EFFECTIVENESS OF RAIN GARDEN FACILITIES IN NITROGEN AND PHOSPHORUS REMOVAL THROUGH BIORETENTION COLUMNS

by

Vivien Tening John

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

Supervisor

Husna binti Takaijudin

MAY 2012

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Effectiveness Of Rain Garden Facilities In Nitrogen And Phosphorus Removal Through Bioretention Columns

by

Vivien Tening John

A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

Approved by,

____

(HUSNA BT TAKAIJUDDIN)

UNIVERISITI TEKNOLOGI PETRONAS

TRONOH, PERAK

August 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.

____

VIVIEN TENING JOHN

ABSTRACT

Bioretention or rain gardens is widely used as stormwater best management practice (BMP) and have been long implemented as a part of low impact development (LID) because of its ability to remove nutrients from stormwater runoff. A major concern in water quality problem is eutrophication which is caused by the nutrients, namely nitrogen and phosphorus. The objective of this study is to examine and evaluate the efficiency of rain garden in nitrogen and phosphorus removal by varying the types of the mulch layers in a bioretention column and further select the best to be used in rain garden design. Three (3) bioretention columns with size of 46mm in diameter and a height of 400mm were is used for this study where the inflow and outflow runoff will be collected and analyzed to measure the nutrient concentration. Filter media at the depth of 200mm consisted of river sand with soil mix of 80% fine sand and 20% coarse sand were used. Three different types of mulch layer wood chip, tea waste and coconut fibres were applied at the top of filter media at a height of 50mm. Phosphorus concentration in the bioretention column was reduced by 73.9% using woodchip, 23.1% using tea leaves and 50% using coconut fibres. Lower removal efficiency was seen for nitrogen where 24.4% using woodchip, 0% for tea leaves and 4.4% using coconut fibre. Woodchip was seen to be favourable compared to the other two mulch layer due to its removal efficiency in removing both phosphorus and nitrogen from the incoming stormwater runoff. The absorption capacity was seen as the main factor that affects the removal rate. Further research can be conducted by adding a vegetative layer inside the bioretention column or by changing the filter media depth and configuration to further enchance the removal rate of pollutant from the stormwater runoff.

ACKNOWLEDGEMENT

First and foremost, I would like to lift up praises to God for His unconditional blessing throughout the period of my project.

My deepest appreciation and heartfelt gratitude is extended to my supervisor, Madam Husna binti Takaijudin for being a wonderful guidance and supporter throughout the whole process of completing this final year project. Without her constant supervision and encouragement, I may not have been able to complete this project successfully.

Apart from that, I am very thankful towards the lab technicians who have helped me setup my laboratory equipment and provide the needed experiment materials in the laboratory. Thank you Mr. Zaa'ba, Mr. Anuar Miss Imma, and Miss Yusmawati for providing me the assistance required to do the laboratory work.

Besides that, I would like to thank my fellow friends, especially Aishah, Shahraziman, Izatul, Amynurashid and Yu Yang Long who have been accommodating and cooperative whenever I am in need of ideas, opinion and help throughout the process of completing this project.

Lastly, I would acknowledge my family for keeping me motivated and supporting me financially throughout my studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Urban stormwater runoff that flows through road surfaces, parking areas, vehicle and buildings carries a broad range of pollutants that are transported to rivers and other water bodies which effects the environment and ecology negatively. Effects on receiving waters include oxygen depletion, eutrophication, species stress, and toxicity (Davis *et al*., 2001).

The bioretention systems, also referred to as "raingardens," "bioinfiltration," and other names, has rapidly become one of the most versatile and widely used stormwater best management practices (BMPs) throughout the United States and many parts of the world (Davis *et al*., 2009) and is an urban stormwater BMP developed to reduce runoff quantity and improve quality in a natural, aesthetically pleasing manner (Hsieh and Davis, 2005). A typical bioretention garden cross section can been seen in Figure 1.0. Bioretention systems are one option for direct storm water infiltration (Morzaria-Luna *et al.*, 2004). It is a component of the low impact development (LID) concept, which employs microscale stormwater retention and infiltration tracts throughout developed areas (Hsieh and Davis, 2005).

Bioretention systems are designed to remove both dissolved pollutants and particulate matter from stormwater runoff (Read *et al.*, 2008). Another advantage of bioretention systems is their ability to significantly reduce stormwater volumes through infiltration and evapotranspiration (Roy-Poirier and Filion, 2010). Continued research will allow greater refinement of bioretention design criteria and encourage wider use of this technology to address many urban runoff challenges (Davis *et al*., 2009).

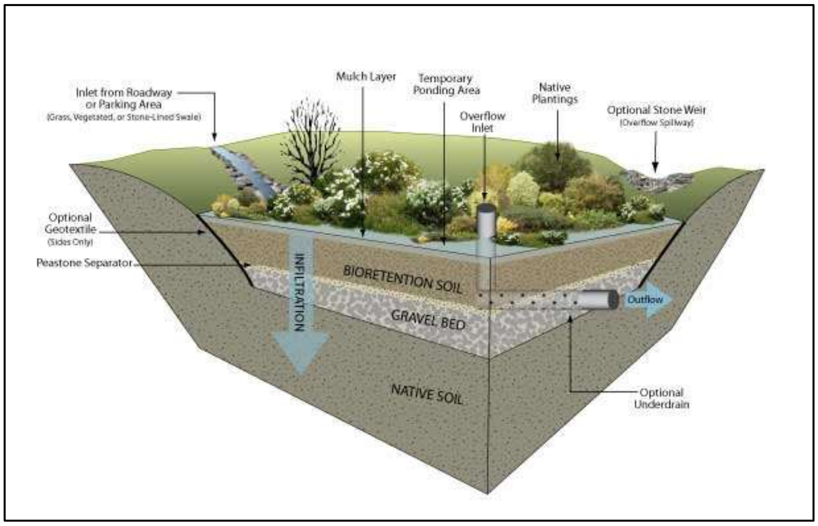

Figure 1.0 Typical Bioretention Garden Cross Section (Douglas County Environmental Services, 2012)

1.2 Problem Statement

Nitrogen and phosphorus, the primary nutrients implicated in eutrophication, enter water bodies via a variety of pathways (Davis *et al*., 2006). Eutrophication causes algae growth on water surfaces which leads to oxygen depletion and high turbidity levels in aquatic ecosystem. The presence of nitrogen in stormwater runoff may come from fertilizers, atmospheric deposition and nutrient cycling while presence of phosphorus may also come from fertilizers, atmospheric deposition and other sources such as soil erosion, animal waste and detergents.

Currently, bioretention systems also known as biofilters or rain gardens, are used widely as an effort to mitigate effects that is harming the environment. Bioretention has been demonstrated to be promisingly efficient in the removal of phosphorus and organic nitrogen from infiltrating runoff (Davis *et al*., 2006).

Other concern regarding the effectiveness of bioretention gardens according to Hatt *et al*. (2009) was the lack of performance data at field scale when conducting the investigation of the performance of the system. According to Hsieh and Davis (2005), the configuration of the media in the bioretention media can also influence the bioretention performance as it depends on the infiltration rate of the runoff through the media.

1.3 Objectives

The objective of this project study was divided into two which are:

i. To examine and evaluate the effectiveness of the mulch layer in removing the nutrient pollutants based on current bioretention design in a laboratory setting
ii. To select the appropriate mulch layer for the bioretention system

1.4 Scope of Study

i. Setup of the impermeable bioretention columns
ii. Measure nutrient concentration in stormwater runoff in a laboratory testing
iii. Examine efficiency of bioretention media in removing nutrient from stormwater runoff
iv. Determine mulch variation that removes nutrient efficiently

1.5 Significance of Study

Results obtained from this study will be evidence that bioretention media in rain garden is able to remove nutrients from the stormwater runoff. The current study conducted is to provide nutrient removal of nitrogen and phosphorus information for bioretention under laboratory setting.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This project is conducted to evaluate the relationship between the mulch layer and pollutant concentration removal in a rain garden. Different mulch layer will be used in the bioretention column to get the correlation between these two parameters. Researches have been conducted in the past to investigate the efficiency of bioretention in removing pollutant from the stormwater runoff. This literature review will include past research works regarding pollutant removal using bioretention, bioretention design and mulch layer as a bioretention media.

2.2 Low Impact Development (LID) Stormwater Management

Low-impact development (LID), such as bioretention, is increasingly being used to manage storm-water runoff and mitigate the effects of urban development (Palhegyi, 2010). LID controls stormwater at the source by creating a hyrdrological functional landscape that mimics natural watershed hydrology (Liaw *et al.*, 2000). Site design techniques that infiltrate, evaporate, store and discharge runoff is applied to mimic the natural site hydrology. The purpose of the site design is to preserve as much of the site in an undisturbed condition, and where disturbance is necessary, reduce the impact to the soils, vegetation, and aquatic system on the site (Dietz, 2007). Bioretention is a mulch/soil/plant-based stormwater best management practice (BMP) that is an integral part of the LID philosophy (Davis *et al.*, 2006)

2.3 Bioretention Gardens

Bioretention is a vegetated infiltration practice for managing stormwater runoff from developed areas (Hsieh *et al.*, 2007b). Bioretention systems filter polluted stormwater through biologically active plants and soils thereby removing contaminants from the water (Trowsdale and Simcock, 2010). It has recently become identified as a preferred site practice for green building design and leadership in energy and environmental design (LEED) certification (Davis *et al*., 2009).

2.3.1 Bioretention Garden Design

Engineering manuals for the design of bioretention gardens commonly originate from United States of America (USA). However, there have been an extensive bioretention documents published in other countries in recent years. In a typical configuration, bioretention includes a layer of approximately 75 to 100 cm of an engineered soil/sand/organic media, supporting a mixed vegetated layer (Hsieh *et al*., 2007b). The soil typically has a high sand content to provide rapid infiltration but with low levels of silt and clay to promote attenuation of pollutants during the infiltration (Davis *et al*., 2001). A 5 to 8 cm shredded hardwood mulch layer is added on the surface to maintain soil moisture and filter incoming sediment (Davis *et al*., 2006). Figure 2.1 shows a diagram of the common bioretention design layers

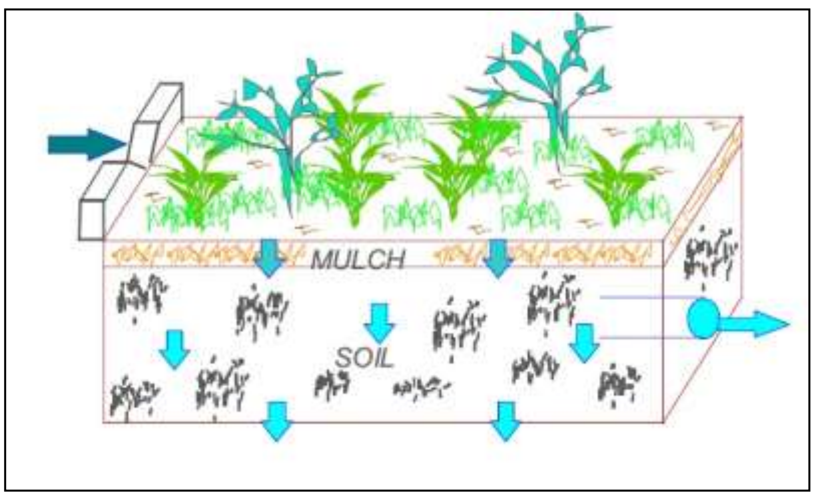

Figure 2.1 Diagram of bioretention facility (Davis *et al.*, 2009)

2.3.2 Pollutant Removal

Several researches have been conducted to measure the pollutant removal capacity of a bioretention cell in laboratory setting and at field scale.

Blecken *et al.* (2010) was able to show the ability of the bioretention filter media in removing nutrient loads from the stormwater runoff in a laboratory setting. Bioretention gardens have shown impressive pollutant removal through laboratory studies by Davis *et al*. (2001, 2006) where reduction in concentration of copper, lead, and zinc (>92%, 2001), phosphorus (70 to 85%, 2006) and ammonium (60 to 80%, 2001). Table 1 display the removal efficiency for pollutant of a 6 hours bioretention column test conducted by Hsieh and Davis (2005).

Table 1 Characteristic and Results of 6h Bioretention Column Test (Hsieh and Davis, 2005)

Experiment number	Mass ratio (%)			Experimental set	Infiltration rate (cm/min)	Removal efficiency (%)					
	Mulch	Soil	Sand			TSS	O/G	Lead	TP	Nitrate	Ammonium
1[a]	0	0	100(I)	A,B	0.84±0.01	>96	>96	>98	85±1.5	11±16.7	8±3.4
2[a]	0	0	100(II)	A	8.15±0.18	>96	>96	96±0.7	10±3.1	1±0.7	15±0.8
3[a]	2	93(I)	5(I)	A,B	0.28±0.04	29±2.9	>96	>98	47±3.4	1±0.6	6±2.2
4[a]	2	93(II)	5(I)	A	0.95±0.01	88±0.9	>96	>98	41±4.5	14±2.2	24±0.8
5[a]	2	93(III)	5(II)	A	0.40±0.02	91±0.3	>96	>98	48±4.0	8±0.7	16±1.1
6[a]	91	0	9(I)	A	0.28±0.01	86±1.0	>96	75±2.0	4±4.5	43±3.2	16±1.9
7[a]	0	0	100(I)	—	0.81±0.02	—[e]	>96	66±7.0	84±1.3	13±6.4	5±1.7
8	3	0	97(I)	B	0.77±0.01	>96	>96	>98	61±4.5	9±0.4	9±2.0
9[b]	2	21(I)	77(I)	C-1	0.32±0.02	66±2.5	>96	>98	47±4.6	3±0.8	2±1.1
10[b]	8	26(I)	66(I)	C-1	0.31±0.01	94±0.6	>96	>98	50±3.8	4±0.7	7±1.0
11[b]	6	32(I)	62(I)	C-1	0.30±0.01	93±0.9	>96	>98	39±4.0	4±0.5	7±0.8
12[b]	0	24(I)	76(I)	C-1	0.30±0.01	93±0.5	>96	>98	39±3.5	2±0.5	5±2.2
13[c]	3	43(I)	54(I)	B,C-2	0.48±0.02	>96	>96	>98	83±1.4	13±59	26±2.6
14[c]	3	24(I)	73(I)	B,C-2	0.66±0.01	>96	>96	>98	57±2.7	24±2.9	17±2.1
15[c]	11	19(I)	70(I)	B,C-2	0.71±0.02	>96	>96	>98	54±2.7	27±1.1	20±1.2
16[d]	2	17(II)	81(II)	D	5.40±0.15	>96	>96	97±0.2	24±3.8	6±1.5	11±0.6
17[d]	2	72(III)	26(II)	D	1.15±0.02	92±0.3	>96	>98	72±0.8	9±0.9	19±0.6
18[d]	2	49(III)	49(II)	D	1.93±0.01	93±0.3	>96	>98	74±0.9	8±0.5	20±0.5

[a]Native media.
[b]Column with upper Soil I layer.
[c]Column with synthetic media I (mixture of Soil I/mulch/sand I).
[d]Column with upper Soil II or Soil III layer.
[e]Influent without suspended solids; (I),(II),(III): Different types of sands and soils—see Table 2.

From this study conducted by Hsieh and Davis (2005) shown in Table 1, it was found that the bioretention columns and on-site facilities were excellent in removing Oil and Grease (O/G) and lead (Pb). For Total Suspended Solid (TSS), it shows good removal in the column studies compared to field studies. However, removal of nitrate and ammonium was found to be ineffective during the column studies.

At a field scale study conducted by Hunt *et al.* (2006), removal rates of nitrate-nitrogen varied between 75% and 13% whereas zinc, copper and lead removal rates were 98%, 99% and 81% respectively from the three fields in North Carolina. These removal rates were high as the outflow volume from the bioretention was decreased where the ratio of volume entering and leaving the cell were 0.07 in winter and 0.54 during summer.

Another study by DeBusk and Wynn (2011) on an existing bioretention cell at a parking lot showed that the bioretention cell achieved cumulative mass removal of greater than 99% for suspended sediment, total nitrogen and total phosphorus which is a higher result than results reported by other studies. This was achieved as the bioretention cell was deeper than the standard bioretention depth (0.6 to 1.2 m), which may have caused the high volume reduction and high pollutant load reduction. It was mentioned by DeBusk and Wynn (2011), that the bioretention cell could be further improved by increasing the length to with ratio of the bioretention cell design and higher density shrubs are planted at downstream of the inflow.

Based on the studies by Hsieh and Davis (2005) and Debusk and Wynn (2011), it shows that the selection of filter media plays an important role in removing pollutants especially nitrogen and phosphorus. From a study conducted by Hsieh et al. (2007a) on phosphorus removal, the column media with high hydraulic conductivity overlying one with low hydraulic conductivity was more efficient in total phosphorus removal that ranged from 67% to >98% compared to the column media with low hydraulic conductivity overlying high hydraulic conductivity as less permeable soil layer at the bottom of the column increases the retention time between dissolved phosphorus and media.

Hsieh *et al.* (2007b) also conducted a study on nitrogen removal whereby two different columns with different filtration media configuration gave different removal rate where the first column was designed for high-rate infiltration and second column was designed for runoff retention. The second column proved greater net mineral nitrogen removal efficiency compared to the first column as water was held longer in the filtration media to allow nitrification and denitrification to occur.

2.3.3 Mulch Layer

Mulch layer is one of the main filtration media in the bioretention as it has its own advantages which lead to it being evaluated in this project. According to Debusk and Wynn (2011), the mulch layer acts as a media to promote plant growth, maintain the infiltration rate into the soil layer and reduce pollutant concentration. Davis *et al.* (2001) mentioned that a thin layer of wood mulch in the bioretention can help to avert erosion from occurring, avoid the soil layer from extreme drying and contribute to the stormwater treatment process.

Other than that, Hsieh and Davis (2005) found that the mulch layer acts as filter for the incoming TSS, prevents underlying media from clogging, maintains the soil during dry weather and provides nutrients for future vegetation.

Pine bark, tree fern, rice husk and wood fibres are a number of natural materials mentioned by Ray *et al*. (2006) that is used to remove dissolved pollutants from aqueous media as they are inexpensive compared to activated carbon and synthetic resin. From the research conducted by Ray *et al.* (2006), the common garden store variety hardwood mulch can be used to remove water soluble pollutants such as heavy metals and toxic organic compounds that are normally found in stormwater runoff.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This section describes the process and method of the research to obtain the result.

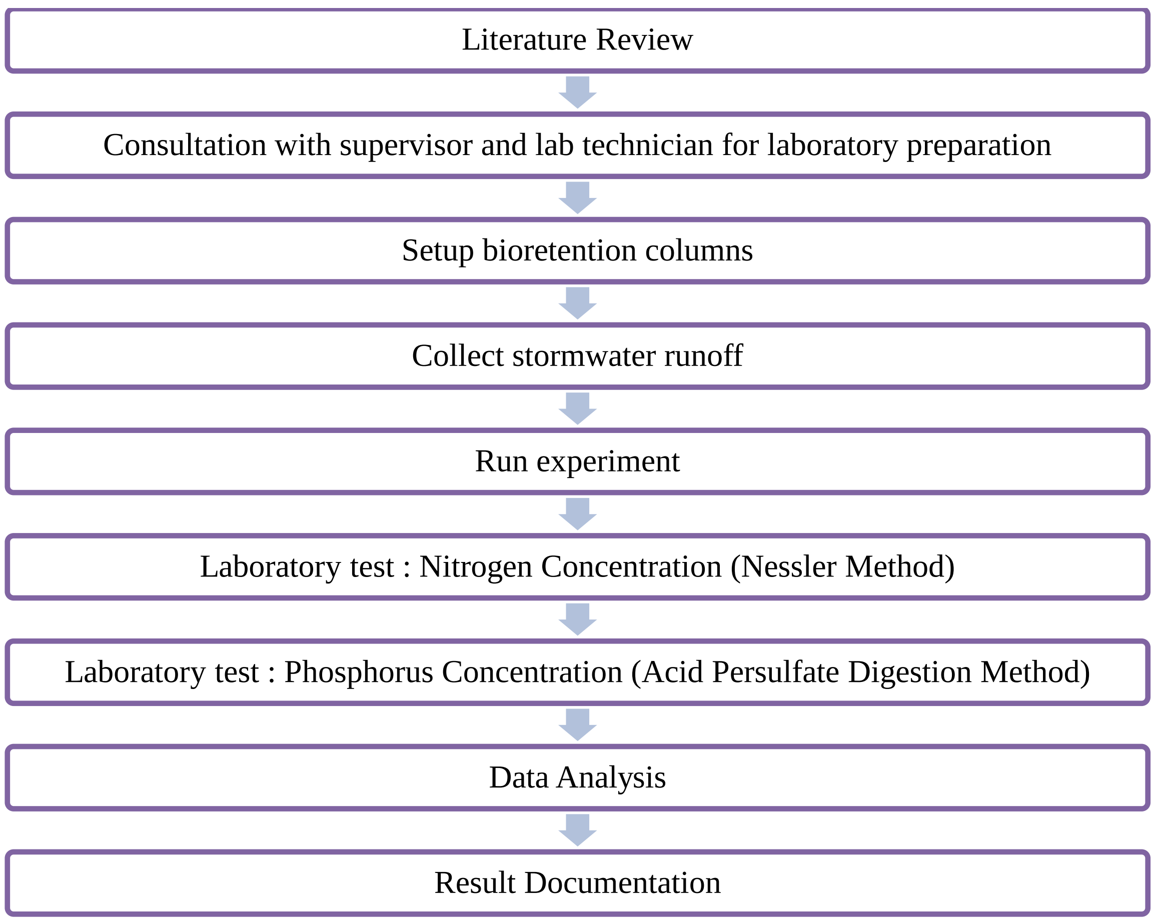

Figure 3.1 Research Process Flow

3.2 General Experimental Procedure and Materials

The bioretention columns were constructed to match the field condition as closely as possible for the study. Three different bioretention columns with different mulch layer was setup to compare the nitrogen and phosphorus removal efficiency.

Parameters observed during the laboratory experiment were:

i. Flow rate
ii. Nutrient concentration
iii. Type of mulch layer
iv. Depth of bioretention media

3.3 Pump Flow Rate

An analog pump with a maximum capacity of 100rpm was used to supply the stormwater runoff into the bioretention columns. An early run was conducted to test the maximum flow rate of the pump which was 42mL/min at 100rpm. The experiment was run in a 6 hour period where a volume of 9 litres stormwater runoff was pumped through the bioretention column. Therefore, a constant flow rate of 25mL/min was kept throughout the whole experiment.

Figure 3.2 Analog Pump

3.4 Collecting Stormwater Samples

To determine the nutrient content from stormwater**,** stormwater influent and effluent was collected for each bioretention column (i.e. two samples obtained from each bioretention column). Each sample was tested and analyzed for nitrogen and phosphorus concentration. Three runs were conducted for each bioretention column. The stormwater sample collected was from a drain outlet between a parking lot and an open field.

The nitrogen concentration was tested using the Nessler Method where the unit is in mg/L NH_3-N. Phosphorus concentration was tested using the Acid Persulfate Digestion Method where the unit is in mg/L PO_4^{3-}.

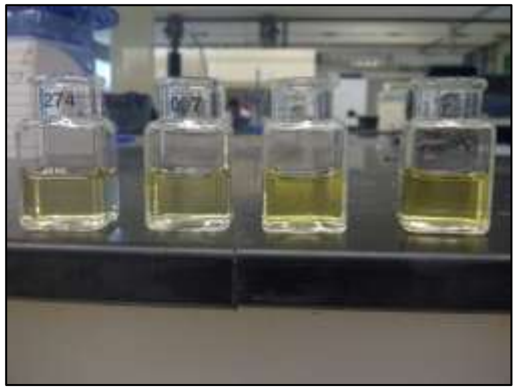

Figure 3.3 Nessler Square Sample Cell

Figure 3.4 Total Phosphorus Test N' Tube Vials

The experimental work analysis procedure to test nitrogen and phosphorus concentration can be referred to APPENDIX A and APPENDIX B.

3.5 Particle Size Distribution

This test was conducted to determine the distribution of the coarse and fine sand in the soil mix. Equipment for the test are:

i. Perforated-plate sieves (3.35mm, 2.00mm, 1.18mm, 600µm, 425µm, 310µm, 212µm, 150µm and 63µm)
ii. Mechanical sieve shaker
iii. Electronic balance

Figure 3.5 Mechanical Sieve Shaker

From the stock pile sand, approximately 1kg of sand sample was weighed and place in the mechanical sieve shaker shown in figure 3.5, for 5 to 10 minutes. After sieving, the sand retained in each sieve was weighed. The percentage of sand passing each sieve was calculated and a semi logarithmic graph of grain size versus percent passing was plotted.

3.6 Setup of Impermeable Bioretention Column

In figure 3.6 shows the cross section of the bioretention column design which was used for the laboratory study.

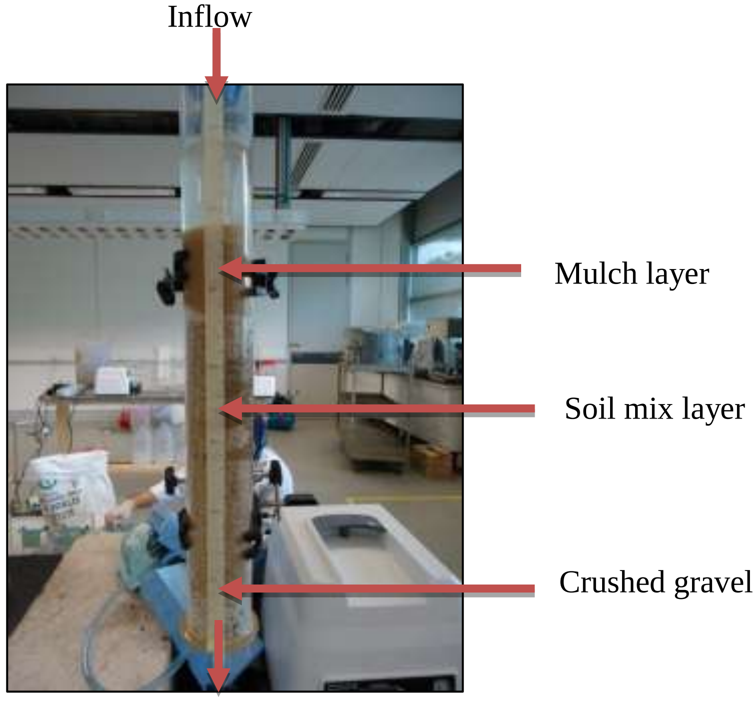

Figure 3.6 Bioretention Column Setup

The bioretention column consists of the mulch layer, soil mix layer and crushed gravel layer.

3.6.1 Filter Media Depth

The size of the bioretention column is 46mm in diameter with a depth of 400mm. The filter media depth was kept constant throughout the whole experiment. An illustration of the filter media depth is shown in figure 3.7.

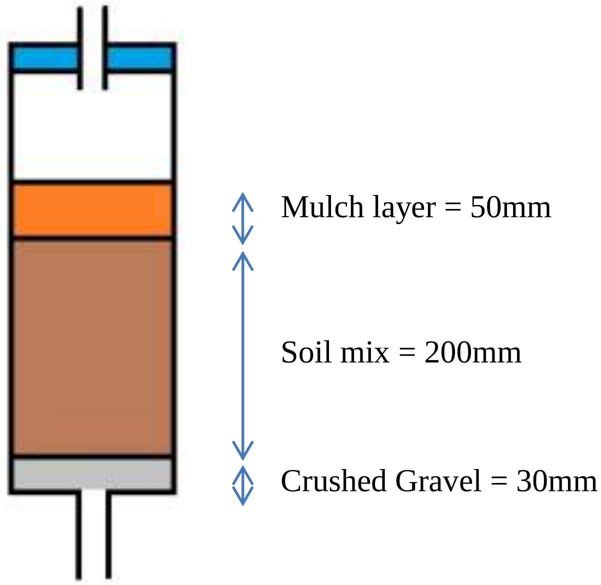

Figure 3.7 Filter Depth

The depth of the bioretention media is kept constant throughout the whole experiment.

3.6.2 Mulch Layer

As the main focus will be on the efficiency of the mulch layer in removing the concentration of nitrogen and phosphorus, there will be three different types of mulch that will be used which area:

i. Tea waste
ii. Wood chip/saw dust
iii. Coconut fibre

These materials are commonly used as organic mulch in landscaping, inexpensive and easily available. Organic mulch is preferred over inorganic mulch as it adds nutrients to the soil as it decomposes.

Before putting the mulch layer in the bioretention column, all of the materials were soaked in distilled water and air dried in an oven for 12 hours to remove any contaminants that may have been present. After drying and placed inside the bioretention column, it is once again flushed with 1 litre of distilled water to cleanse and ensure that water is able to transmit through the mulch layer and down into the underlying soil layer. The bioretention column is left for 24 hours before the laboratory experiment begins to allow water dry out completely from the bioretention column.

The full setup of the bioretention column for each mulch layer can be reffered to APPENDIX C.

3.7 Project Activity and Milestones

3.7.1 Final Year Project 1

Activity	**Weeks**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Topic Selection														
Research Work and Data Gathering														
Submission of Extended Proposal														
Proposal Defense														
Setup of Bioretention Column														
Bioretention Column testing														
Submission of Interim Draft Report														
Submission of Interim Report														

Key Legend:

Project Activity	
Key Milestones	

3.7.2 Final Year Project 2

Activity	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Research work and data gathering															
Run laboratory experiment and data analysis															
Submission of Progress Report															
Pre-EDX															
Submission of Draft Report															
Submission of Project Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation (hard bound)															

Key Legend:

Project Activity	
Key Milestones	

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Sieve Analysis

Materials selected for the soil mix layer is a mixture of coarse and fine sand. According to Biofiltration Filter Media Guidelines by the Facility of Advancing Water Biofiltration (2009), the particle size distribution of the soil mixture should range between 0.075mm to 4.75mm sieve for it to be a well-graded filter media.

Although particle size distribution of the sand is not the main focus of the project, however, it is important in terms of the hydraulic performance of the bioretention column. Therefore, sieve analysis was conducted to determine the particle size distribution of the selected coarse and fine sand. Table 2 and Table 3 show the result of the sieve analysis conducted and Figure 4.1 shows the particle size distribution graph of the sand.

<u>Coarse Sand</u>

Table 2 Coarse Sand Sieve Analysis Result

Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Total passing (%)
3.350	0	0	100
2.000	0	0	100
1.180	664.9	72.15	27.85
0.600	242.7	26.34	1.51
0.425	3.1	0.34	1.17
0.300	10.8	1.17	0.00
0.212	0	0	0
0.150	0	0	0
0.063	0	0	0
Pan	0	0	0
Total	921.5	100	

Fine Sand

Table 3 Fine Sand Sieve Analysis Result

Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Total passing (%)
1.180	8.8	0.86	99.14
0.600	986.4	96.72	2.42
0.425	6.5	0.64	1.78
0.300	10.8	1.06	0.73
0.212	7.3	0.72	0.01
0.150	0.1	0.01	0.00
0.063	0	0.00	0.00
Pan	0	0.00	0.00
Total	1019.9	100.00	

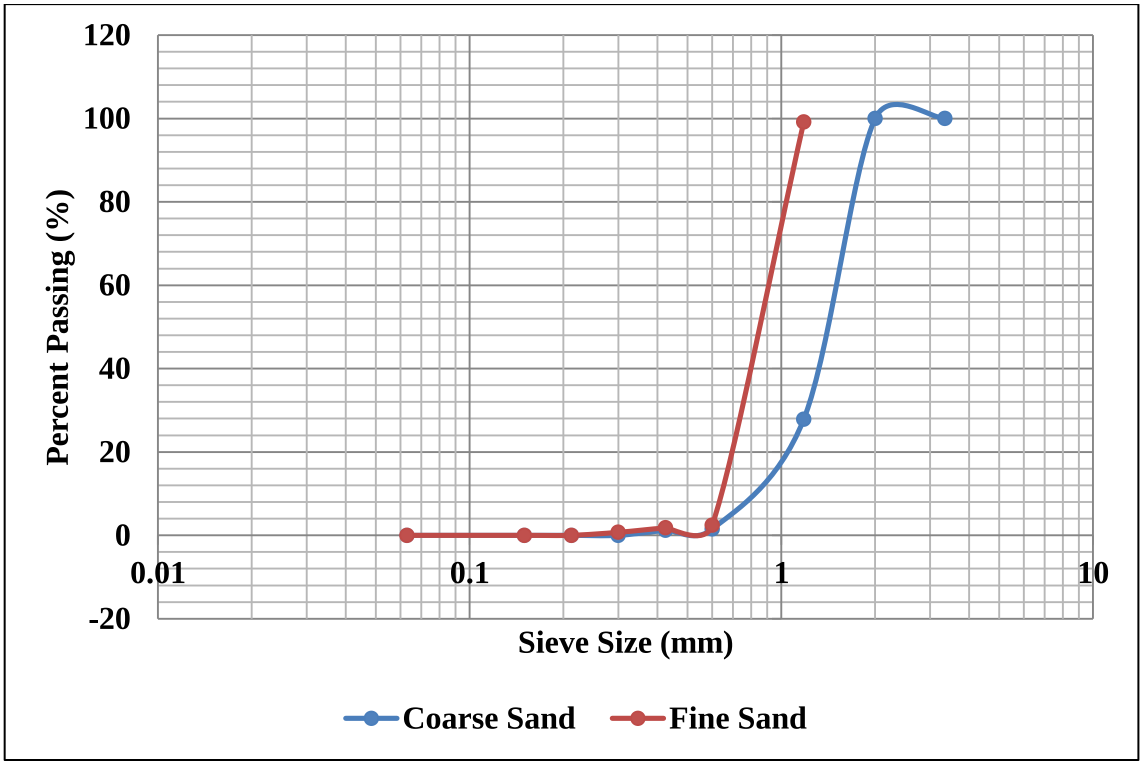

Figure 4.1 Particle Size Distribution of Coarse and Fine Sand

The ratio of the soil mix is 80% fine sand and 20% coarse sand. Table 4 shows the sieve analysis result of the soil mix and Figure 4.2 shows the particle size distribution for the mixture.

Table 4 Soil Mix Sieve Analysis Result

Size (mm)	Weight Retained (g)	% Retained	Total passing (%)
3.350	0	0.00	100.00
2.000	1.5	0.15	99.85
1.180	668.3	66.85	33.00
0.600	323.2	32.33	0.67
0.425	5.9	0.59	0.08
0.300	0.6	0.06	0.02
0.212	0.2	0.02	0.00
0.150	0	0.00	0.00
0.063	0	0.00	0.00
Pan	0	0.00	0.00
Total	1000	100	

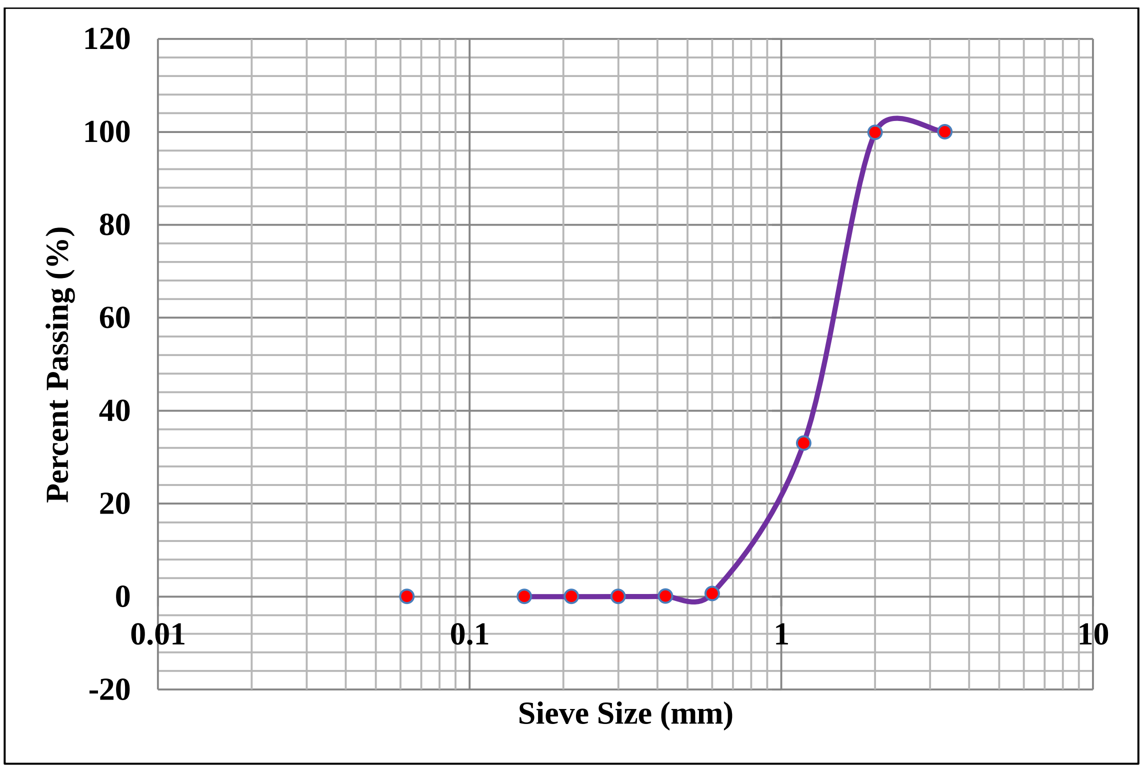

Figure 4.2 Soil Mix Particle Size Distribution

Figure 3.4 shows the soil mixture. The mass of the soil mix used for each bioretention column is calculated as below:

$$Volume = \pi r^2 h$$

$$= \pi\ (23)^2\ (200)$$

$$= 3.32 \times 10^5\ mm^3$$

Density of dry sand = $1602\ kg/m^3$

Mass of soil mix = Volume x Density

$$= 3.32 \times 10^{-4} \times 1602$$

$$= 0.53kg \text{ per column}$$

Figure 4.3 Soil Mix Sample

4.2 Nitrogen and Phosphorus Concentration

Table 5 Nitrogen and Phosphorus Concentration using Woodchip

	Influent	Effluent		
Run 1	Stormwater Runoff	Column 1	Column 2	Column 3
Nitrogen (mg/L)	0.55	0.46	0.44	0.47
Phosphorus (mg/L)	1.37	0.39	0.46	0.32
Run 2				
Nitrogen (mg/L)	0.75	0.62	0.57	0.56
Phosphorus (mg/L)	1.33	0.38	0.26	0.34
Run 3				
Nitrogen (mg/L)	0.44	0.32	0.26	0.29
Phosphorus (mg/L)	1.32	0.29	0.35	0.37

Table 6 Nitrogen and Phosphorus Concentration using Tea Leaves

	Influent		Effluent	
Run 1	Stormwater Runoff	Column 1	Column 2	Column 3
Nitrogen (mg/L)	0.55	0.76	0.77	0.69
Phosphorus (mg/L)	1.37	0.99	0.98	1.05
Run 2				
Nitrogen (mg/L)	0.75	1.04	1.07	0.87
Phosphorus (mg/L)	1.33	1.03	0.99	0.97
Run 3				
Nitrogen (mg/L)	0.44	0.63	0.87	0.86
Phosphorus (mg/L)	1.32	0.94	1.28	1.08

Table 7 Nitrogen and Phosphorus Concentration using Coconut Fibre

	Influent		Effluent	
Run 1	Stormwater Runoff	Column 1	Column 2	Column 3
Nitrogen (mg/L)	0.55	0.53	0.54	0.53
Phosphorus (mg/L)	1.37	0.68	0.66	0.71
Run 2				
Nitrogen (mg/L)	0.75	0.74	0.72	0.72
Phosphorus (mg/L)	1.33	0.61	0.59	0.61
Run 3				
Nitrogen (mg/L)	0.44	0.39	0.42	0.41
Phosphorus (mg/L)	1.32	0.72	0.74	0.71

All of the mulch layers were able to reduce the phosphorus concentration from the stormwater runoff as seen in Table 5, Table 6 and Table 7. The bioretention column with woodchip as the mulch layer reduce an average of 1.34mg/L to 0.35mg/L, a reduction of 73.9% of phosphorus concentration. From table 6, mulch layer that uses tea leaves reduces the phosphorus concentration an average from 3% to 29%. For the bioretention that uses the coconut fibre based on the results in Table 7, the phosphorus was reduced at an average of 44.8% to 54.5%.

In Table 6, for nitrogen removal, the tea leaves were unable to show any capability in reducing the nitrogen concentration from the stormwater runoff. Instead, the effluent increased from an average of 0.58mg/L to 0.84mg/L, a 44.8% increment of nitrogen concentration in the bioretention column. In a book written by Deborah L. Martin and Grace Gershuny, they mentioned that tea leaves is a good compost material as it is high in nitrogen content which acts as a natural fertilizer to the plant. The microorganism in the tea leaves absorbs the nitrogen and uses it to break down the organic matters and later release it back into the soil.

4.3 Removal Efficiency

Table 8 Removal Efficiency

	Woodchip			Tea leaves			Coconut Fibre		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Nitrogen (%)	16.4	22.7	34.1	0	0	0	3.6	2.7	6.8
Phosphorus (%)	70.1	75.2	74.2	26.3	24.8	16.7	50.4	54.9	45.5

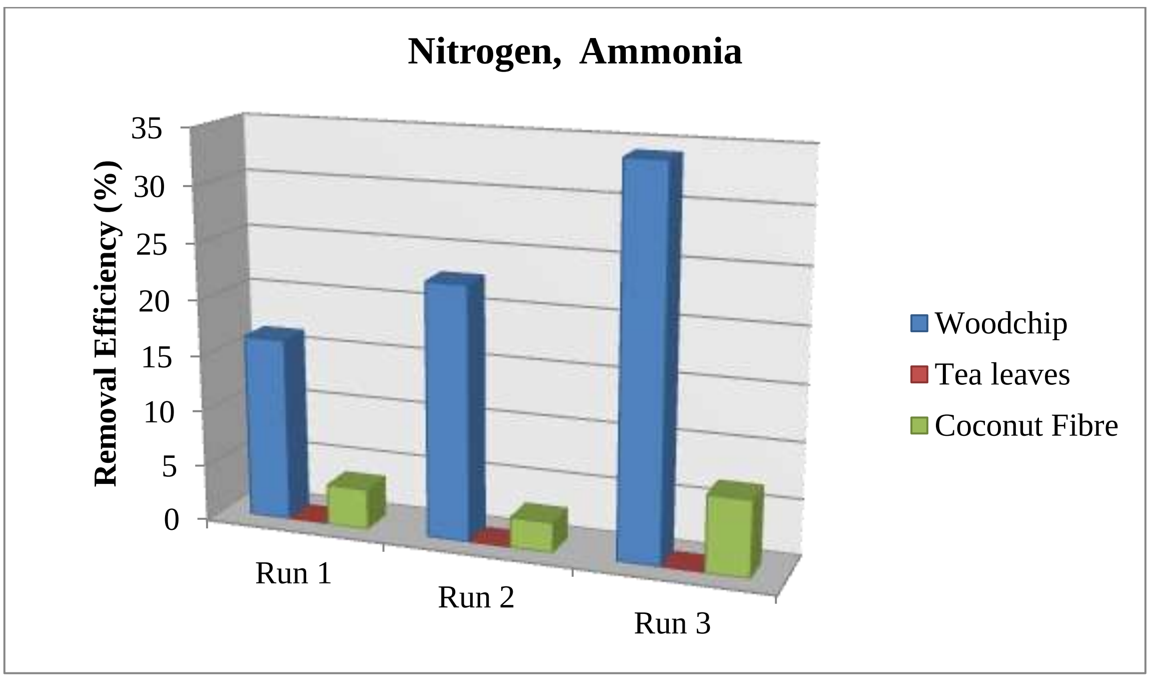

Figure 4.4 Removal Efficiency for Nitrogen from Bioretention Column

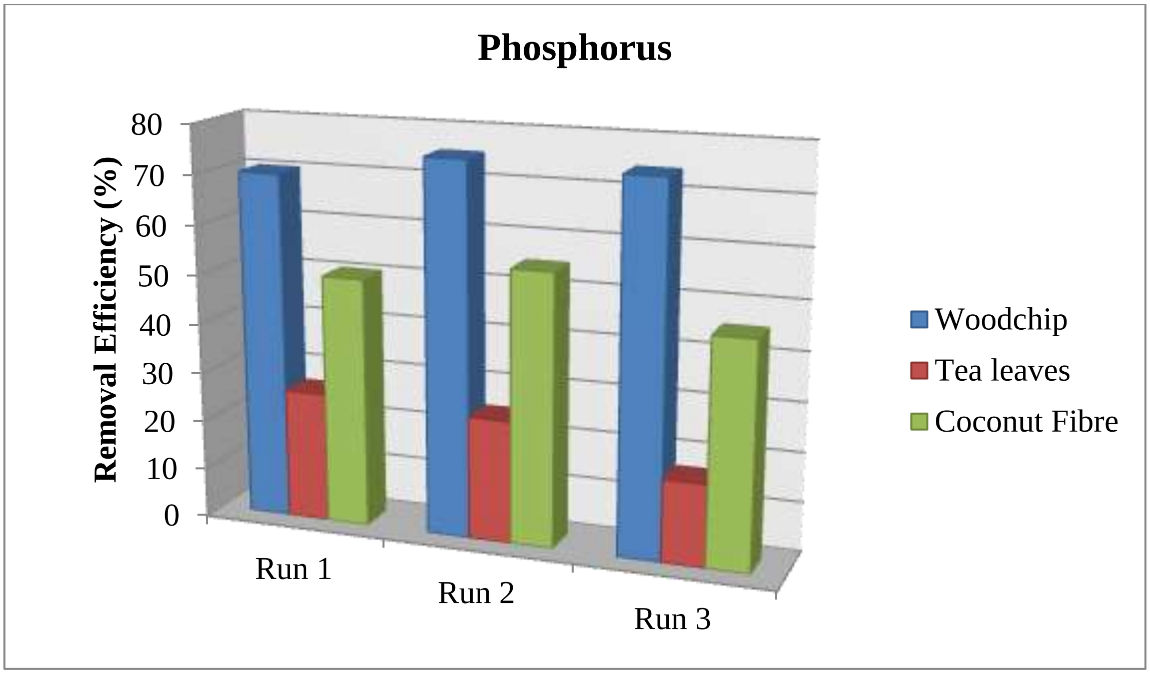

Figure 4.5 Removal Efficiency of Phosphorus in Bioretention Column

Comparing the three different mulch layers for nitrogen and phosphorus removal from Table 8, the woodchip has the best capability with an average efficiency of 24.4% for nitrogen and 73.2% for phosphorus. One main factor is the surface area of the woodchip is larger compared to tea leaves and coconut fibre which enables it to absorb better from the stormwater runoff. Larger surface area allows higher absorption from the stormwater runoff and water retention. As the surface area get smaller, in this case tea leaves and coconut fibre, the capability to absorb water decreases which causes the pollutant from incoming stormwater runoff to immediately infiltrate the underlying soil.

4.4 Ponding Time

To support the justification made above regarding the correlation between absorption and retention capacity of the filtration media and the removal efficiency, the hydraulic performance for each column with the different mulch layer was tested. Tap water was pumped into the bioretention column at the maximum capacity of 42mL/min and water was left to pond at a depth of 50mm. Figure 4.6 shows the ponding in the bioretention column using the woodchip as the mulch layer. The time for water to pond was recorded as below:

Table 9 Ponding Time

Mulch Layer	Ponding Time
Woodchip	8 minutes 25 seconds
Tea leaves	5 minutes 33 seconds
Coconut Fibre	5 minutes 25 seconds

According to Table 9, the time taken for water to pond in the bioretention column with woodchip as the mulch layer is longer compare to the tea leaves and coconut fibre. The ponding depth in the biorention with the woodchip as mulch layer can be seen in Figure 4.6. This shows that the large surface area of the woodchip particles absorbs the water from incoming runoff and when all the pores are filled, the water flows to the underlying soil layer which takes time for the bioretention column to be filled with water and the ponding to reach a depth of 50mm. This contributes to longer contact time between the pollutant and filtration media as the pollutant is absorb by the organic matter in the mulch and soil mix layer. Therefore, the absorption and retention capacity does affect the pollutant removal efficiency in the bioretention column which supports the justification.

Figure 4.6 Water Ponding in Bioretention Column

4.5 Project Limitation

There were several limitation encountered during the experiment. The main limitation is the size of the bioretention column used for this experiment. Compared to the previous studies that have been conducted, the size of the bioretention used for this project was small. This project had to be completed within a period of 2 semesters; therefore, to fabricate new bioretention column would take time and is expensive. Bioretention columns used were recycled columns used from another project. Modifications were made to the column to fit the design specification needed for the experiment.

As seen in the typical design of bioretention in Figure 2.1, the vegetative layer was not included in the bioretention column for this project due to the small diameter size. Common vegetation that are used in a bioretention garden are shrubs and it is not able to fit in the opening on the bioretetion column as it was only 46mm in diameter. Therefore, without the presence of the vegetative layer, it may have affected the efficiency especially in nitrogen removal capability.

Another limitation was the collection of stormwater sample. During the period of the experiment conducted, there were not many days with rainfall around the area of the university. Therefore, supply was scarce and the experiment could not be conducted a lot of times for each mulch layer. Only one trial run and three decisive run for result purposes was conducted using the stormwater runoff collected.

Although there were problem encountered during the project, it was able to be completed on time. Thus, changes can be made for studies conducted in the future to overcome and improve these problems.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Bioretention is seen as an attractive stormwater management practice that can be implemented in Malaysia as it shows the ability of removing pollutant from the stormwater runoff. Out of the three organic mulch layer, woodchip has the highest nitrogen and phosphorus removal efficiency with an average removal efficiency of 24.4% for nitrogen removal and 73.2% for phosphorus removal.

From an economical point of view, although the woodchip shows favourable results, the coconut fibre would be the best option implemented for rain gardens in Malaysia. For a large scale bioretention system, a large woodchip volume would be needed. Woodchip is an expensive landscaping material in Malaysia as it has other uses in the manufacturing industry. Coconut fibre is a more feasible option to be implemented in a large scale field as it can be obtain easily as coconut husk is thrown out and the hard shell which contain the water and flesh is kept to be sold commercially.

As there were limitation faced during the project mentioned earlier, the experiment can be improved by using a bigger size bioretention column as previous study conducted have mostly used bigger diameter bioretention column. Besides that, the type of soil used in the mix should be varied not only between coarse and fine sand but also loam, silt and clay according to the composition that has been set in Guidelines for Soil Filter Media Bioretention Systems by Facility of Advancing Water Biofiltration (2008), to improve the permeability of the bioretention column. By having different composition in the filtration media, the absorption rate and water retention capacity would be greater which can promote a higher removal rate. The higher the absorption rate, the higher possibility for the pollutant removal is decreased in the bioretention system. Thus, a future study on correlation between the permeability coefficient and pollutant removal can be conducted to further investigate the efficiency of bioretention in removing pollutant.

As the nitrogen removal rate was very low, further research work can be continued by applying a vegetation layer in the bioretention column. The vegetation layer can further enhance the absorption, especially of nitrogen from the stormwater runoff as it is used for plant growth.

REFERENCES

1) Blecken, G., Zinger, Y., Deletic, A., Fletcher, T.D., and Hedström, A. (2010). "Laboratory study on stormwater biofiltration: Nutrient and sediment removal in cold temperatures." *Journal of Hydrology*, 394, 507-514.
2) Davis, A.P., Shokouhian, M., Sharma, and H., Minami, C. (2001). "Laboratory Study of Biological Retention for Urban Stormwater Management." *Water Environment Research,* 78(1), 5-14.
3) Davis, A.P., Shokouhian, M., Sharma, H., and Minami, C. (2006). "Water Quality Improvement through Bioretention Media: Nitrogen and Phosphorus Removal." *Water Environment Research*, 78(3), 284-293.
4) Davis, A.P., Hunt, W.F., Traver, R.G., and Clar, M. (2009). " Bioretention Technology: Overview of Current Practice and Future Needs." *Journal of Environmental Engineering,* 135(2), 109-117.
5) Debusk, K.M., and Wynn, T.M. (2011). "Storm-water Bioretention for Runoff Quality and Quantity Mitigation." *Journal of Environmental Engineering,* 137(9), 800-808.
6) Dietz, M.E. (2007). "Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions." *Water Air Soil Pollut.*, 186, 351-363.
7) Facility for Advancing Water Biofiltration (2008) "Guidelines for Soil Filter Media in Bioretention Systems." *Bioretention Filter Media Guidelines,* Version 2.01.
8) Hsieh, C., and Davis, A.P. (2005). "Evaluation and Optimization of Bioretention Media for Treatment of Urban Storm Water Runoff." *Journal of Environmental Engineering*, 131(11), 1521-1531.
9) Hsieh, C., Davis, A.P., and Needelman, B.A. (2007a). "Bioretention Column Studies of Phosphorus Removal from Urban Stormwater Runoff." *Water Environment Research,* 79(2), 177-184.
10) Hsieh, C., Davis, A.P., and Needelman, B.A. (2007b). "Nitrogen Removal from Urban Stormwater Runoff Through Layered Bioretention Columns." *Water Environment Research,* 79(12), 2404-2411.

11) Liaw, C., Cheng, M., and Tsai, Y. (2000). "Low-Impact Development: An Innovative Alternative Approach to Stormwater Management." *Journal of Marine Science and Technology,* 8(1), 41-49.

12) Morzaria-Luna, H.N., Schaepe, K.S., Cutforth, L.B., and Veltman, R.L. (2004). "Implementation of Bioretention Systems: A Wisconsin Case Study." *Journal of the American Water Resources Association*, 1053-1061.

13) Palhegyi, G.E. (2010). "Modeling and Sizing Biorention Using Flow Duration Control." *Journal of Hydrologic Engineering,* 15(6), 417-425.

14) Read, J., Wevill, T., Fletcher, T., and Deletic, A. (2008). "Variation among plant species in pollutant removal from stormwater in biofiltration systems." *Water Research,* 42, 893-902.

15) Ray, A.B., Selvakumar, A., and Tafuri, A.N. (2006). "Removal of selected pollutants from aqueous media by hardwood mulch." *Journal of Hazardous Materials*, B136, 213-218.

16) Roy-Poirier, A., and Filion, Y. (2010). "Review of Bioretention System Research and Design: Past, Present, and Future." *Journal of Environmental Engineering*, 136(9), 878-889.

17) Trowsdale, S.A., and Simcock, R. (2011). "Urban Stormwater treatment using bioretention." *Journal of Hydrology,* 397, 167-174.

18) *Bioretention Gardens.* (n.d.). Retrieved April 17, 2012, from Douglas County Environmental Services: http://dcplanning.org/kiosk/bioretention-gardens

APPENDIX A

APPENDIX B

APPENDIX C

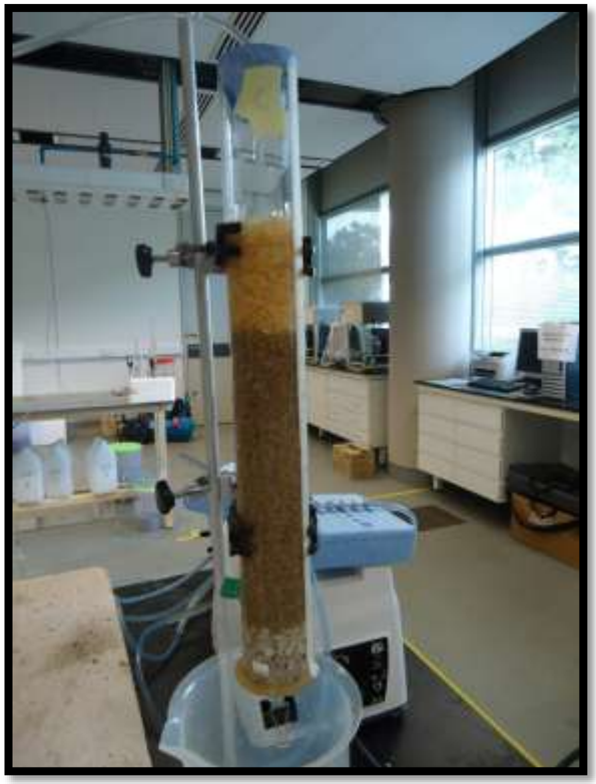

Figure A1 Woodchip As Mulch Layer

Figure A2 Coconut Fibre As Mulch Layer

Figure A3 Tea Leaves As Mulch Layer