of dry old shredded leaves as leaf composts
iii. Determination of the hydraulic characteristics of the soil mixture using sand column
iv. Determination of percentage water removal with different kinds of soil mixture.

CHAPTER 2: LITERATURE REVIEW

2.1 Bioretention

Bioretention is a system that combines a natural and engineered system to manage stormwater from developed areas (Brown, Hunt 2010). They are designed to at least treat the water quality volume of runoff. Bioretention removes runoff pollutants through adsorption, biological decomposition, filtration and sedimentation (Davis et al, 2001). Bioretention cells also function to remove pollutants load through adsorption, biological composition, filtration and sedimentation (Hunt et al. 2006; Li et al 2009; Jones and Hunt 2009).

Bioretention system can be designed as permeable or impermeable system (DOW, 2009). The permeable system allows the water to infiltrate through the filter media and sand bed layer before spreading to the surrounding native soil. The condition is similar to the impermeable system; the only different is the water is discharged from this system to the underdrain soil to connect to the drainage system. This system is usually used in an area where native soils have relatively low infiltration capacity or higher rainfall intensity. The underdrain is needed as to carry excess water away from the site as to prepare the system for the next storm event. If the underdrain is not implemented, the basin area will be incapable of holding much volume of water and overflowing will occur for the next storm.

In terms of LID, bioretention is the most widely used under the best management practice (BMP) because of its versatility and level of performance (Brown and Hunt, 2011). Bioretention is a prominent LID technology that has been installed in many areas and continues to draw increasing interest (Davis, 2008).

In Malaysia, Urban Stormwater Management Manual for Malaysia (MSMA) under Department of Irrigation and Drainage (DID) had issued a guideline for to design the bioretention system in Malaysia. There are several design consideration from several aspects such as the siting, drainage area, slope of the system, types of soil to be used and the groundwater concern. Under MSMA, certain depth had been suggested for the systems, which are divided into permeable and impermeable bioretention system.

Figure 2 and **Figure 3** below shows the different types of system guidelines by MSMA.

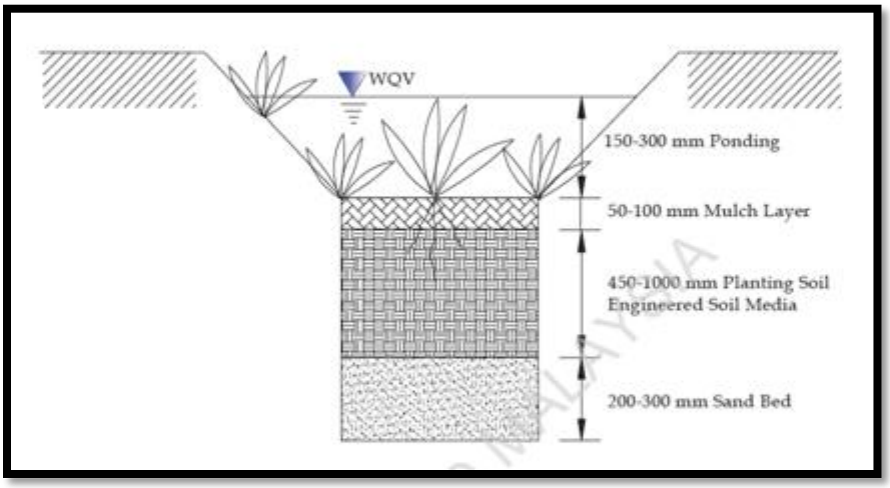


Figure 2: Specification of Permeable Bioretention System (DID, 2012)

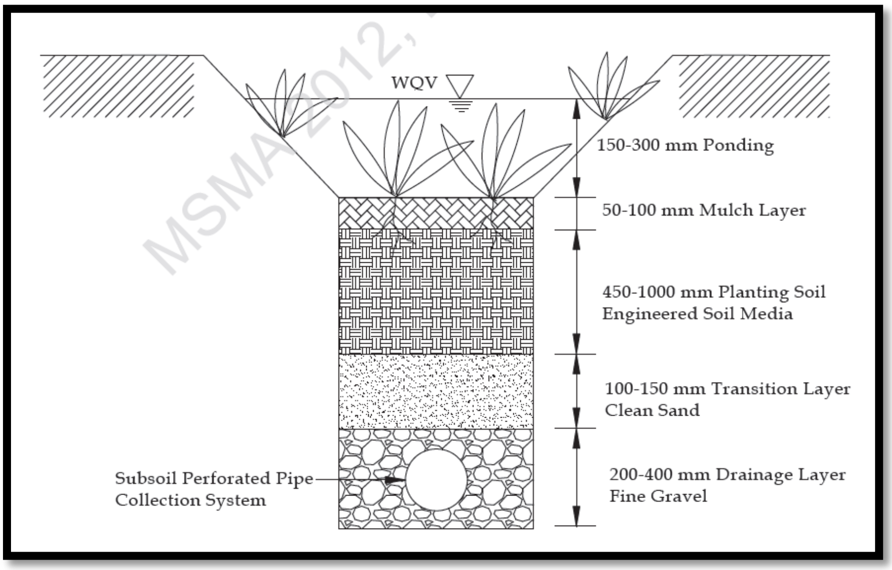


Figure 3: Specification of Impermeable Bioretention System (DID, 2012)

2.2 Hydraulic Conductivity

Hydraulic conductivity can be defined as a measure of the ability of a soil to transmit water. Under saturated conditions this parameter is usually denoted as K_{sat} *or* (K_s) and is assumed to be constant for a given space and time within a soil (Amoozegar and Wilson, 1999).The knowledge of K_{sat} for a specific soil is too important for instance in drainage design, the saturated hydraulic conductivity is used to compute the velocity in which water can move toward and into the drain lines below the water table (Amoozegar and Wilson, 1999).

There are several factors that influence the value of soil hydraulic conductivity. Some of the most influential factors are the porosity of the soil, the size particle and the bulk density of the soil. Porosity refers to the number of voids or holes in the soil particle, while the bulk density is the measure of the soil mass per unit volume of soil.

Hydraulic conductivity can be determined through field testing or laboratory testing. The advantage of doing field testing on soil is that the soil is undisturbed and the result could accurately represent the real situation. However, the issue of transport and the environment might be little disadvantages to the testing. For laboratory testing, the investigation can be done in a highly controlled laboratory environment. However, the sample might have been aggravated during the transport and the result might not be accurate.

Kremer (Kremer, 2003) had divided the field measurement methods into two, which are measurement below a water table and under the water table. The measurement above the water table are such single auger hole method and piezometer method. The measurement below the water table includes tension infiltrometer method, ring infiltrometers, and constant head well permeameter method.

Meanwhile, laboratory measurement method are such constant-head conductivity test with permeameter cylinder, falling-head conductivity test with permeameter cylinder, conductivity test with sampling tubes, conductivity test with pressure chamber and conductivity test with back pressure. These measurements however, depends on the characteristics of soil such as the soil disturbed or undisturbed nature and size of particles.

Table 2 shows the saturated hydraulic conductivity of various types of soils.

Table 2: Saturated Hydraulic Conductivity of Various Types of Soils (Freeze and Cherry, 1979)

Soil Type	**Saturated Hydraulic Conductivity, K (m/yr)**
Unconsolidated Deposites	
Gravel	1×10^{4} - 1×10^{7}
Clean sand	1×10^{2} - 1×10^{5}
Silty sand	1×10^{1} - 1×10^{4}
Silt, loess	1×10^{-2} - 1×10^{2}
Glacial till	1×10^{-5} - 1×10^{1}
Unweathered marine clay	1×10^{-5} - 1×10^{-2}
Rocks	
Shale	1×10^{-6} - 1×10^{-2}
Unfractured metamorphic and igneous rocks	1×10^{-7} - 1×10^{-3}
Sandstone	1×10^{-3} - 1×10^{1}
Limestone and dolomite	1×10^{-2} - 1×10^{1}
Fractured metamorphic and igneous rocks	1×10^{-1} - 1×10^{3}
Permeable basalt	1×10^{1} - 1×10^{5}
Karst limestone	1×10^{1} - 1×10^{5}

Different soil texture also shows different value of soil conductivity such as in **Table 3** below:

Table 3: Saturated Hydraulics Conductivity for Different Soil Texture (Clapp and Hornberger, 1978)

Soil Texture	Saturated Hydraulic Conductivity, K (m/yr)
Sand	5.55 x 10^3
Loamy sand	4.93 x 10^3
Sandy loam	1.09 x 10^3
Silty loam	2.27 x 10^3
Loam	2.19 x 10^3
Sandy clay loam	1.99 x 10^3
Silty clay loam	5.36 x 10^1
Clay loam	7.73 x 10^1
Sandy clay	6.84 x 10^1
Silty clay	3.21 x 10^1
Clay	4.05 x 10^1

The textures are actually the mixtures between clay, sand and silt. **Figure 4** shows the texture triangle, explaining the percentage of soil, silt and clay in different types of soil texture.

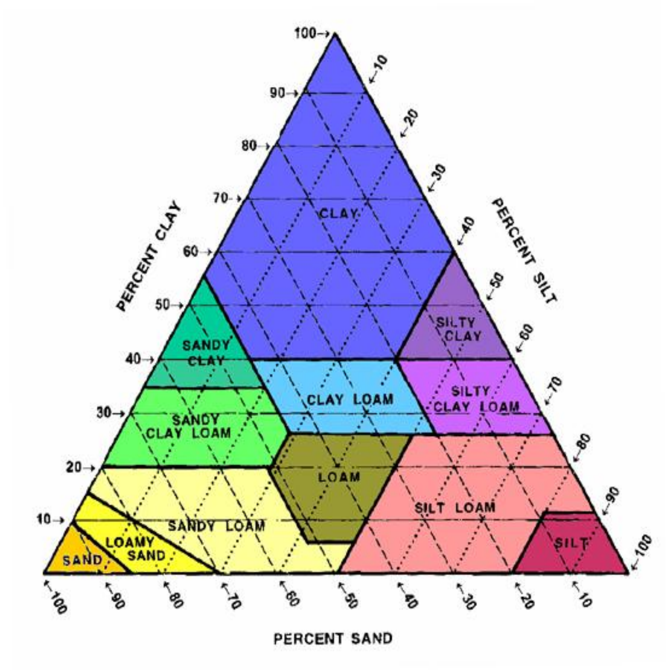


Figure 4 : Percentage of Silt, Clay and Sand in Different Types of Soil Texture (Whiting et.al, 2011)

2.2 Sand Properties and Permeability

In the soil textures series, sand is the coarsest among the textures in the soil group. Sand ranges from the grain size of 0.002mm to 1mm. **Table 4** below shows the size of the soil textures.

Table 4: The Size of Soil Particles of Different Types of Soil Textures based on USDA Classification

Name	**Size Range (mm)**
gravel	> 2.0
very coarse sand	1.0-1.999
coarse sand	0.500-0.999
medium sand	0.250-0.499
fine sand	0.100-0.249
very fine sand	0.050-0.099
silt	0.002-0.049
clay	< 0.002

Since sand is the larger among the group, it has the highest permeability which allows more infiltration of water. Roy, Raymond and John (1983) states that the most rapid water and air movement is in sands and strongly aggregated soils, whose aggregates act like sand grains and pack to form many large pores.

Porosity is the ratio between the void area and the total volume of the sediment. While sand is relatively big in particle size, the porosity of sand can be high. According to Holt (1965), the porosity of sand-plain province can reach as high as 32%- 38%. A mixture of sand and gravel will produce a porosity of 20% - 35% (Fetter, 1994).

2.4 Infiltration Testing Method

There are methods which hydraulic conductivity testing can be done, either under controlled environment (laboratory) or field testing.

Asleson (Asleson et.al, 2009) had done infiltration rate test on the rain garden by using Modified Philip-Dunne Infiltrometer, which an infiltrometer is set on the soil to determine how fast the water will be able to infiltrate into the soil. The illustration of the set up is shown in **Figure 5** below.

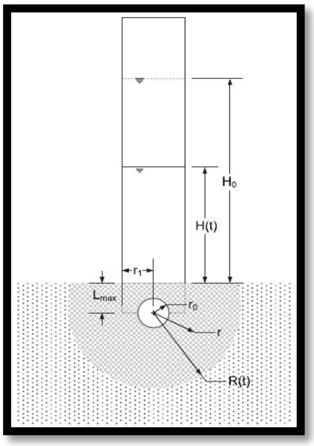


Figure 5: Illustration of Modified Philip-Dunne Infiltrometer (Asleson et. al, 2009)

From the illustration, H_o is the initial height if water, $H(t)$ is the height of water at certain time, L_{max} is the depth of insertion into the soil, r_o is the equivalent source radius, r_1 is the radius of the cylinder, r is any radius within the wetted front, and $R(t)$ is the radius to the sharp wetted front at time t.

Another infiltration test had been done in a laboratory scale (Bright *et.al*,2010) using sand column. The plastic tube sand column is design to meet the following criteria:

- Soil particle diameter ratio : 1/50
- Thickness: 0.38cm
- Height: 1.8m
- Outer diameter: 5.1 cm
- Inner diameter: 4.45 cm

2.5 Darcy’s Law on Hydraulic Conductivity

In fluid dynamics and hydrology, Darcy's law is a derived constitutive equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand. It also formed the scientific basis of fluid permeability used in the earth sciences.

One application of Darcy's law is to water flow through an aquifer. Darcy's law along with the equation of conservation of mass are equivalent to the groundwater flow equation, one of the basic relationships of hydrogeology. Darcy's law is also used to describe oil, water, and gas flows through petroleum reservoirs.

Darcy’s apparatus consisted of a sand-filled column with an inlet and an outlet similar to that illustrated in **Figure 6**. Two manometers (essentially very small piezometers) measure the hydraulic head at two points within the column ($h1$ and $h2$). The sample is saturated, and a steady flow of water is forced through at a discharge rate Q [L^3/T].

Darcy found through repeated experiments with specific sand that Q was proportional to the head difference Δh between the two manometers and inversely proportional to the distance between manometers Δs:

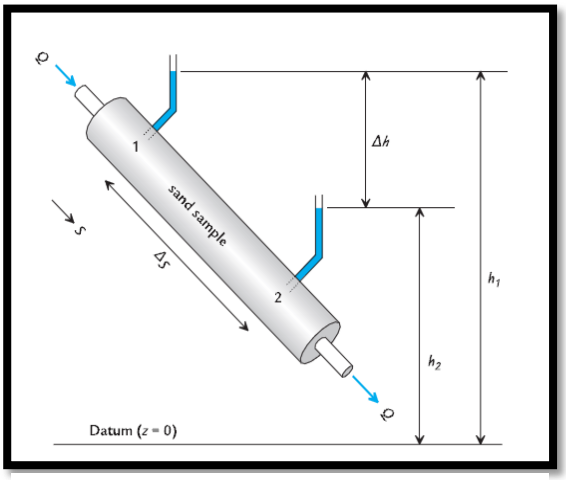


Figure 6: Darcy's Experiment Setup

Where;

h_1 and h : manometers

Δh : head difference between two manometers

Δs : distance between manometers

Q : flow across sand medium

Combining these observations, and writing an equation in differential form gives Darcy’s law for one-dimensional flow:

$$Q = -K_s \frac{dh}{ds} A \qquad (1)$$

where Q_s is discharge in the s direction. The constant of proportionality K_s is the hydraulic conductivity in the s direction, a property of the geologic medium. Hydraulic conductivity is a measure of the ease with which a medium transmits water; higher K_s materials transmit water more easily than low K_s materials. The term hydraulic conductivity is sometimes abbreviated to just conductivity. The minus sign on the right side of this equation is necessary because head decreases in the direction of flow. If there is flow in the positive s direction, Q_s is positive and dh/ds is negative. Conversely, when flow is in the negative s direction, Q_s is negative and dh/ds is positive.

CHAPTER 3: METHODOLOGY

3.1 Study Methodology

In this study, laboratory testing was carried out to determine the optimum grain size distribution to obtain maximum performance of rain garden in terms of hydraulic conductivity and solid removal. **Figure 7** below shows the methodological path on how the study was completed.

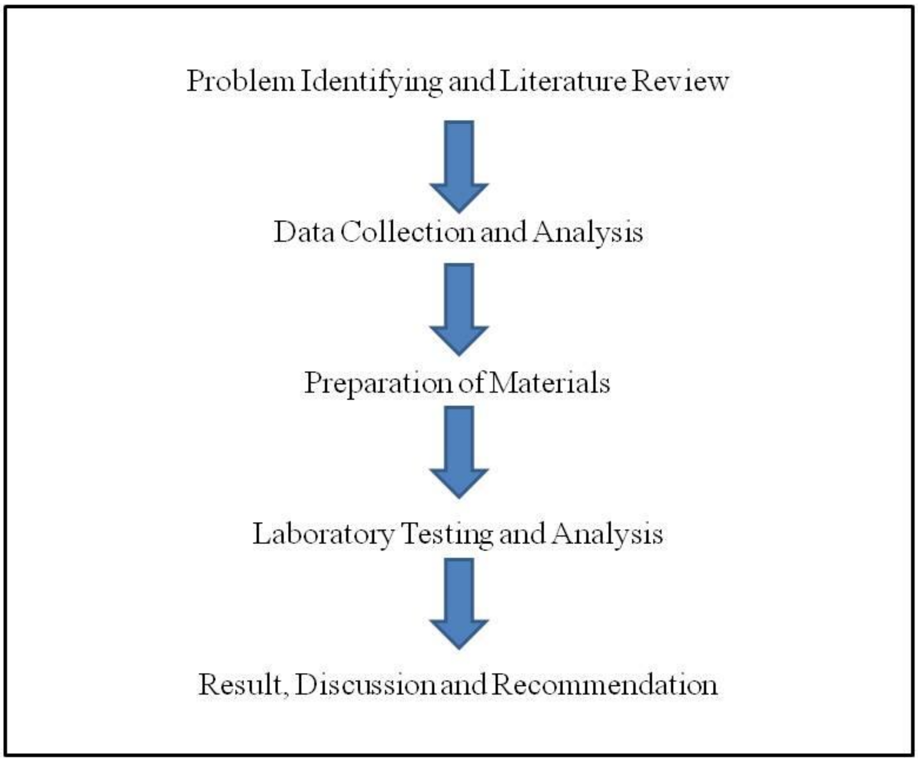
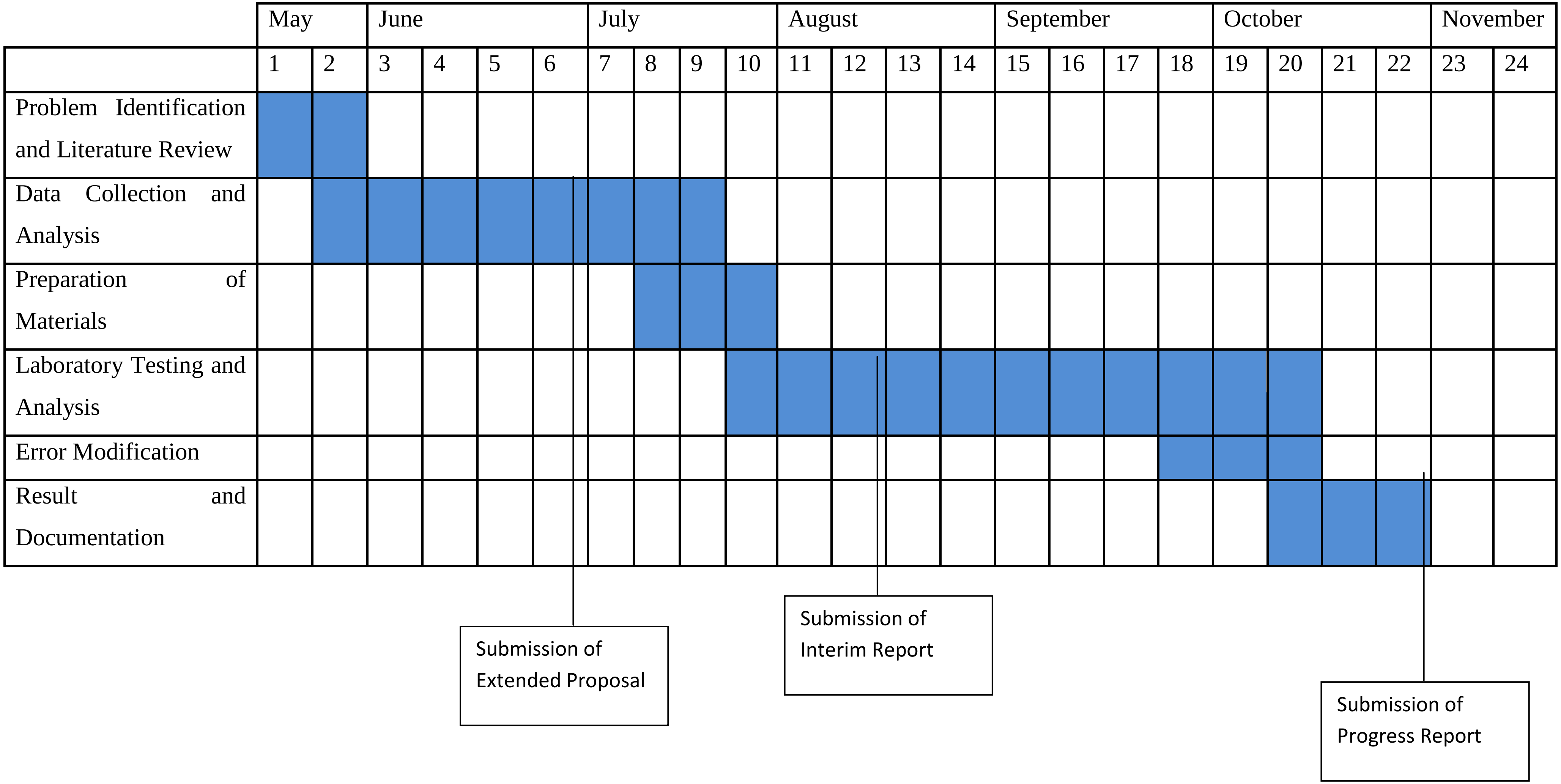


Figure 7: Study Methodology

The project was expected to finish within 24 weeks. The Gantt chart below shows the distribution of works within the period.

Table 5: Gantt Chart for the Project



	May		June				July				August				September				October				November	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Problem Identification and Literature Review	■	■																						
Data Collection and Analysis		■	■	■	■	■	■	■	■															
Preparation of Materials								■	■	■														
Laboratory Testing and Analysis										■	■	■	■	■	■	■	■	■	■	■				
Error Modification																		■	■	■				
Result and Documentation																				■	■	■		

Submission of Extended Proposal

Submission of Interim Report

Submission of Progress Report

The investigation was done in a small scale, which does not involve a real field investigation. The experiment was conducted in a fully controlled laboratory environment, with several equipments, procedure and precautions. The flow chart in **Figure 8(a) and Figure 8 (b)** below suggest the flow of the investigation.

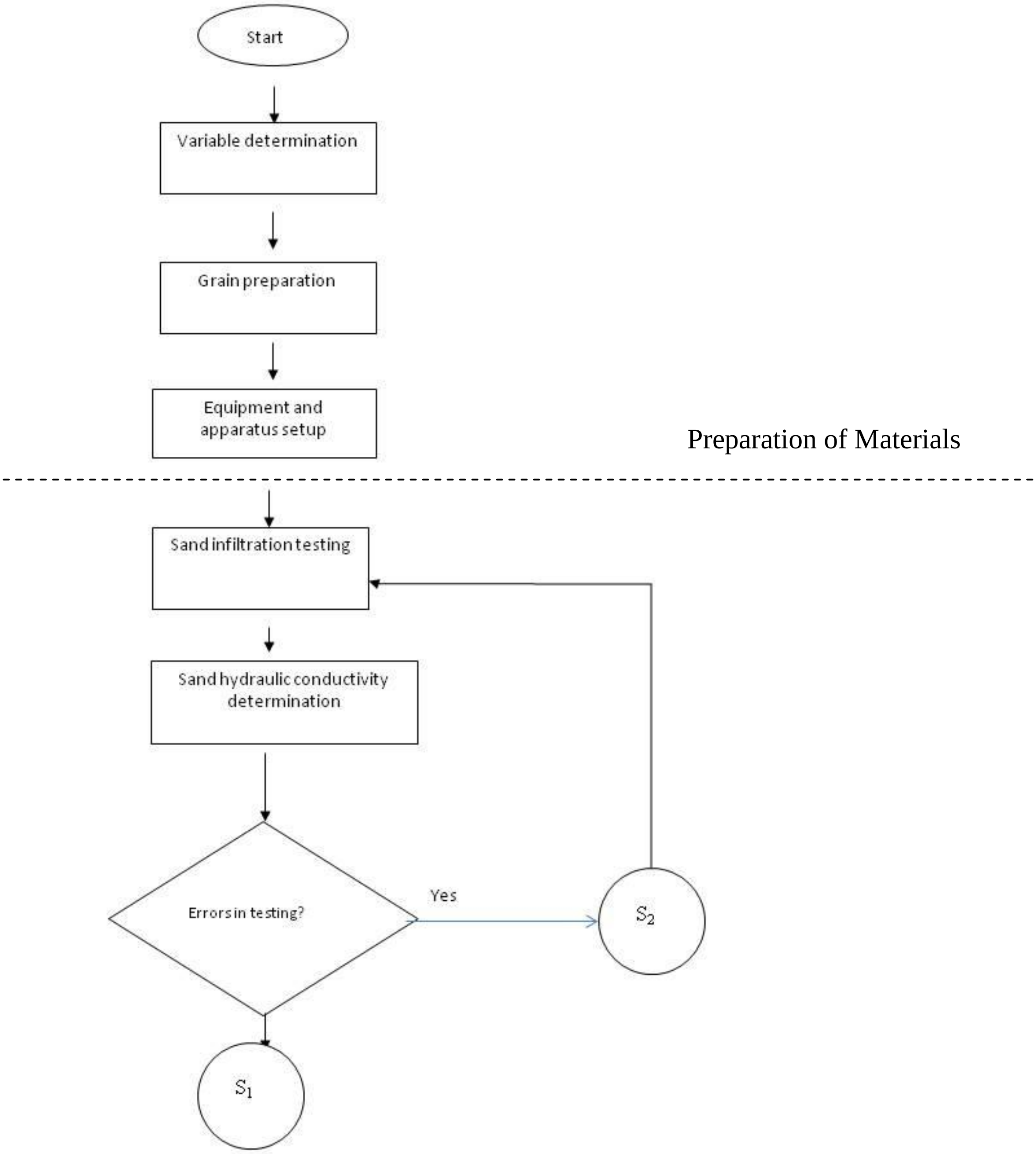


Figure 8 (a): Flowchart of the Study

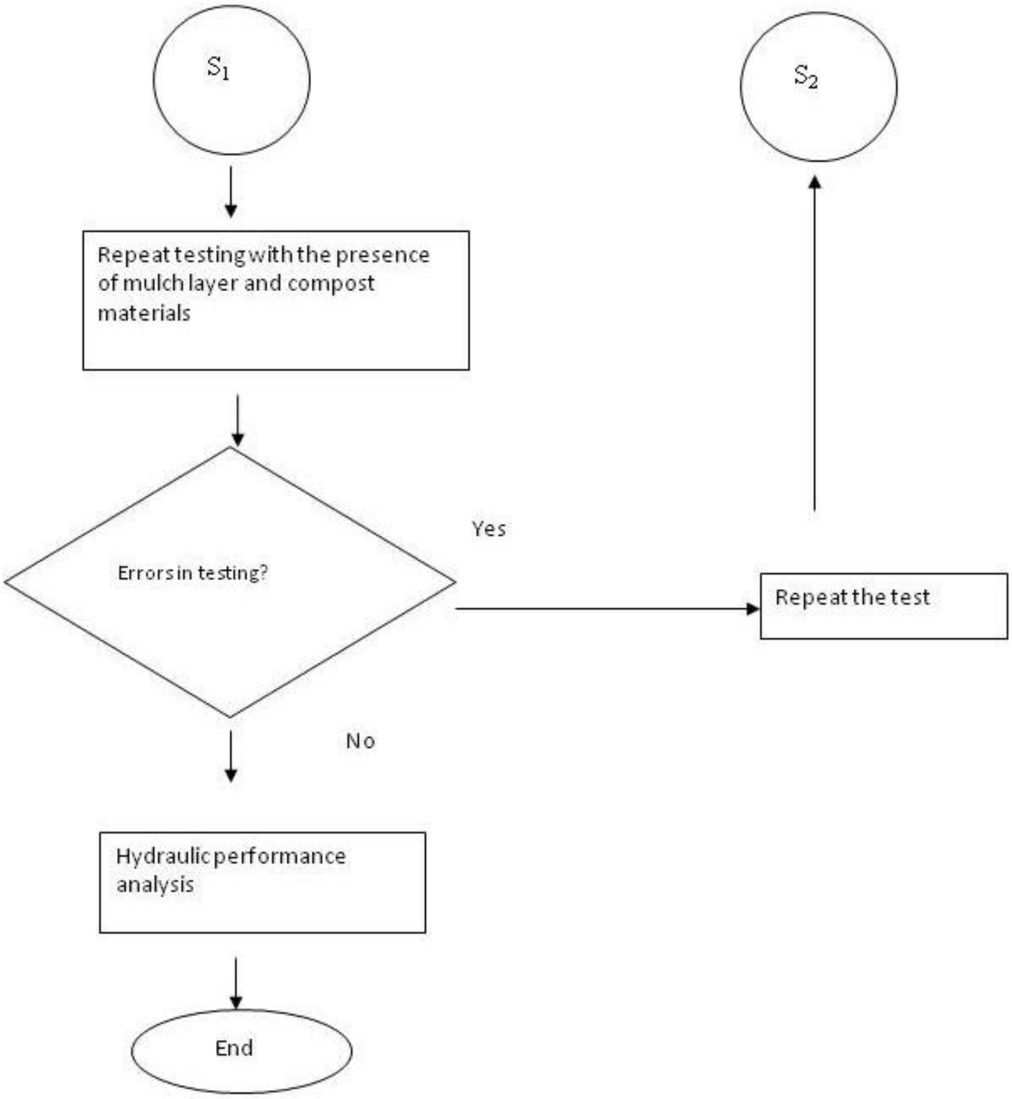


Figure 8 (b): Flowchart of the Study (continued)

3.2 Apparatus and Equipment Setup

In this investigation, there was two (2) major equipments setup needed. The first setup is the grain preparation while the next setup is the sand column setup.

The grain that was used in this investigation is river sand. The sand however consists of different size and gradation, which will need to undergo a series of grain preparation called sieving.

Sieving is a method of separating and classifying the grain size according to their diameter. The diameter of coarse sand that was used in this study ranges from 1.0mm to 2.0mm. The mass of the sand for each diameter is taken so the median size can be determined.

The next setup is the preparation of the sand column. Sand column symbolises the rain garden system, which the soil will be layered in a column and water will be flowed from the top to see the effect of the grain size to the water infiltration.

In determining the design of the sand column to be used, sample calculations from MSMA for bungalow area was used. The bungalow area and other measurements are taken as the prototype and a hydraulic constant will be used to scale down the bungalow bioretention area to design the model in form of sand column.

In designing the model, assumptions were made for the bungalow bioretention area such as the retention time, rainfall, discharge, catchment area, permeability and the hydraulic conductivity of the area. Froude number was used as the hydraulic constant to scale down the prototype.

A scale factor was used to determine the most suitable dimension for the sand column. From the scale factor, other dimensions can be determined from the design discharge of the sand column, such as the diameter of the column and the height of the column.

The sand column was designed based on the values obtained from MSMA. According to the values and a few assumptions, the calculation below can be done:

3.2.1 Design discharge

$$Catchment\ area, A = 371.612\ m^2\ \times \frac{1ha}{1000m^2} = 0.03716ha$$

$$I\ for\ 5\ year\ ARI\ with\ 15\ minutes\ duration = 166.436\frac{mm}{hr}$$

$$C_{avg} = \frac{C_pA_p + C_{imp}A_{imp}}{\sum A} = \frac{0.4 \times 232.258 + 0.65 \times 139.355}{371.612} = 0.494$$

$$Estimated\ Q_{peak} = \frac{CIA}{360} = \frac{0.494 \times 166.436 \times 0.03716}{360} = 8.487\ \times 10^{-3}\ m^3/s$$

3.2.2 Design dimensions of sand column

$$(\mathrm{Fr})_{\mathrm{m}} = (\mathrm{Fr})_{\mathrm{p}} \tag{2}$$

$$\frac{L_m}{L_p} = \frac{1}{25}$$

$$Q_p = 8.487\ \times 10^{-3}\frac{m^3}{s}$$

$$Assuming\ Q = VL^2, \tag{3}$$

$$\left(\frac{L_m^2}{L_m^2}\right)\left(\frac{V_m}{\sqrt{gL_m}}\right) = \left(\frac{L_p^2}{L_p^2}\right)\left(\frac{V_p}{\sqrt{gL_p}}\right)$$

Q_m = 0.00000271580 m^3/s or 2.7158 cm^3/s

From the design discharge of the column, the other parameters can be known as well. For scale 1: 25, a column diameter of 74 mm yields the column height of 0.5683m.

3.2.3 Design of layers in the sand column

In designing the layers accordance to MSMA bioretention non-permeable rain garden design, column is separated into few layers as to serve different functions in the experiment. The layers with their height are:

- Drainage layer : 20 mm
- Engineered sand layer : 407.1 mm
- Ponding level : 122.28 mm

Drainage layer is the bottommost layer of the column. The layer consists of small cobbles which are relatively flat and have a diameter ranges from 3.0 mm to 6.0 mm. The layer is made thin to avoid errors in doing the experiment since the cobbles will affect the discharge of water flowing out of the column. A layer of net is also placed between the drainage layer and the soil layer to prevent clogging and to distinguish between the layers.

Engineered soil is the most important part of the sand column. It is made up to 74% of the column. Engineered soil will consist of the sand with different types and dimensions, and leaf composts, which are made up of grinded dry leaves. The proportions of the mixture are varied to see their effects to the infiltration rate of water.

Ponding is a freeboard layer above the mulch layer, functions to retain water above the engineered sand layer. Ponding layer is made as to simulate the condition during the storm event when the water is accumulating on the soil before seeping into the ground.

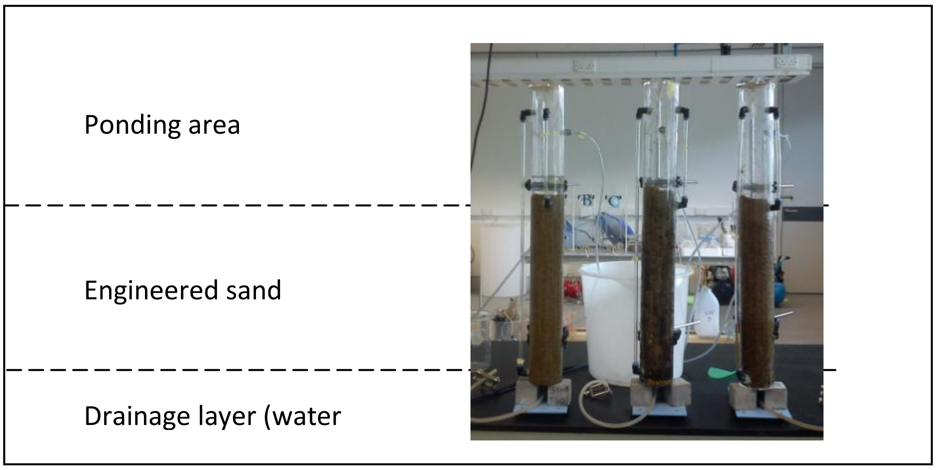


Figure 9: Sand Column

CHAPTER 4: RESULT AND DISCUSSION

4.1 Overall Result of the Experiment

Table 6 shows the overall result of the experiment in average. The experiment is repeated three times for each case. The extreme values within the data are taken out (if any) for each case, and the average is calculated for the remaining values. The raw results from the experiment are shown in the **APPENDICES**.

4.2 Graphical Comparison

4.2.1 Flow of water based on different engineered soil composition.

From the graph in **Figure 11** and **Figure 12**, it can be seen that the flow of water is decreasing with the additional of fine sand to the coarse sand. With the addition of leaf compost, the result is similar, which the flow will be decreasing. The reduction of flow might be caused by the amount of voids inside the engineered soil mixture. The sand columns with 100% coarse sand have a higher amount of voids as compared to the other column where the mixture is not coarse sand alone. Therefore, water can easily flowed through these voids and resulting in higher flow of water.

However, with the addition of fine sand into the mixture, the gaps between the coarse sand are filled up with these smaller particles thus reducing the amount of spaces between the particles. Hence, the passage of water is reduced, and the flow of water is also reduced.

The addition of the leaf compost into the particles shows the similar result with the one without the leaf compost addition, however, in terms of figures, the flow of water is slightly reduced. This shows that the addition of leaf compost might give a little or insignificant effects to the flow of water across the engineered soil media.

Table 6: Overall Result of the Experiment

	Case	Coarse	Fine	Compost	Volume if water in (ml)	Volume of water out (ml)	Percentage of Water Removed (%)	Flow of water (m3/min)	Hydraulic conductivity (m/min)
Without Composts	100% Coarse Sand	100	0	0	1536.94	1370.00	89.14	0.00157	0.6682
	95% Coarse Sand + 5% Fine Sand	95	5	0	1503.75	1360.00	90.44	0.00151	0.3867
	90% Coarse Sand + 10% Fine Sand	90	10	0	1390.50	1255.00	90.26	0.00124	0.3362
With Composts	100% Coarse Sand	80	0	20	1509.72	1350.00	89.42	0.00157	0.5447
	95% Coarse Sand + 5% Fine Sand	76	4	20	1521.94	1386.67	91.11	0.00121	0.3118
	90% Coarse Sand + 10% Fine Sand	72	8	20	1456.79	1375.00	94.39	0.00117	0.2476

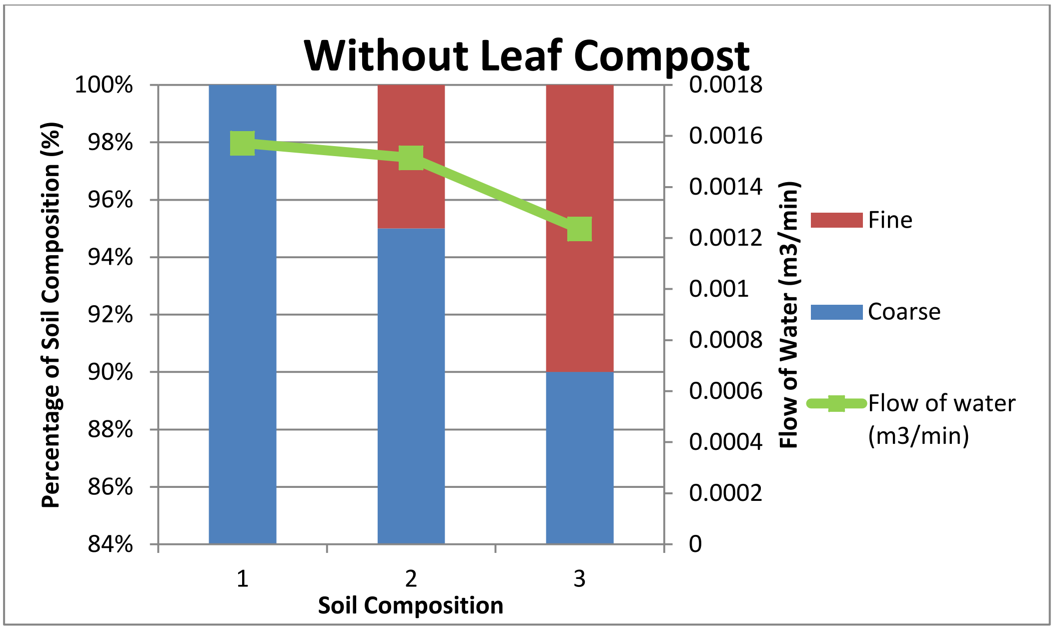


Figure 10: Flow of Water across Engineered Soil Media without Leaf Compost

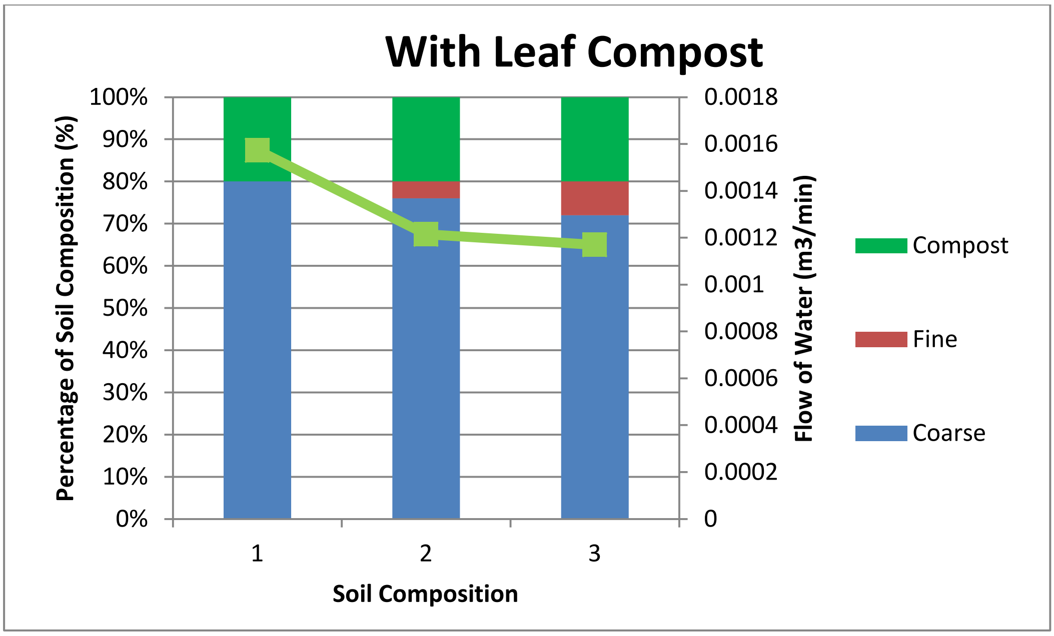


Figure 11: Flow of Water across Engineered Soil Media with Leaf Compost

4.2.2 Hydraulic conductivity of soil based on different engineered soil composition

Figure 13 and **Figure 14** shows the hydraulic conductivity of different kinds of engineered soil, in m/min. From the graphs, it shows that the reductions of hydraulic conductivity for both with and without leaf compost are in similar pattern. The usage of coarse sand yields a higher value in terms of hydraulic conductivity, while these values decrease with the addition of fine sand. In terms of leaf compost addition, the effects are rather insignificant in terms of improving the hydraulic conductivity. From graph 13, it can be seen that the hydraulic conductivity for every cases of fine sand addition is lower than the cases where no leaf compost involved. Therefore, it can be said that the leaf compost reduces the hydraulic conductivity of an engineered soil, rather than improving them.

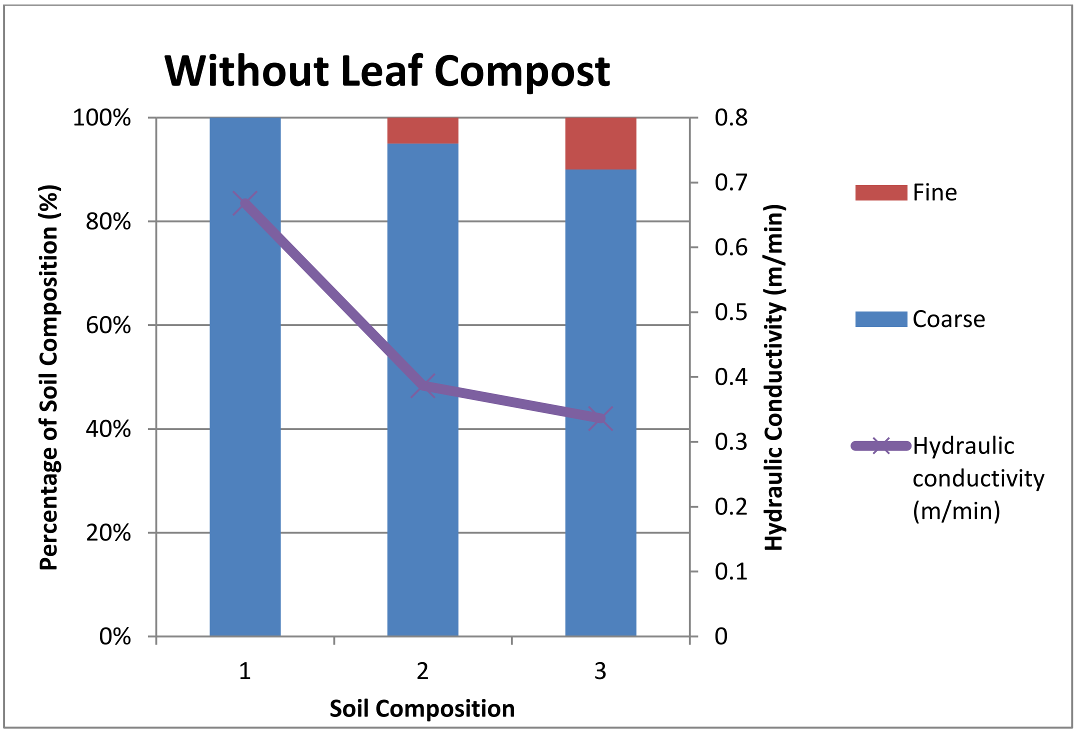


Figure 12: Hydraulic Conductivity of Engineered Soil Media without Leaf Compost

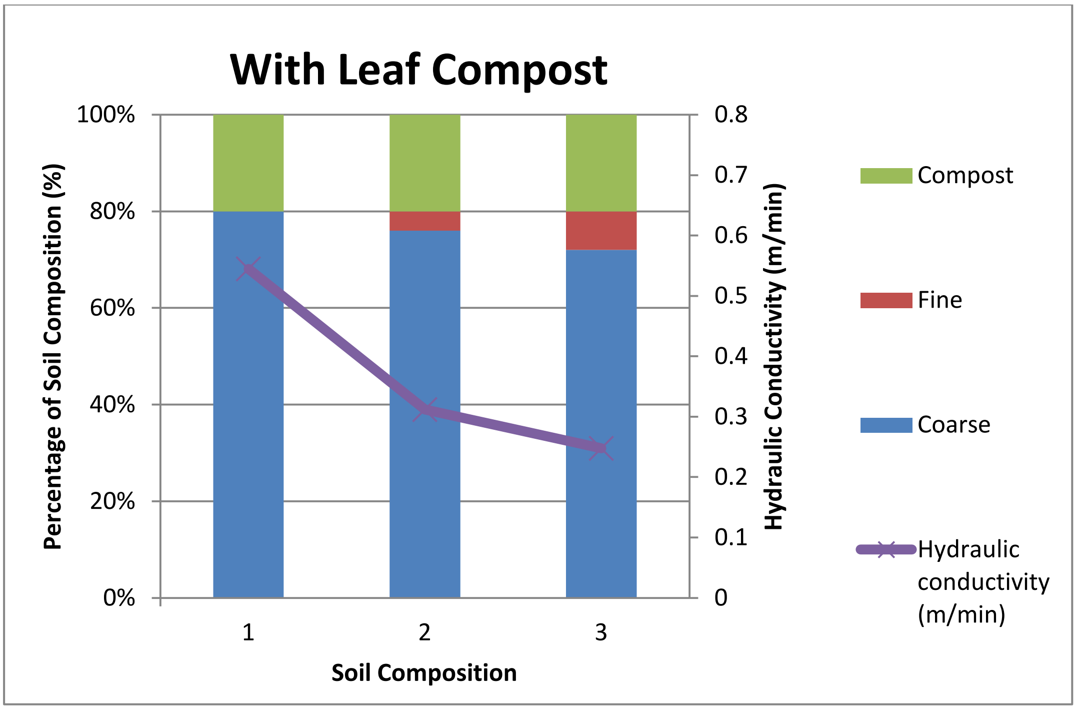


Figure 13: Hydraulic Conductivity of Engineered Soil Media with Leaf Compost

4.2.3 Percentage of water removal based on different engineered soil composition

Another parameter that is observed in this experiment is the water removal efficiency of the engineered soil, which is represented in Figure 14 and 15. From the graphs, it can be seen that the efficiency of water removal is greater with the addition of leaf compost. Without leaf compost, the water removal can go as high as 90.2%, however, the test with the leaf compost yields the water removal efficiency of approximately 94.2%. The difference might due to the difference in hydraulic properties between the sand and the leaf compost. Leaf compost is an organic material. Therefore, it might possess different properties that it enables the water to be removed in a higher volume as compared to the sand alone.

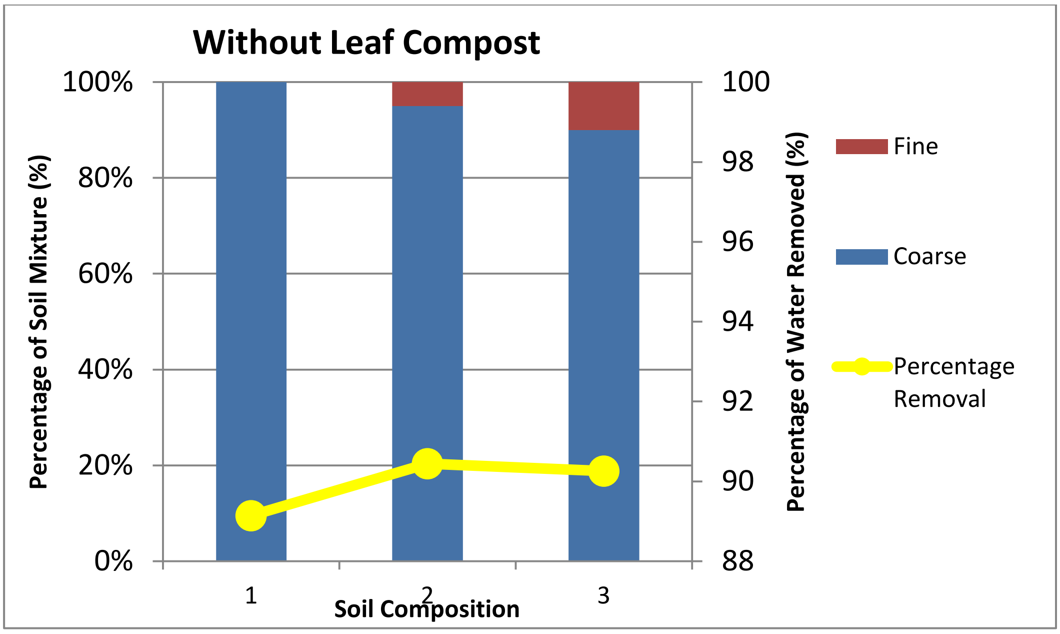


Figure 14: Percentage of Water Removed by Engineered Soil without Leaf Compost

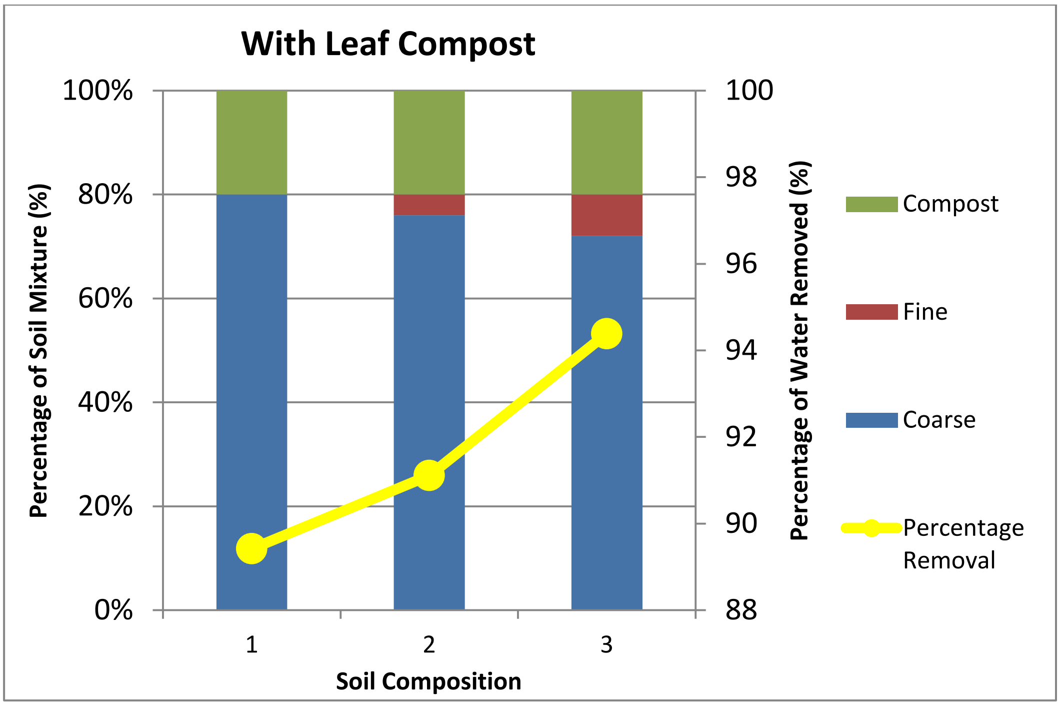


Figure 15: Percentage of Water Removed by Engineered Soil with Leaf Compost

CHAPTER 5: CONCLUSION AND RECOMMENDATION

As a conclusion, the hydraulic conductivity, flow of water and water removal efficiency are really affected by the soil media itself. Addition of fine sand decreases the flow and hydraulic conductivity of water, while addition of leaf compost causing the amount of water removed from the engineered soil composition to increase, thus increases its efficiency.

Rain garden offers great benefits to human and environments. Not only it contributes to better environments and surroundings, but it is also maintainable and can be implemented in most of the spaces as it did not require a larger area.

In the study there are a few limitations while conducting the experiment such as the usage of mulch layer, varieties of composts, and time as well as resources. Therefore, there are certain recommendations that can be implemented in making a further study and research within this area. Some of the recommendations include:

i. To do various sets of tests to get more data

   In this study, each samples were only tested three times, thus less distribution of data can be obtained. In future studies, more tests for each sample should be conducted as to reduce the percentage of error and as to yield a better and promising result with higher degree of confidence.

ii. To analyse the data by using ANOVA (analysis of variance) and MANOVA (multi analysis of variance).

   Statistical analysis is importance in determining whether the outputs received by doing some tests are acceptable, inter-correlated or represents the opposite. In this study, there might be some correlations between the parameters, and statistical analysis such as multi analysis of variance (MANOVA) can be done to prove that the correlation exists between the parameters, and hence can be used to support the hypothesis.

iii. To find another suitable compost materials

As can be seen from the output of the study, a random dry leaves are used as the leaf compost. In future studies, another organic material should be tested in order to find the one that have a better performance than the leaf. Another compost material that could be tested includes vegetation wastes as this might be very economical and environmental friendly.

iv. To include mulch layer and vegetation.

Mulch layer and vegetation can be included in future studies, as to represents the real outside situation. The inclusion of mulch layer might give a positive influence to the performance of the rain garden.

REFERENCES

Allen P. Davis (2007) , “*Bioretention and Rain Garden*”. [Public Presentation]

Allen P. Davis, P.E.,F. ASCE (2008). “*Field Performance of Bioretention: Hydrological Impacts*.”Journal of Hydrologic Engineering, *Vol. 13, No. 2.*

Amoozegar, A., and G. V. Wilson. (1999). “*Methods for Measuring Hydraulic Conductivity and Drainable Porosity*”. p. 1149-1205. In R. W. Skaggs and J. van Schilfgaarde (ed.) *“Agricultural Drainage.* Monograph No. 38, *ASA-CSSA-SSSA*, Madison, WI.

Asleson, Brooke C., Rebecca S. Nestingen, John S. Gulliver, Raymond M. Hozalski, and John L. Nieber, 2009.*Performance Assessment of Rain Gardens. Journal of the American Water Resources Association (JAWRA)* 45(4):1019-1031. DOI: 10.1111⁄j.1752-1688.2009.00344.x

B.P Mohanty, R.S. Kanwar and C.J Everts (1994), *Comparison of Saturated Hydraulic Conductivity Measurement Methods for a Glacial-Till Soil*.” Journal of Soil Sciebce Society of America Journal, *Volume 58, No. 3.*

Clapp, R. B. and G. M Hornberger (1978), Empirical Equations for Some Soil Hydraulic Properties, *Water Resour. Res. 14 (4,)* 601-604, doi:10.1029/WR014i004p00601.

Department of Irrigation and Drainage, DID (2012). “Urban Stormwater Management Manual for Malaysia (MSMA) 2nd Edition.

Hart, D.J., and Hammon, W.S., III, 2002. Measurement of hydraulic conductivity and specific storage using the shipboard Manheim squeezer. *In*Salisbury, M.H., Shinohara, M., Richter, C., et al., *Proc. ODP, Init. Repts.,* 195: College Station, TX (Ocean Drilling Program), 1–15.doi:10.2973/odp.proc.ir.195.106.2002

Donahue, Roy; Miller, Raymond; and Shickluna, John.. (1983). *Soils: An Introduction to Soils and Plant Growth*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Fetter, C. W. (1994). *Applied Hydrogeology*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, Inc.

Freeze, R.A., and J.A Cherry, 1979, *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604p.

Holt, C. L. R., Jr. (1965). *Geology and Water Resources of Portage County, Wisconsin*. [Geologic Survey Water-Supply Paper 1796 and Plate 1]. Washington, DC: US Government Printing Office.

Hydraulic Conductivity, adapted from *http://web.ead.anl.gov/resrad/datacoll/conuct.htm*

Le Coustumer, S., et al., *The influence of Design Parameters on Clogging of Stormwater Biofilters: A Large-Scale Column Study, Water Research* (2012), doi: 10.1016/j.watres.2012.01.026

Li, H., Sharkey, L. J., Hunt, W. F., and Davis, A. P. _2009_. "Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland." *J. Hydrol. Eng.*, 14_4_, 407–415.

Loxnachar, Thomas E.; Brown, Kirk W.; Cooper, Terence H.; Milford, Murray H. (1999). *Sustaining Our Soils and Society.* American Geological Institute, Soil Science Society of America, USDA Natural Resource Conservation Service publication.

Robert A. Brown and William F. Hunt III, P.E., M.ASCE (2010) "*Impacts of Construction Activity on Bioretention Performance.*" Journal of Hydrologic Engineering, *Vol. 15, No. 6.*

Robert A. Brown and William F. Hunt III, P.E., M.ASCE (2010). "*Impacts of Media Depth on Effluent Water Quality and Hydrologic Performance of Undersized Bioretention Cells.*" Journal of Irrigation and Drainage Engineering, Vol. 137, No. 3.

State University of New York college of Environmental Science and Forestry (SUNY-ESF) 2012, Image of Rain Garden [Online image], Retrieved 26th December 2012 from http://www.esf.edu/sustainability/action/raingarden.htm.

T.M. Bright, J.M Hathaway, W.F. Hunt III, et. al (2011). "*Impact of Storm-Water Runoff on Clogging and Fecal Bacteria Reduction in Sand Column*." Journal of environmental Engineering*, Vol. 136, No. 12*.

Russell G. Shepherd, (1990), *Correlations of Permeability and Grain Size*, Journal of Department of Geological Sceince, University of Kentucky, *Vol. 27, No. 5.*

S. Le Coustumer, et.al., (2007). "*Hydraulic Performance of Biofilters for Stormwater Management: First Lessons from Both Laboratory and Field Studies." Water Science and Technology,* Vol 56 No 10 pp 93-100, *IWA Publishing 2007.*

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman, 2001. *Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales*. Environmental Management 28(2):255-266.

Whiting D. (2011). Soil Textural Triangle [Online Image] Retrieved 26 December, 2012 from *http://www.cmg.colostate.edu/gardennotes/214.html*

APPENDICES

Table 7: The Inflow and Outflow Volume of Water with Different Composition of Engineered Soil

					Volume of water in (ml)			Volume of water out (ml)		
	Case	**Coarse**	**Fine**	**Compost**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Without Composts	100% Coarse Sand	100	0	0	1471.67	1601.67	1537.50	1360.00	1400.00	1350.00
	95% Coarse Sand + 5% Fine Sand	95	5	0	1522.50	1515.00	1485.00	1360.00	1390.00	1360.00
	90% Coarse Sand + 10% Fine Sand	90	10	0	1505.00	1405.83	1375.17	1200.00	1250.00	1260.00
With Composts	100% Coarse Sand	80	0	20	1505.00	1505.00	1519.17	1230.00	1360.00	1460.00
	95% Coarse Sand + 5% Fine Sand	76	4	20	1475.00	1534.17	1556.67	1360.00	1380.00	1420.00
	90% Coarse Sand + 10% Fine Sand	72	8	20	1475.00	1469.58	1444.00	1340.00	1390.00	1360.00

Table 8: The Percentage Water Removal and Amount of Water Retained in Different Engineered Soil Composition

					Percentage water removal (%)			**Water retained (ml)**		
	Case	**Coarse**	**Fine**	**Compost**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Without Composts	100% Coarse Sand	100	0	0	92.41	87.41	87.80	111.67	201.67	187.50
	95% Coarse Sand + 5% Fine Sand	95	5	0	89.33	91.75	91.58	162.50	125.00	125.00
	90% Coarse Sand + 10% Fine Sand	90	10	0	79.73	88.92	91.63	305.00	155.83	115.17
With Composts	100% Coarse Sand	80	0	20	81.73	90.37	96.11	275.00	145.00	59.17
	95% Coarse Sand + 5% Fine Sand	76	4	20	92.20	89.95	91.22	115.00	154.17	136.67
	90% Coarse Sand + 10% Fine Sand	72	8	20	90.85	94.58	94.18	135.00	79.58	84.00

Table 9: Flow of Water and Hydraulic Conductivity based on Different Engineered Soil Composition

					Flow of water (m^3/min)			Hydraulic conductivity (m/min)		
	Case	**Coarse**	**Fine**	**Compost**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Without Composts	100% Coarse Sand	100	0	0	0.001632	0.001533	0.001551	0.6280	0.7844	0.5921
	95% Coarse Sand + 5% Fine Sand	95	5	0	0.001556	0.001662	0.001473	0.3796	0.6101	0.3939
	90% Coarse Sand + 10% Fine Sand	90	10	0	0.001253	0.001355	0.001116	0.2525	0.3305	0.3418
With Composts	100% Coarse Sand	80	0	20	0.001608	0.001608	0.001503	0.4894	0.5953	0.5495
	95% Coarse Sand + 5% Fine Sand	76	4	20	0.001445	0.001084	0.001114	0.3212	0.3227	0.2915
	90% Coarse Sand + 10% Fine Sand	72	8	20	0.000480	0.001121	0.001219	0.3495	0.2694	0.2258

Table 10: Determination of the Height and Diameter of the Sand Column

Prototype discharge : 8486.868 cm^3/s

Time : 15 minutes

Model: Prototype Ratio (1:n)	Model discharge (m^3/s)	Model volume (m^3)	Diameter / Height of the Column (m)							
			0.0640	**0.0675**	**0.0700**	**0.0725**	**0.0740**	**0.0775**	**0.0800**	**0.0825**
			Height of Column (m)							
5	0.000151818	0.136636	42.473	38.183	35.504	33.098	31.770	28.965	27.183	25.560
10	0.000026838	0.024154	7.508	6.750	6.276	5.851	5.616	5.120	4.805	4.518
15	0.000009739	0.008765	2.725	2.449	2.278	2.123	2.038	1.858	1.744	1.640
20	0.000004744	0.004270	1.327	1.193	1.110	1.034	0.993	0.905	0.849	0.799
25	0.000002716	0.002444	0.760	0.683	0.635	0.592	**0.568**	0.518	0.486	0.457
30	0.000001722	0.001549	0.482	0.433	0.403	0.375	0.360	0.328	0.308	0.290
35	0.000001171	0.001054	0.328	0.295	0.274	0.255	0.245	0.223	0.210	0.197
40	0.000000839	0.000755	0.235	0.211	0.196	0.183	0.176	0.160	0.150	0.141
45	0.000000625	0.000562	0.175	0.157	0.146	0.136	0.131	0.119	0.112	0.105
50	0.000000480	0.000432	0.134	0.121	0.112	0.105	0.100	0.092	0.086	0.081