The Effect of Compost Variation in Engineered Soil Media on Hydraulic and Hydrologic Performance - Soil Column Study

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons) Civil

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CERTIFICATION OF APPROVAL

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A dissertation submitted to the
Civil Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

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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.

____

(NAWAL NADIA NABILLA MOHD RAZALI)

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ABSTRACT

Bioretention system is one of the stormwater best management practice (BMP) that utilize vegetation plant, mixtures of medium soil, medium sand and also compost to filter stormwater runoff and to reduce peak runoff flow rate. However, presence of compost in the soil mixture will give variation to the soil characteristic such as the permeability, porosity and the hydraulic conductivity that eventually will affect the hydraulic and hydrologic performance. This study is conducted to investigate the effect of compost variation used in engineered soil media on hydraulic and hydrologic performance of bioretention system. Analysis on the effect of compost variation in the soil mixture used on hydraulic and hydrologic performance have been done by using soil column study approach. Seven (7) soil columns been set up and being monitored in six (6) weeks time. Two (2) types of composts are been used which are organic and rabbit's manure compost. In addition, each of the soil mixtures with compost used in the system being planted with hibiscus plant and ixora plant. The parameters that being observed throughout the periods are stormwater runoff inflow and outflow rate, water ponding volume, evaporation rate, hydraulic retention time (HRT), and saturated hydraulic conductivity (K_{sat}). Results shows that the type of compost used in the soil mixture does affect the hydraulic and hydrologic performance of the system. Each of the compost have different characteristic, hence produced different performance in term of hydraulic and hydrologic. Overall, mixtures of medium soil with organic compost that planted with ixora plant produced the best hydraulic and hydrologic performance for a bioretention system.

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LIST OF ABBREVIATIONS

ABC Water	Active Beautiful Clean Water
ARI	Average Recurrence Interval
BMP	Best Management Practice
DID	Department of Irrigation and Drainage Malaysia
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matters
FAWB	Advancing Water Biofiltration
FYP	Final Year Project
HRT	Hydraulic Retention Time
IP	Infiltration Patch
Ksat	Saturated Hydraulic Conductivity
MSMA	Urban Stormwater Management Manual for Malaysia
PU	Polyurethane
PUB	Public Utilities Board (Singapore)
PVC	Polyvinyl Chloride
STP	Sewerage Treatment Plant
TSS	Total Suspended Solid
Tot-N	Total Nitrogen
Tot-P	Total Phosphorus
UTP	Universiti Teknologi PETRONAS
WSUD	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1 Background

Due to increases in population and urbanization, impervious area in the earth surface also increase affecting the time of concentration, runoff volume and peak-flow rate at watershed (Palanisamy and Chui, 2015; Braud et al., 2013; Hamel et al., 2013; Gulbaz and Kazezyilmaz-Alhan, 2013; Line and White, 2017). Pollutant transport rate become higher due to excess runoff causing water pollutant in water resources. Because of the changes in land-use, specific solutions need to be implemented to solve this problem. Bioretention system which also called as biofilter system or rain gardens have been widely used to control and manage the stormwater runoff in urban areas (Winogradoff, 2002).

Bioretention is the process where pollutants and sedimentations are removed from stormwater runoff by using infiltration process. According to Che et al. (2014), bioretention have solved flooding, water shortage and other environmental problems in Oriental Sun City community in China. The function of bioretention system showed as a pollutant and stormwater control. It being used to decrease the runoff volume and peak flow rate, to increase the evapotranspiration, infiltration and groundwater recharge, and also to reduce the pollutant in surface and groundwater (Gulbaz and Kkazezyilmaz-Alhan, 2014).

Bioretention consist of gravel, mixture of soil and sand and mulch layer as well as vegetation plant (DID, 2012). In addition to these layer, organic compost also been added into the soil mixture. Different soil mixture and compost used in bioretention system will result in different particle size and distribution, which producing a different amount of hydraulic conductivity in each soil mixture and eventually will affect the hydrology and hydraulic performance in the system. Nowadays, many researches has been done to study the bioretention system using soil column study or also known as the mesocosm study. Soil column is being used to represent bioretention system in laboratory scale. According to Gulbaz et al., (2017), a standard bioretention system column consist of gravel, soil mixture of sand and vegetative soil, mulch and plants, adopting the real composition of bioretention system into smaller scale.

Mangangka et al., (2015) reported that hydraulic and hydrologic factor will affect the performance of bioretention in long term. One of the most crucial factor affecting the hydraulic and hydrologic performance is the composition of soil used in the system which eventually will affect the infiltration rate of the soil. DID (2012), proposed that composition of soil in bioretention system can be the mixture of top soil, medium sand and compost. According to Mullane et al. (2015), compost can help in plant growth as it provide nutrients, and also improve water holding capacity and soil structure. This statement is also agreed by Iqbal et al. (2015) who's stated that compost is used in bioretention system to improve soil quality, water infiltration and retention of contaminants. Although presence of compost in bioretention system is important, size determination of compost is most crucial in order to ensure the variation of soil medium size to enhance the infiltration rate of soil and eventually increase the hydraulic and hydrologic performance.

1.2 Problem statement

Bioretention system is widely used as one of the best stormwater management practices and be used to treat stormwater runoff by using filtration process. Nowadays, many researches has been done to study the pollutant removal performance of bioretention system and less attention has been given to their hydrologic and hydrology performance (Hatt et al., 2009). According to Mangangka et al. (2015), hydrologic and hydraulic factors such as rainfall characteristics and inflow and outflow discharges give such an important influence to the treatment performance of bioretention system.

Other than that, there is no specific guideline stated which type of compost can optimize the performance in term of pollutant removal and hydraulic and hydrology performance in bioretention system. DID, (2012) proposed that composition of engineered soil in bioretention system include of top soil, medium sand and organic leaf compost. Nevertheless, there is no clearer statement outlining hydraulic conductivity for that type of compost. Holman-Dodds et al. (2003) reported that bioretention does not reduce runoff as well when be sited on soil that have low infiltration capacity. Engineered soil medium used in bioretention system plays an important role to the performance of the system. It should drain quickly and at the same time, it has to provide enough detention time for the treatment and vegetation growth (Coustumer et al., 2009). Variation of organic compost in engineered soil will result in different value of saturated hydraulic conductivity (K_{sat}) and the infiltration rate of the soil media. This parameters is expected to result in different outcome of hydrology and hydraulic performance of the system according to the type of organic compost used.

Besides, compost itself can release particulate and dissolved organic carbon (DOC) which can give environmental concerns if the leachate flows directly into surface or groundwater (Iqbal et al., 2002). Mullane et al. (2015) added that nutrients present in compost may leach during rainstorms and potentially contaminate environmentally sensitive waters or ecosystems. Many study has been done to investigate the leachate of compost used in bioretention system and less attention has been given to study the effect of compost presence in soil medium to their hydraulic and hydrologic performance. Although presence of compost is good for the system especially to the plant growth, further study to investigate which type of compost can be used that will produce less leachate, give good hydraulic and hydrologic performance and can be used safely to the environment need to be done.

Lastly, the potential for bioretention system to clog is also an important issue (Bouwer, 2002). Clogging happened will not only affect the hydraulic performance of the system but also impacting the pollutants treatment performance. Particle sizes and textures of the vegetative soil and sand are the important key factor for each of different regions, resulting in different infiltration rate in bioretention system. The amount of clays, silt and sand are crucial in designing bioretention to control the infiltration rate. Texture composition of layers of different materials should be evaluated carefully before implementation of bioretention system (Gulbaz and Kkazezyilmaz-Alhan, 2017).

1.3 Objective

The objectives in this project are:

i. To investigate the hydraulic and hydrologic performance for variation type of compost in engineered soil media through soil column study.
ii. To analyze the correlation between the hydraulic and hydrologic parameters observed in soil column study.

1.4 Scope of study

This project focuses on the hydraulic and hydrologic performance of compost variation in engineered soil media for bioretention system. To achieve the objective mentioned, soil column study will be conducted. This study consist of seven (7) nos. of columns with usage of two (2) different type of organic compost to be mix in the soil media. Test run-out of the hydraulic and hydrologic performance for the system will be carried out in six (6) weeks time.

CHAPTER 2

LITERATURE REVIEW

2.1 Bioretention System

Bioretention system which also known as biofilters or raingardens, are one of the stormwater best management practices (BMPs) that are commonly used and promoted widely at US (Davis et al., 2009) and also elsewhere (Fujita, 1997; Wong, 2006; Woods-Ballard et al., 2007). According to Urban Stormwater Management Manual for Malaysia (MSMA), by using the biological uptake and porous media filtration process, this system able to filtrate the polluted stormwater and remove the contaminants from the water (DID, 2012). Traditional bioretention basin consist of several elements that have different functions such as grass buffer strip, sand bed, ponding area, organic layer and vegetation. Mainly, bioretention system integrate vegetation such as trees, shrub and grasses, and layered media of soil, sand and mulches to filtrated the stormwatar runoff (DID, 2012).

As noted by New Jersey Stormwater Best Management Practices Manual (2009), biorentention system works to collect the stormwater runoff and control the capture into the treatment area. The stormwater runoff entering the system passes through the soil planting bed which consist of organic layer and evenly distribute along the length of the ponding area. This process will eventually slows and control the runoff's velocity. The runoff then gradually infiltrates into the soil or is evatranspired. Vegetation planted in the soil bed provide the uptake pollutants from the runoff and also helps to increase the infiltration rate of soil in the system.

2.2 Design of Bioretention System

2.2.1 Type of Bioretention System

As mentioned in MSMA, bioretention system can be designed into two types which are permeable or impermeable system (DID, 2012). Permeable bioretention system carries the stormwater runoff through the filtration media and sand bed layer at a certain rate. Then the runoff spread to the surrounding soil and recharge groundwater (Estes, 2007). Contradict to permeable system, impermeable system have underdrain or subsoil pipe located in the drainage layer despite similarly drains the water through the filtration media and sand bed layer. This system apply to area where the soil have low infiltration capacity or higher rainfall intensity to make sure that the storage of the system is available for the next storm event (DID,2012).

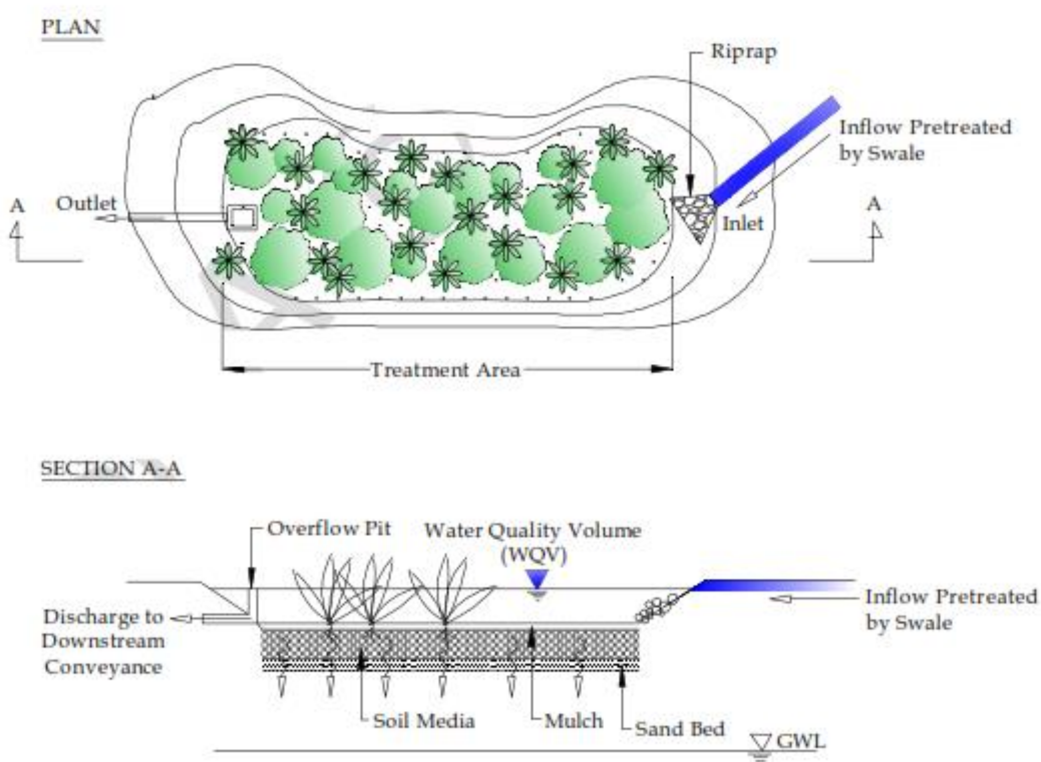


Figure 2.1: Permeable Bioretention System

* *Adapted from Urban Stormwater Management Manual for Malaysia (MSMA), (2012)*

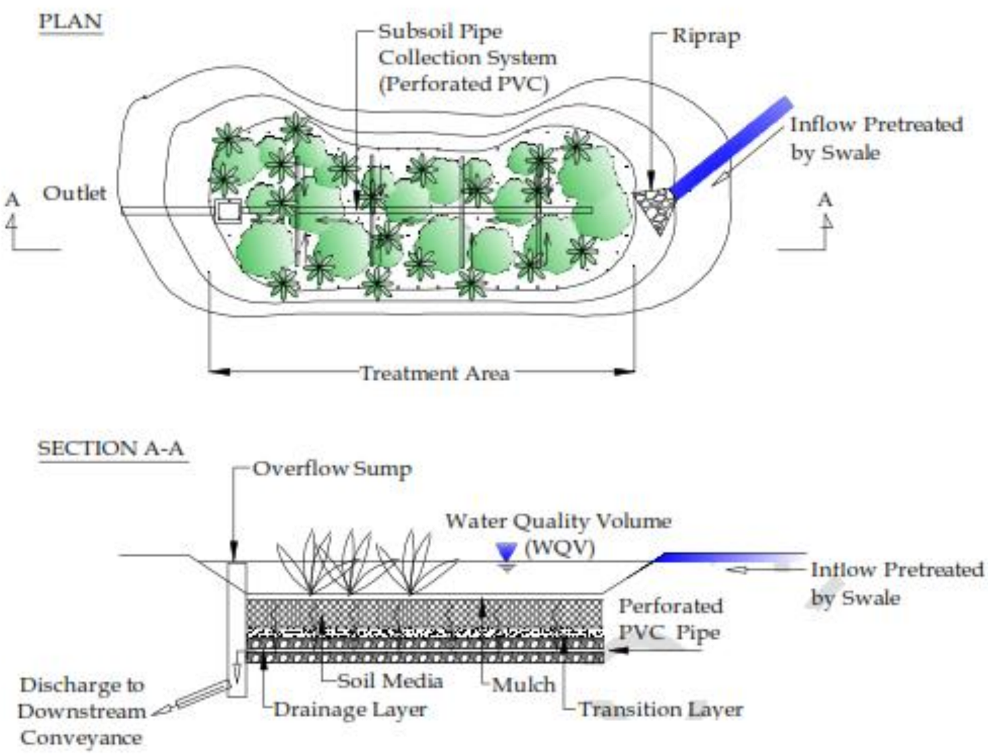


Figure 2.2: Impermeable Bioretention System

* *Adapted from Urban Stormwater Management Manual for Malaysia (MSMA), (2012)*

2.2.2 Components of Bioretention System

Usually, bioretention system consist of seven (7) components which provide different functions (State of Minnesota Stormwater Manual, 2005). These component can be simply as:

i. <u>Grass buffer strip</u>

To reduce the runoff velocity and filter the suspended solid from runoff.

ii. <u>Vegetation plant</u>

To help remove runoff through evapotranspiration process and remove the excess nutrient through nutrient cycling process.

iii. Water ponding area

To provide a storage to the excess runoff and its subsequent evaporation as well as helps in settlement of suspended solid.

iv. Mulch layer

An organic layer that support the micro biological degradation of petroleum-based pollutants and help in pollutant filtration as well as reduction of soil erosion.

v. Engineered soil

To support the vegetation growth as well as served as the nutrient uptake and giving more space for runoff storage. Some clay should be included in the soil to adsorb pollutants such as hydrocarbons, heavy metals and nutrients.

vi. Sand bed

To equip drainage and aeration of plating soil as well as provide flushing pollutants from soil materials.

vii. Underdrain system

To remove excess treated runoff to receiving waters.

2.2.3 Recommended Design Criteria

Design criteria of bioretention system for worldwide is different according to each country. Summary of guidelines for design criteria for bioretention system according to the country are presented in Table 2.1

Table 2.1: Recommended Design Criteria from Several International Guidelines

Guidelines	Country Used	Design Flow	Recommended Filter Media Depth	Recommended Soil Composition	Saturated Hydraulic Conductivity *(Ksat)*	Pollutant Removal Efficiency		
						TSS	TN	TP
Stormwater Management Manual Malaysia (MSMA), (DID, 2012)	Malaysia	40mm rainfall depth / 3 month ARI	450-1000mm (both permeable and impermeable)	20-25% Topsoil 50-60% Medium sand 12-20% Organic leaf compost	13-200 mm/hr	80	50	60
Engineering Procedures for ABC Water Design Features (PUB, 2011)	Singapore	5 years ARI (Minor storm) 100 years ARI (Major storm)	400-600mm (exclude transition and drainage layer)	Topsoil with less than 12% clay	50-200 mm/hr (not exceed 500 mm/hr)	80	45	45
Bioretention Manual (The Prince George Country, 2009)	USA	25.4mm rainfall depth / 1 year ARI	At least 458mm	50% Construction sand 20-30% Topsoil 20-30% Leaf compost	13.2-61.2 mm/hr	97	33 - 66	35 - 65
WSUD Engineering Procedures (Melbourne Water, 2005)	Australia	<u>Minor Storm:</u> 5 years ARI (temperate climate) 2 years ARI (tropical climate) <u>Major Storm:</u> 100 years ARI (temperate climate) 50 years ARI (tropical climate)	300-500 mm (Lined biofiltration system with submerged zone) 400-700 mm (Standard lined biofiltration)	Sandy loam / Sand-based media	100-300 mm/hr	80	45	45
North Shore City Bioretention Guidelines (North Shore City, 2008)	New Zealand	1/3 of 2 years ARI	500-1000mm minimum 300mm for shrub & grass maximum 1000mm for trees	40% Sand 30% Topsoil 30% Compost	100-300 mm/hr	-	-	-

2.3 Filter Media Specification

2.3.1 Media Particle Size

Filter media is the most crucial factor in bioretention design. Selection of media filter used is important in order to improve the hydrology and hydraulic performance as well as pollutant removal performance. As stated by Gulbaz and Kazezyilmaz-Alhan (2017), particle size and textures of soil media from vary regions is important as it will results in different infiltration rate in bioretention system. Composition of different materials of layer should be considered and evaluated in every bioretention filter media.

2.3.2 Composition of Soil Mixture

Usually, composition of soil mixture in bioretention system include of topsoil, sand and compost. Urban Stormwater Manual Malaysia (MSMA) recommended that soil composition in bioretention system in Malaysia can be in the mixture of topsoil (sandy/silt loam), medium sand and organic leaf compost. According to Liu et al., (2014), a typical bioretention media include of approximately 50%-60% sand and 40%-50% mix of loam or sandy loam on per volume basis. Meanwhile, clay also plays an important role as filter media. Presence of clay in the system will reduce the infiltration rate and it should be minimize to maintain proper hydrology performance. The recommended clay content for bioretention system ideally in the range of 5%-8% (Neil et al., 2009).

2.3.3 Filter Media Depth

Other than composition of media used, the depth of media layer is also one of the important factor in design criteria controlling the hydrology and hydraulic performance n bioretention system. A monitoring study was conducted by Li et al., (2009) comparing six (6) of bioretention cells in Maryland and North Carolina which have different soil media depth. Two (2) of the bioretention cells have 1.2 m depth of media soil meanwhile the rest have 0.5-0.6 m depth. Cell with larger media depths met 80% the time of their targeted water quality volume control compared to the smaller media depth which only 44% of the time. This suggested that media depth may be the important parameter as well affecting hydrologic performance. The filtering media depth for permeable and impermeable bioretention system already been specified in MSMA as in Figure 2.3 and 2.4

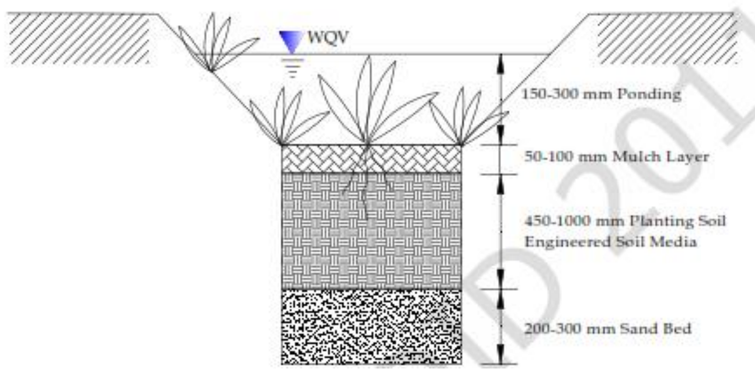


Figure 2.3: Depth of Media in Permeable Bioretention System

**Adapted from Urban Stormwater Management Manual for Malaysia (MSMA), (2012)*

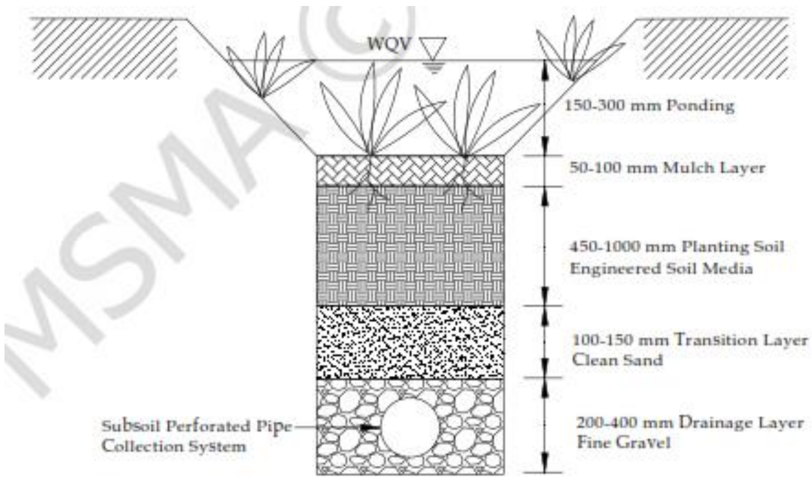


Figure 2.4: Depth of Media in Impermeable Bioretention System

**Adapted from Urban Stormwater Management Manual for Malaysia (MSMA), (2012)*

2.4 Hydraulic and Hydrologic Performance

2.4.1 Flow Reduction

Bioretention is widely used as the best management practice to manage stormwater because of the capability of the system to reduce peak runoff flow rate. As stated before, hydraulic and hydrologic factor are important to enhance the pollutant removal performance of the system in long time period. According to Hunt et al. (2006), reduction of runoff outflow was important for pollutant removal computation. Flow reduction of runoff not only due to filtration process occurs throughout the system but it is also expected due to exposure of the runoff to exfiltration and evaporation. Seasons and weather are the crucial aspect to enhance these natural process to happen causing flow reduction of runoff to occur. Hunt et al. (2006) stated in their paper that, one of the outcome form their study is outflow reduction was lower during warm season compared to winter. This mainly due to mass removal rate depending on inflow and outflow are much lower during winter season.

The author have gone through some paper of previous study to analyze the ability of bioretention system in flow reduction. It can be conclude that bioretention system able to reduce outflow rate with average 80%. Previous study of hydraulic and hydrologic performance of bioretention system is presented in Table 2.2.

Table 2.2: Previous Study on Hydraulic and Hydrologic Performance of Bioretention System

Author (Year)	Description	Method	Inflow (L/s)	Outflow (L/s)	Flow Reduction (%)
Lucke and Nichols (2015)	Evaluated five, 10-year old street-side bioretention systems, subjected to a series of simulated rainfall events using synthetic stormwater.	Five discrete bioretention basins located directly adjacent to the roadway which runs centrally through the catchment.	0.2 – 0.5	0.04 – 0.05	80 – 90%
Line and Hunt (2009)	Monitored inflow, outflow, and on-site rainfall for at least 13 storm events of a bioretention area and a level spreader-grass filter strip implemented at North Carolina highway facilities.	Using bioretention area and level spreader-grass filter strip BMPs located in North Carolina.	19.63	7.22	64%
Hunt et al. (2009)	Monitored o reinforced concrete level spreader upslope mixed grass/weed vegetated filter strip for runoff reduction for 23 precipitation events.	Using Westfield level spreader located in Charlotte, N.C.	34240*	5260*	85%
Gilroy and McCuen (2009)	Analyzed the effects of both location and quantity of two types of BMPs: cisterns and bioretention pits.	Spatio-temporal model of a microwatershed for: Single family 1-year Storm Event Townhome 1-year Storm Eevent	 9.67 10.17	 0.77 0.92	 92% 86%
Davis (2008)	Monitored flows into and out of two bioretention facilities constructed on the University of Maryland campus for nearly 2 years, covering 49 runoff events.	Field bioretention cell located at University of Maryland campus: Deep Cell Shallow Cell	3.10	1.50	 63% 44%

** Parameters used in the study is in volume*

2.4.2 Infiltration Rate

Infiltration rate is one of the most important factor to be considered in bioretention system as it is the key for a good performance in term of hydraulic and hydrologic. Infiltration helps in reduction of runoff and is applicable for any type of development (Brander et al., 2004). If the soil medium used in bioretention system have low infiltration rate, the possibility flooding to occur is high (Davis and McCuen, 2005). Technically, saturated hydraulic conductivity (K_{sat}) of the soil is important that will represent the capability of the soil in infiltration rate. Infiltration rate of a soil is influenced by many factors. The crucial factors that always be analyzed are soil characteristics, soil surface condition, soil compaction and fluid characteristics. The author have gone through some paper of previous study to analyze the saturated hydraulic conductivity of soil that has been used. As conclusion, the saturated hydraulic conductivity of the soil used in previous study can be analyzed in Table 2.3.

2.4.2.1 Clogging Problems

Clogging is one of the biggest problem that might happen to bioretention system if its filter media infiltration rate is poorly designed and eventually will affect the performance of the system. According to Lindsey et al. (1992), only 38% of infiltration basin in their study were functioning as designed after four (4) years of the operation while 31% considered to be clogged.

Clogging happened due to the gathering of small size particle of soil around the outlet valve at the bottom of the system. This can be prevented by having variation of filter media type and size. Texture composition of layers in bioretention system containing different materials and size should be considered and evaluated locally before the system implemented (Gulbaz and Kazezyilmaz-Alhan, 2017). Other than that, filter media type and depth is also important to prevent clogging from happening.

Table 2.3: Comparison of Saturated Hydraulic Conductivity (Ksat) used in Previous Study

Author (Year)	Description	Method	Soil Material	***Ksat*** **(mm/hr)**
Carpenter and Hallam (2010)	Three investigations undertaken to determine the influence of planting soil mix characteristics.	Conducted using a falling head permeability test in accordance with ASTM 2434-68 standard test method for permeability of granular soils.	100% Compost 100% Sand 100% Topsoil 80% Compost 20% Sand 20% Compost 50% Sand 30% Topsoil 50% Compost 50% Sand 35% Compost 65% Sand	183.9 259.8 16.8 455.9 46.7 55.4 70.4
Hatt et al. (2008)	Overall assessment of the hydraulic and pollutant removal behavior of sand- and soil-based stormwater filters at the laboratory scale.	Non-vegetated filter columns	80% Sandy Loam 10% Mulch 10% Compost 60% Sandy Loam 20% Mulch 20% Compost	216 – 300 5760
Hunt et al. (2006)	Monitored three bioretention field sites in North Carolina for pollutant removal abilities and hydrologic performance with variation of fill media type or drainage configuration in cells.	Three bioretention field sites in North Carolina.	Clay Loam	5.04 – 15.12
Brander et al. (2004)	Four develop-ment types (conventional curvilinear, urban cluster, coving, andnew urbanism) were modeled both with and without infiltration practices to determine their relative effects on urban runoff.	Infiltration Patch (IP) Model.	Loamy Sand	30.5

2.5 Compost in Engineered Soil

According to DID, (2012), engineered soil filter media in bioretention system include of topsoil, medium sand and compost. Bioretention system works with presence of vegetation, mixtures of soils, sand and compost altogether to filter stormwater runoff. Presence of compost in soil mixture used in bioretention system is important as it is beneficial for plant growth. According to Mullane et al. (2015), compost is beneficial for plant in bioretention system as it provides nutrients, also improves water holding capacity and soil structure. In addition, presence of compost also help in pollutant removal. Compost also has a high affinity to absorb contaminants, particularly metals (Morgan et al., 2011) and organics et al., 2013) and thereby helps to treat stormwater (Mullane et al., 2015).

Even though compost give benefits in bioretention system, it also will affect the environment. Compost contains dissolved organic matters (DOM), nitrate and phosphorus will eventually may be leach out during rainstorms and potentially contaminate ground and surface waters. Considerable amounts or dissolved organic matters (DOM) can leach out from matured compost (Beesley, 2012) but also inorganic constituents can leach out (Hsu and Lo, 2001).

From research that have been done by the author, most of past study on compost used in bioretention system focused more to the compost characteristic and their leachate. Less attention have been given to the effect of compost in hydraulic and hydrologic performance. Therefore, the author will investigate the effect of compost in hydraulic and hydrologic performance, as well as the leachate produced by the compost, in order to make sure safe design criteria of bioretention system can be produced.

Table 2.4: Previous Study on Compost Leachate

<table>
<tr><td>Author (Year)</td><td>Mullane et al. (2015)</td><td>Iqbal et al. (2015)</td></tr>
<tr><td>Description</td><td>Characterized and quantified the leachate composition of compost following intermittent, stimulated storm events. Columns of municipal compost were irrigated to stimulate 6 months, 24 hour rain storm in the Seattle-Tacoma region.</td><td>Study to reduce the leaching of nutrients and dissolved organic matter from compost, by mixing biochar into bioretention system.</td></tr>
<tr><td>Experimental Setup</td><td>• 6 PVC columns (64 cm height, 10.2 cm diameter)
• Compost height is 25cm</td><td>• Compost (100%)
• Biochar (100%)
• Biochar (100%)
• Co-composted biochar (100%)
• Sand (100%)
• Compost (75%) and biochar (25%): mixed
• Compost (75%) and co-composted biochar (25%): mixed
• Compost (30%) and sand (70%): mixed
• Compost (30%) and sand (70%): layered</td></tr>
<tr><td>Compost Used</td><td>6 and 24 month old compost:
• 80% yard waste
• 20& food waste</td><td>6 and 24 month old compost:
• 80% yard waste
• 20& food waste
Biochar (350 g) placed into 10 by 20 cm Nylon meshbags</td></tr>
<tr><td>% Leached from Compost</td><td>
<table>
<tr><td></td><td>Compost age</td><td></td></tr>
<tr><td></td><td>6-Month old</td><td>24-Month old</td></tr>
<tr><td>Parameter</td><td>% leached</td><td>% leached</td></tr>
<tr><td>Dissolved organic carbon</td><td>5.39 ± 0.05[a]</td><td>3.98 ± 0.37[b]</td></tr>
<tr><td>Particulate organic carbon</td><td>0.53 ± 0.12[a]</td><td>0.31 ± 0.04[b]</td></tr>
<tr><td>Total nitrogen</td><td>8.07 ± 0.19</td><td>7.63 ± 1.46</td></tr>
<tr><td>Total phosphorus</td><td>8.87 ± 0.44</td><td>7.37 ± 1.39</td></tr>
<tr><td>Total copper</td><td>2.82 ± 0.88[a]</td><td>1.21 ± 0.14[b]</td></tr>
<tr><td>Dissolved copper</td><td>2.36 ± 0.84</td><td>1.13 ± 0.25</td></tr>
</table>
</td><td>
<table>
<tr><td>Treatments</td><td>Tot-N</td><td>Nitrate/nitrite</td><td>Tot-P</td><td>Ortho-P</td><td>DOC</td></tr>
<tr><td></td><td>% leached</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Compost</td><td>7.8</td><td>5.2</td><td>3.0</td><td>2.9</td><td>0.0</td></tr>
<tr><td>Biochar</td><td>0.0</td><td>0.0</td><td>16.7</td><td>16.7</td><td>0.0</td></tr>
<tr><td>CC-biochar</td><td>3.3</td><td>2.4</td><td>8.2</td><td>8.1</td><td>0.0</td></tr>
<tr><td>Sand</td><td>0.0</td><td>0.5</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>Compost + biochar</td><td>6.8</td><td>4.9</td><td>3.8</td><td>3.7</td><td>0.0</td></tr>
<tr><td>Compost + cc-biochar</td><td>7.7</td><td>4.8</td><td>4.6</td><td>4.4</td><td>0.0</td></tr>
<tr><td>Compost + sand (M)</td><td>4.0</td><td>2.8</td><td>1.7</td><td>1.5</td><td>0.0</td></tr>
<tr><td>Compost + sand (L)</td><td>4.6</td><td>3.0</td><td>3.2</td><td>3.1</td><td>0.0</td></tr>
</table>
</td></tr>
</table>

CHAPTER 3

METHODOLOGY

3.1 Overview

Seven (7) columns of bioretention basin have been design and set up at Sewerage Treatment Plant (STP) UTP to study the hydraulic and hydrologic performance for variation type of compost in engineered soil media for bioretention system at laboratory scale. One (1) of the columns is set to be the control measure of the study. Three (3) of the columns will be planted with hibiscus (Hibiscus Rosa-Sinensis) plant meanwhile three (3) columns left will be planted with ixora (Ixora Coccinea) plant. Each of the plant species will be planted in soil media that consist of two (2) different types of compost materials which are organic compost and rabbit's manure compost and is expected to give different result in term of hydraulic and hydrologic performance.

This chapter discusses the methodological approach used in order to achieve the aforementioned objective. General activities are showed briefly by the flow chart and the discussion continued with the brief explanation about each of the steps that will done throughout this project. By the end of the chapter, project's key milestone and Gantt chart is attached for progress tracking.

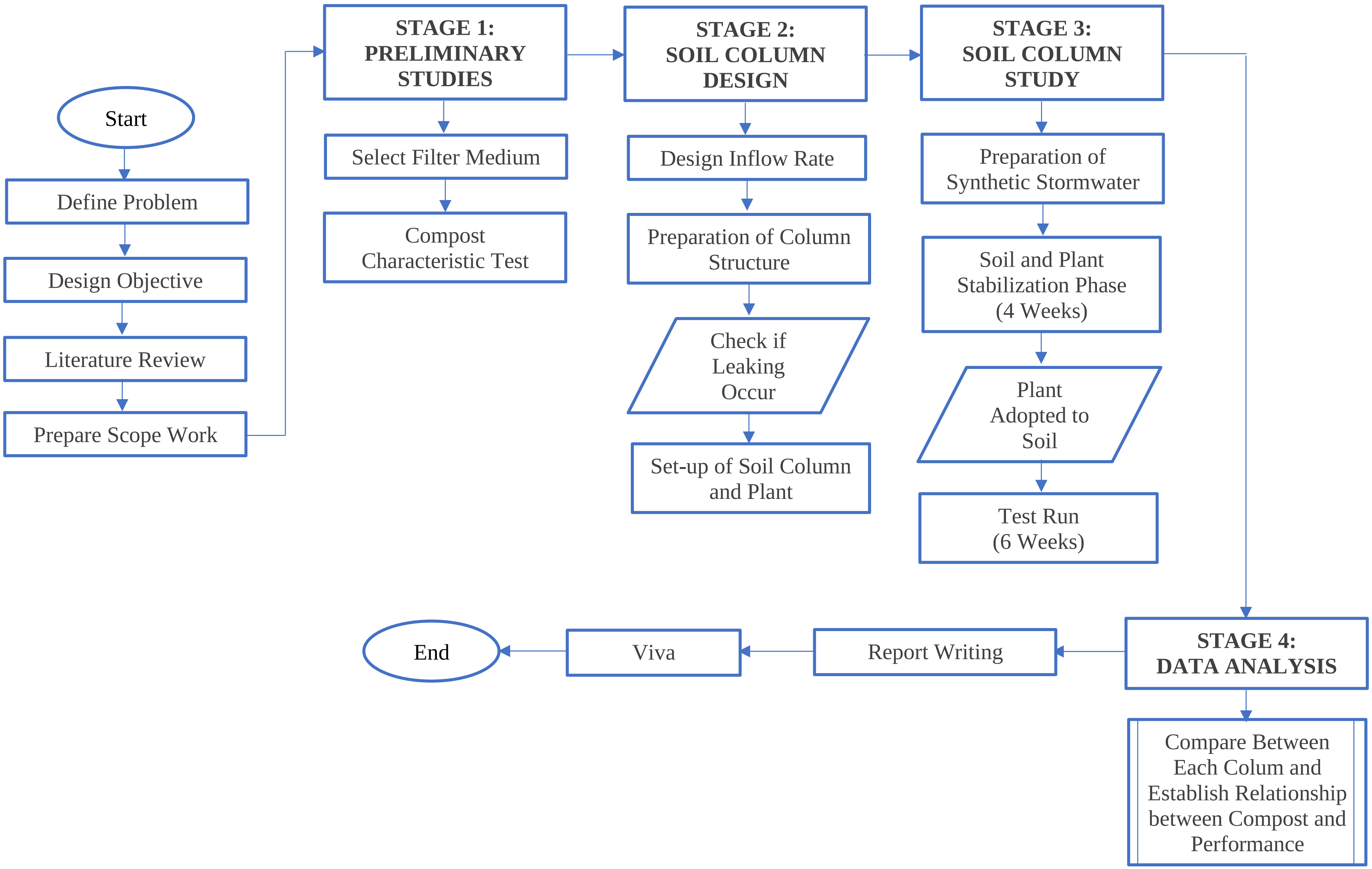


Figure 3.1: Overall Flow Chart of Project

3.2 Stage 1: Preliminary Studies

3.2.1 Bioretention Filter Medium

Type of medium used and the medium size particle plays a very important role to determine the infiltration rate and effectiveness of hydrologic performance in bioretention system (Gulbaz and Kazezyilmaz-Alhan, 2017). There are five (5) components of filter media that will be used in this project which consist of:

i. Medium soil
ii. Compost materials
iii. Medium sand
iv. Mesh geotextile
v. Gravel

3.2.1.1 Medium Soil

As noted by the past researcher (Baharudin, 2016), the mixture of sand and top soil with ratio of 60:40 produced the best hydrologic performance in bioretention system compared to the mixture of sand and top soil with ratio 50:50 and 70:30. Thus, this project use 60:40 ratio of sand and top soil mixture as the main media filter in the system. Before mixing the sand and the top soil, top soil firstly need to be dried overnight at 120^{o}C. Then, it will be crushed and sieved passing through 2 mm sieve size. Only the passing top soil will be mixed with the sand according to the ratio selected.

Figure 3.2: Top Soil is Crushed and Sieved Using 2mm Sieve Size

Figure 3.3: Mixture of Sand and Top Soil

3.2.1.2 Compost Materials

Two (2) different type of compost material will be used in this project which are:

i. Rabbit manure
ii. Organic compost

Each of the compost have different characteristic and is expected to produce different result in term of hydraulic and hydrology performance. Amount of compost used for each soil column is 10% from the volume of soil medium.

Figure 3.4: Organic Compost

Figure 3.5: Rabbit's Manure Compost

3.2.1.3 Medium Sand

Medium sand used as the transition layer as the transition layer between the soil mixture and gravel layer with purpose to prevent the downward migration of smaller particle of soil with runoff during filtration process. Transition layer is important to prevent the potential for clogging of bioretention system. According to Langergraber et al. (2003) and Winter and Geotz (2003), sediment deposition is considered to be main cause of clogging that may occur near the outlet of the system.

3.2.1.4 Mesh Geotextile

Mesh geotextile usually been placed between the transition and the drainage layer in bioretention system. 2 mm opening mosquito net used in this study replacing the mesh geotextile layer with purpose to prevent the downward migration of smaller particle from medium soil and sand layer. This step also can be considered as the precautionary step to prevent clogging from happening at the outlet area of the system.

Figure 3.6: Mosquito Net

3.2.1.5 Gravel

Gravel layer act as the drainage layer in bioretention system. In this layer, the runoff is stored temporarily before flowing out through the outlet valve. The gravel size used in this study is less than 12 mm.

Figure 3.7: 12mm Size Gravel

3.2.2 Compost Characteristic Test

Each of the compost have been tested to determine its characteristic. Simple procedure to conduct these test are adopted from study by Jr. et al., 2009. The test that have been done are:

i. Moisture percentage content
ii. pH value
iii. Conductivity measurement

3.2.2.1 Moisture Percentage Content

10g of each compost is dried for 24 hours in 105^{o}C oven. Moisture percentage content is calculated by:

$$\textit{Moisture Percentage Content (\%)} = \frac{(W_w - W_d)}{Ww} X\ 100 \quad (1)$$

Where:

W_w = Wet weigh (g)
W_d = Dry weigh (g)

3.2.2.2 pH Value

i. Each of the compost is dried in an oven for 24 hours at 105^{o}C.
ii. After 24 hours, 5 g of each samples are measured out and a solution was made with 25mL of deionized water.
iii. The solution stirred for 2 minutes and let to stand for 5 minutes.
iv. The pH meter calibrated first by using three pH buffers; 4.00, 7.00, and 10.01. Then, pH value for each solution is measured.

3.2.2.3 Conductivity Measurement

i. Each of the compost is dried in an oven for 24 hours at 105^{o}C.
ii. After 24 hours, 5 g of each samples are measured out and a solution was made with 25mL of deionized water.
iii. The solution stirred for 2 min and let to stand for 5 minutes.
iv. The conductivity meter calibrated first by using three conductivity standards; 73.9 lS/cm, 717.8 lS/cm, and 6.678 lS/cm. Then, conductivity value for each solution is measured.

3.3 Stage 2: Soil Column Design

3.3.1 Stormwater Runoff Inflow Rate

Design inflow rate in this project is calculated based on Urban Stormwater Manual Malaysia, DID, (2012).

Assume:

Catchment Area = 400 m^2
Permeable Area = 275 m^2 Coefficient of Permeable Area, $C_{permeable}$ = 0.4
Impermeable Area = 125 m^2 Coefficient of Impermeable Area, $C_{impermeable}$= 0.65
Rainfall Depth = 40mm/hr

$$\begin{aligned} \textit{Runoff Volume} &= \textit{Catchment Area x Rainfall Depth} \qquad (2) \\ &= [(C_{permeable} \text{ x Permeable Area}) + (C_{impermeable} \text{ x Impermeable Area})] \text{ Rainfall Depth} \\ &= [(0.4 \text{ x } 275) + (0.65 \text{ x } 125)]\ 0.04 \\ &= 7.65\text{m}^3 \end{aligned}$$

$$\textit{Filter Bed Area } (A_f) = \frac{(WQ_v)(d_f)}{(k)(h_f + d_f)(t_f)}$$

$$= \frac{7.65m^3 \times 0.6m}{0.312m/day \times (0.1m + 0.6m)(1)}$$

$$= 21.016m^2$$

(3)

Where:

A_f	=	Surface area of filter bed (m^2)
WQ_v	=	Water quality volume (m^3)
d_f	=	Filter bed depth (m)
k	=	Coefficient of permeability of filter media (m/day)
h_f	=	Average height of water above filter bed (m)
t_f	=	Design filter bed drain time (day) – (1 day maximum)

Hence, the inflow runoff volume needed in this study is:

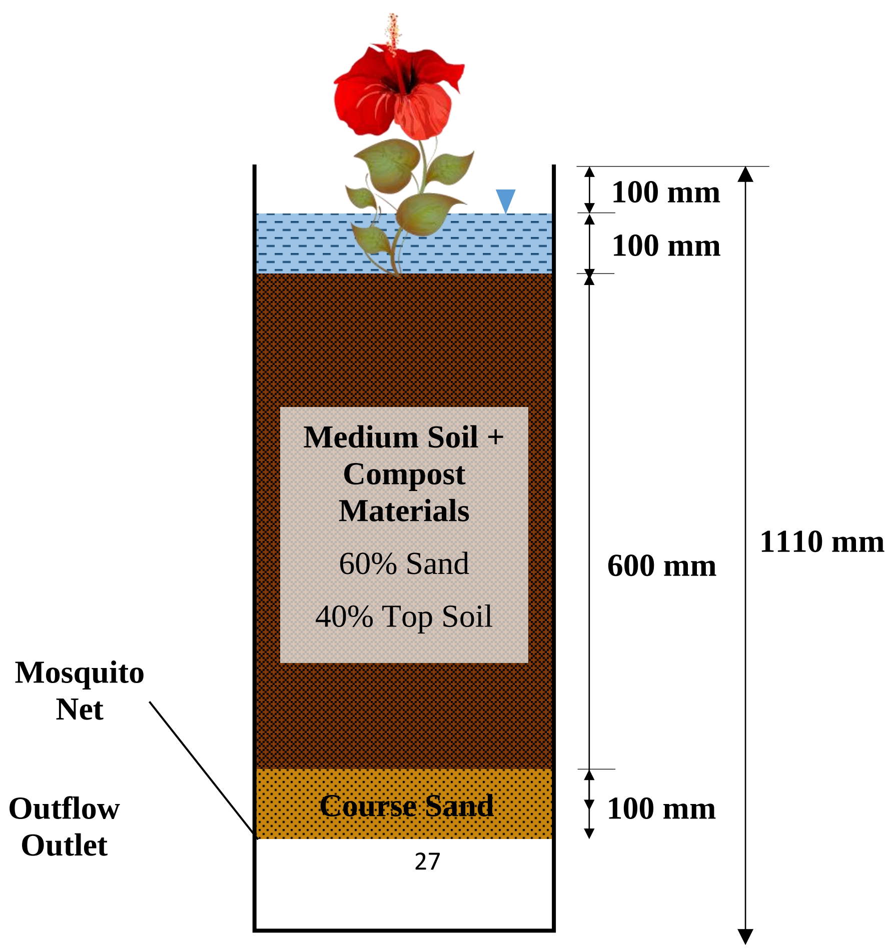
Table 3.1: Inflow Runoff Volume

Diameter (m)	**Surface Area (m^2)** **(πd2)/4**	**Scale** **Bioretention Surface Area /Surface Area**	**Volume (m^3)** **(0.3 x 0.04 x Surface Area) / 0.06**	**Volume (L)**	**Volume for 7 Cells (L)**

0.30	0.071	297	0.014	14.139	98.973 ≈ 99

3.3.2 Soil Column Structure and Design Configuration

Seven (7) bioretention columns are designed for this laboratory scale study. Each column is constructed using a Polyvinyl Chloride (PVC) pipe with the inner diameter of 300 mm and 1110 mm height. It was covered with Poly (Methyl Methacrylate) Glass plate at the bottom with diameter of 320 mm and thickness of 10 mm. Detail design of each column can be referred as in Figure 3.8. Each of the columns will have same height and diameter and also same dimension of filter media.



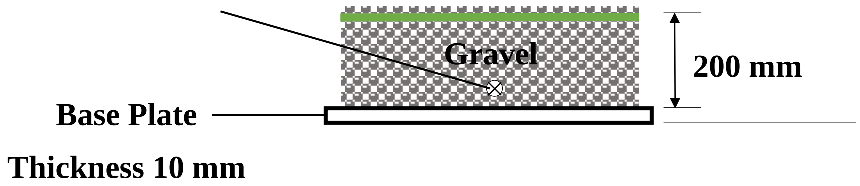


Figure 3.8: Schematic Drawing of Bioretention Column

List of materials used for column fabrication are as follows:

Table 3.2: Column Fabrication Materials

No	Material	Functions
1	1110 x ø300 mm Polyvinyl Chloride (PVC) Pipe	Column Body
2	10 x ø320 mm Poly (Methyl Methacrylate) Glass plate	Column Base
3	10 mm Polyurethane (PU) Tubing	Outlet Valve
4	PC 1002 Tubing Connector	Outlet Tube Connector

One of the column is designed with no presence of organic compost to be mixed with the soil medium as well as vegetation plant. This column will act as the control column. Three of the columns will be planted with hibiscus plant and each of the columns will have different type of organic compost to be mix with the medium soil. This characteristic is also applied to the three more columns left and it will be planted with ixora plant. The designed filtration media mixtures for all columns can be conclude as in Figure 3.9

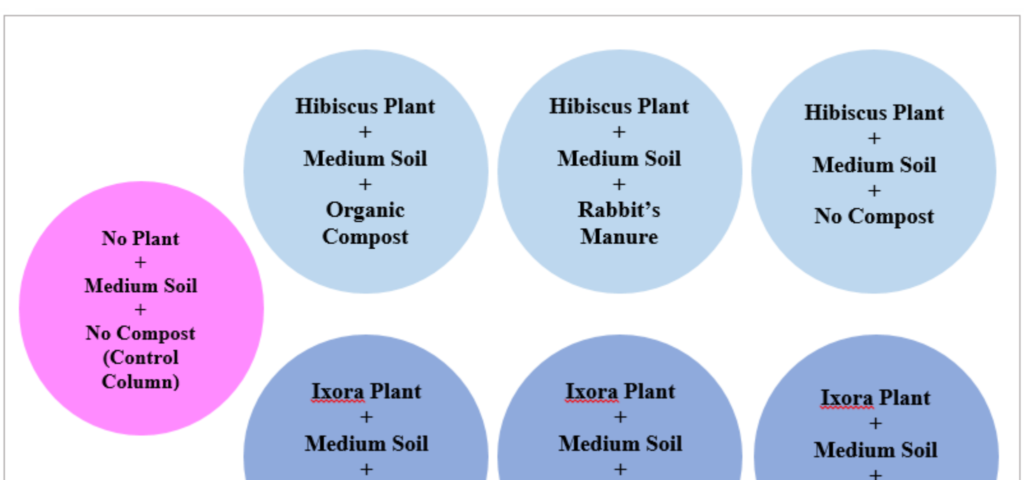


Figure 3.9: Designed Filtration Media Mixtures

Figure 3.10: Soil Column Body

Figure 3.11: Soil Column Set Up at Sewerage Treatment Plant UTP

3.4 Stage 3: Soil Column Study

3.4.1 Synthetic Stormwater

According to Hatt and Poelsma (2009), usage of natural stormwater in bioretention system study is not encouraged because collection of natural stormwater might be difficult and depend on the rain events. Since the rain event at UTP and Seri Iskandar area is unpredictable, it has been decide that this study will use synthetic stormwater as the inflow runoff.

According to Advancing Water Biofiltration (FAWB) Guideline (2009), the steps in preparing synthetic stormwater are:

i. Collect in-situ stormwater
ii. Dilute the in-situ stormwater to targeted TSS concentration

3.4.1.1 Collection of In-Situ Stormwater

The in-situ stormwater runoff will be collected from a drain located at the Petron Seri Iskandar area (4° 21' 52.25" N, 100° 58' 46.74" E). This location have plenty and continuous flow of water especially after stormwater event. About 30 liter of runoff water sample will be collected from that area. The water sample then kept in a water container.

Figure 3.12: Satellite View of In-Situ Stormwater Collection Location

Figure 3.13: In-Situ Stormwater Collection Location

3.4.1.4 Dilution of In-Situ Stormwater

The stormwater then will be dilute with tap water in the water tank at Sewerage Treatment Plant UTP. About 30 liter of in-situ stormwater be diluted with 120 liter of tap water to achieve the targeted TSS concentration. During the test, the synthetic stormwater will be stirred before being flowed into the soil column to avoid any sediment settle in the water tank.

3.4.2 Stabilization Phase

Stabilization phase is important in order to let the plant adopted well to the soil and to enhance the plant growth in healthy condition. Usually, stabilization phase of the plant is conducted at least in four (4) weeks time, hence same time period is also applied in this project. However, the time period for stabilization phase can be change according to the plant condition. In this study, the plants are watered with tap water every day. There will be no addition of fertilizers to each plant to observe the capability of plant in growing with natural condition.

3.4.3 Test Run

Test run of this study will be performed in six (6) weeks. The flow of the test are:

i. 1st and 2nd week – Four times a week inflow runoff using synthetic stormwater
ii. 3rd and 4th week – Three times a week inflow runoff using synthetic stormwater
iii. 5th and 6th week – Once a week inflow runoff using synthetic stormwater

The hydraulic and hydrologic factors will be observed throughout the six (6) weeks which include of:

i. Inflow and outflow rate
ii. Water ponding volume
iii. Hydraulic retention time (HRT)
iv. Saturated hydraulic conductivity (K_{sat})
v. Evaporation rate

Table 3.3: Time flow of Test Run

PARAMETERS TO BE MONITORED		Inflow and Outflow Rate	Water Ponding Volume	Hydraulic retention time (HRT)	Saturated hydraulic conductivity *(Ksat)*	Evaporation rate
Week 1	M					
	T					
	W					
	T					
	F					
Week 2	M					
	T					
	W					
	T					
	F					
Week 3	M					
	T					
	W					
	T					
	F					
Week 4	M					
	T					
	W					
	T					
	F					
Week 5	M					
	T					
	W					
	T					
	F					
Week 6	M					
	T					
	W					

3.4.3.1 Inflow and Outflow Rate

Inflow and outflow rate is crucial in order to monitor the flow reduction rate produced by the system and to evaluate the hydrologic performance of the system. From this, the flow reduction of the system can be determined. About 14 liter of synthetic stormwater will be added to each of the column. Simple procedure to measure inflow rate are:

i. Synthetic stormwater is being poured slowly into soil column.
ii. At the same time, stopwatch is started. Stopwatch is stopped when all of the synthetic stormwater being poured.
iii. Inflow rate is calculated by dividing inflow volume with the time taken for all synthetic stormwater being poured.

Meanwhile, procedure to calculate outflow rate are:

i. Place measuring cylinder at the outlet valve to collect the outflow volume.
ii. Time for the runoff to start flow out from the system is taken until there's no more outflow produced.
iii. Outflow rate is calculated by dividing outflow volume with the time recorded earlier.

3.4.3.2 Water Ponding Volume

Once all the water inflow being poured into each of the column, at one point, water ponding will occurred. Water ponding volume will be calculated for each column by using the equation of volume for cylinder which is $V = \pi r^2 h$. H will be the height of water ponding.

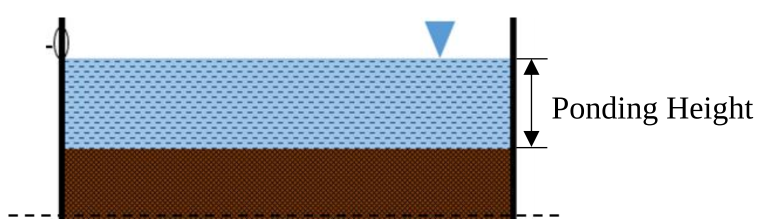


Figure 3.14: Water Ponding in Soil Column

3.4.3.3 Hydraulic Retention Time (HRT)

Hydraulic retention time is the time taken for the runoff to infiltrate through the filter media. It is usually expressed in hours or sometimes days. As soon as the influent runoff reach the surface of soil medium, the stopwatch will be start. Stopwatch will be stop when the flow of runoff already ready through the outlet valve. Time taken from the stopwatch is recorded as the hydraulic retention time for each columns in this study.

3.4.3.4 Saturated Hydraulic Conductivity (K_{sat})

Saturated hydraulic conductivity indicate the performance of infiltration process in bioretention system. This parameters can be computed based on the derivation of Darcy's Law equation.

$$K_{sat} = \frac{QL}{Ac\ (L+H)} \tag{4}$$

Where:

K_{sat} = Saturated hydraulic conductivity (mm/hr)
Q = Outflow rate (m^3/s)
L = Length of soil sample (m)
A_c = Cross sectional area of the cell (m^2)
H = Ponding depth at the top of engineered soil layer (m)

To test the saturated hydraulic conductivity, constant head method will be used. This method typically used for granular soil. Constant head method allows the water to move through the soil layer under a steady head condition while the volume of water flowing through the soil is measured over a period of time. In this project, the water ponding is set to be 100 mm height for all columns. Then, time taken for each of the column to collect 1 liter of outflow water will be recorded.

3.4.3.5 Evaporation Rate

Evaporation is the transformation of liquid water to water vapor. Evaporation rate of water from a water surface depends on several factors such as water temperature, air temperature air humidity and air velocity above the water surface.

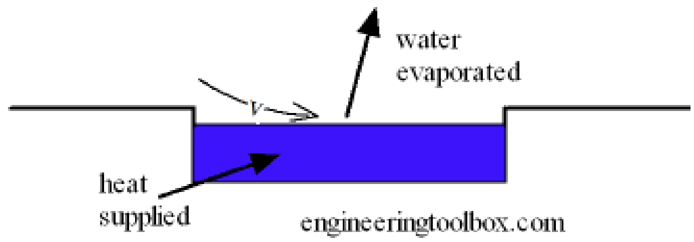


Figure 3.15: Process of Evaporation from Water Surface

To measure the evaporation rate in this study, a basin full of water will be placed at an open area. A measuring scale will be attached to the basin. The initial water level will be recorded and the water level drop also will be recorded every day in a week.

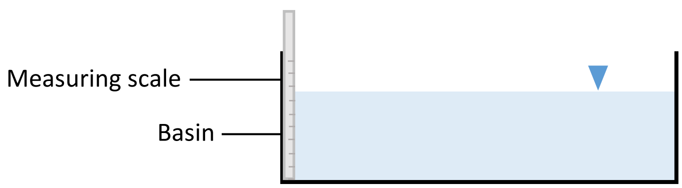


Figure 3.16: Schematic Drawing of Apparatus Set Up for Evaporation Rate Measure

3.5 Project Activities and Key Milestone

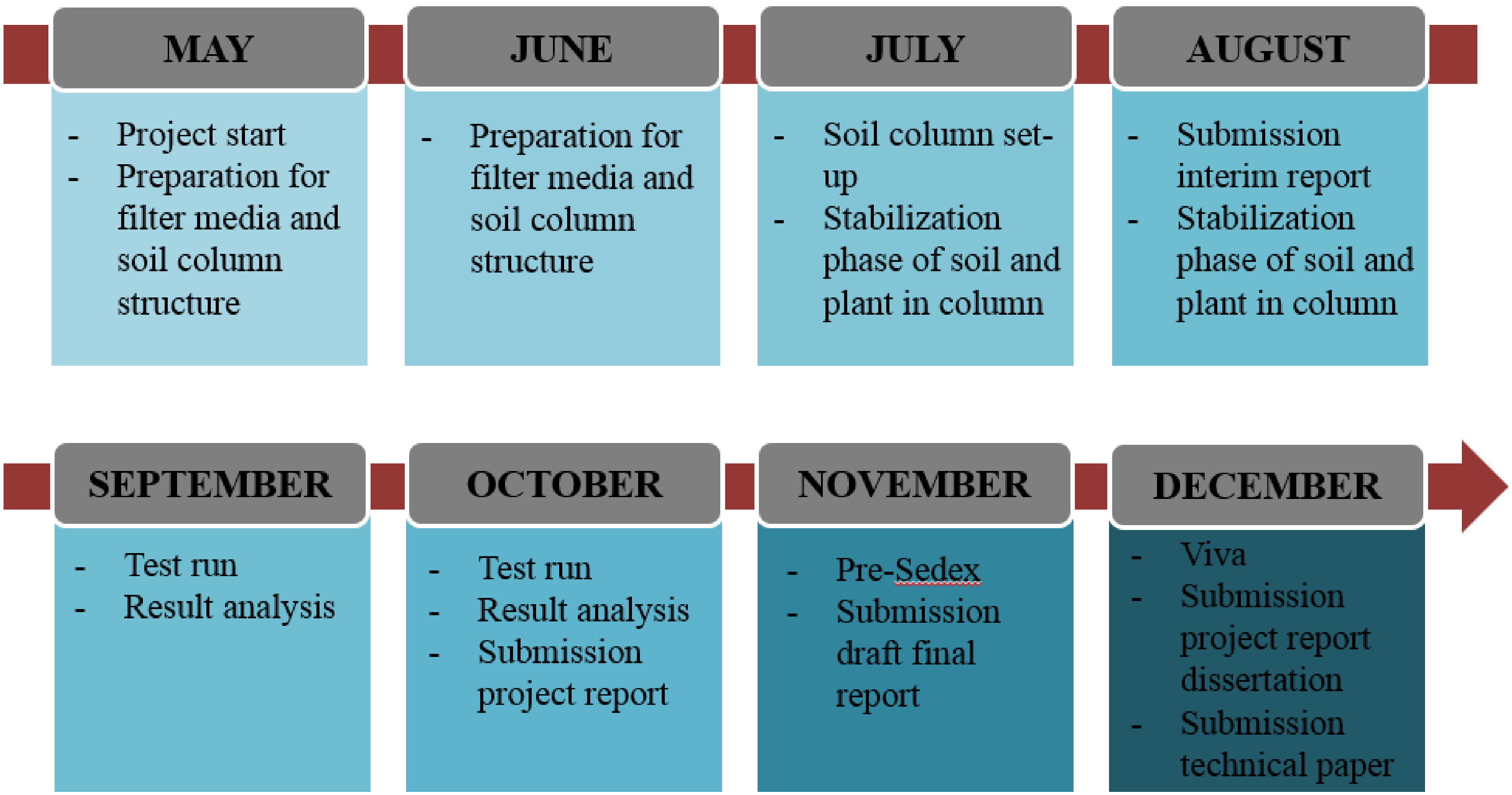


Figure 3.17: Project Activities and Key Milestone

3.6 Gantt Chart

3.6.1 Timeline for FYP 1

Table 3.4: Timeline for FYP 1

No	Activities	May			June				July				August		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of FYP topic														
2	Brief explanation of FYP topic with supervisor														
3	**Project Preparation:** • Filter Media • Soil Column Structure														
4	Soil Column Set-Up														
5	Extended Proposal Preparation														
6	Submission of Extended Proposal														
7	Hari Raya Holiday														
8	Stabilization of Soil in Column and Plant														
9	Proposal Defense														
10	Interim Report Preparation														
11	Submission of Interim Draft Report														
12	Submission of Interim Report														

3.6.2 Timeline for FYP 2

Table 3.5: Timeline for FYP 2

No	Activities	September			October				November				December		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Test Run:** • Preparation of Synthetic Stormwater														
	• Everyday runoff flow														
	• Three times a week runoff flow														
	• Once a week runoff flow														
2	Result Analysis & Discussion														
3	Progress Report Preparation														
4	Submission of Progress Report														
5	Final Report Preparation														
6	Pre-SEDEX														
7	Submission of Draft Final Report														
8	Submission of Dissertation (Soft Bound)														
9	Submission of Technical Paper														
10	Viva														
11	Submission of Project Dissertation (Hard Bound)														

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Overview

This chapter discusses the results obtained throughout the study. Some analysis and discussion for each result is done to analyze the possible reason for each situation happened throughout the study period. The results for this project is divided into two (2) parts which include during stabilization phase and during test run phase. To ensure the results and discussion to be clear and easily understandable, some indication and key word for each soil columns is given. The indication and key word for each soil columns can be referred as in Table 4.1.

Table 4.1: Indication and Key Word for Soil Columns

Key Word	**Soil Column Detail**
Column 1	Hibiscus Plant + Organic Soil Compost
Column 2	Hibiscus Plant + Rabbit's Manure Compost
Column 3	Hibiscus Plant + No Compost
Column 4	Ixora Plant + Organic Soil Compost
Column 5	Ixora Plant + Rabbit's Manure Compost
Column 6	Ixora Plant + No Compost
Column 7	Control Colum (No Plant + No Compost)

4.2 Compost Characteristic

4.2.1 Moisture Percentage Content

Table 4.2: Result for Moisture Percentage Content Test

Compost Type	W_w (g)	W_d (g)	Moisture Percentage Content (%)
Organic Compost	10.00	3.90	61.0
Rabbit’s Manure Compost	10.00	6.89	31.1

From Table 4.2, it can be observed that organic compost have twice higher percentage of moisture content compared to rabbit’s manure compost with 61.0%. It shows that organic compost is more permeable and can retain water more compared to rabbit’s manure compost.

4.2.2 pH Value

Table 4.3: Result for pH Value Test

Compost Type	pH Value
Organic Compost	6.58
Rabbit’s Manure Compost	7.46

Table 4.3 shows that organic compost have lower pH value compared rabbit’s manure compost with value of 6.58 and 7.46 respectively. Organic compost is acidic and almost approaching to neutral condition meanwhile rabbit’s manure compost is alkali. According to United States Environmental Protection Agency (2017), the pH value for normal rain is 5.6. Organic compost have the pH value nearer to the normal rain pH value which is safer for environmental.

4.2.3 Conductivity Value

Table 4.4: Result for Conductivity Value Test

Compost Type	Conductivity Value
Organic Compost	1.1 @ 1000
Rabbit's Manure Compost	2.4 @1000

Conductivity measurements describe the concentration of dissolved solids which have been ionized in water. According to Table 4.4, Rabbit's manure compost have higher conductivity value which is 2.4@1000 compared to organic compost which is 1.1@1000.

4.3 Stabilization Phase

Stabilization phase is done with purpose to let the plant adopt well to the soil and to ensure the plant can grow healthily before being watered using synthetic stormwater. During this phase, each of the plant in soil column is watered using tap water every day. Throughout the period, the inflow and outflow rate, the flow reduction, water ponding volume, hydraulic retention time (HRT) as well as the saturated hydraulic conductivity (K_{sat}) for each soil column is being monitored. Other than that, the evaporation rate at Sewerage Treatment Plant (STP) area is also being observed.

4.3.1 Inflow and Outflow Rate

About 14 liter of tap water is used for each of the soil column as the inflow volume. This amount is calculated based on Urban Stormwater Manual Malaysia, DID, (2012), assuming that the bioretention basin is going to serve a catchment area of 400 m^2 with 275 m^2 of permeable area and 125 m^2 of impermeable area.

Table 4.5: Average Inflow Rate by Week during Stabilization Phase

Week	**1**	**2**	**3**
	Average Inflow Rate X 10^{-5} (m^3/s)		
Column 1	2.57	2.55	2.49
Column 2	2.62	2.47	2.55
Column 3	2.52	2.61	2.50
Column 4	2.65	2.52	2.53
Column 5	2.69	2.53	2.52
Column 6	2.72	2.53	2.45
Column 7	2.65	2.63	2.53

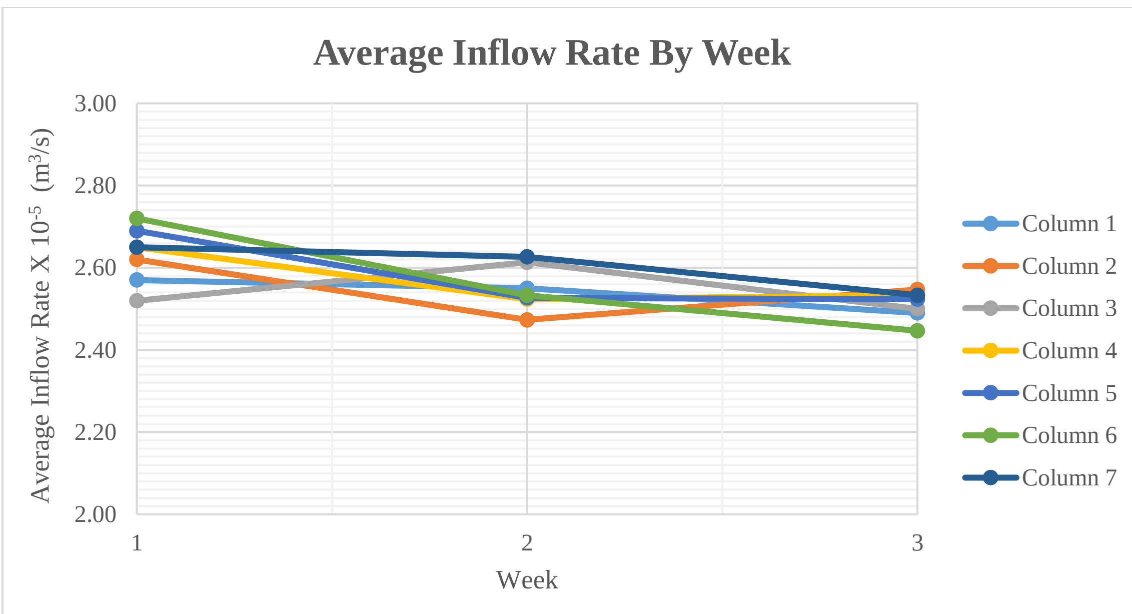


Figure 4.1: Graph of Average Inflow Rate by Week during Stabilization Phase

From Table 4.5 and Figure 4.1, the average inflow rate from Week 1 until Week 3 is almost same for all columns, varying from 2.5 X 10^{-5} m^3/s to 2.72 X 10^{-5} m^3/s. This s because the author control the inflow rate for all columns throughout the stabilization phase.

Table 4.6: Average Outflow Rate by Week during Stabilization Phase

Week	1	2	3
	Average Outflow Rate X 10^{-5} (m^3/s)		
Column 1	0.25	0.40	0.37
Column 2	0.45	0.36	0.33
Column 3	0.11	0.14	0.14
Column 4	0.29	0.38	0.30
Column 5	0.64	0.71	0.42
Column 6	0.73	0.80	0.89
Column 7	0.09	0.14	0.10

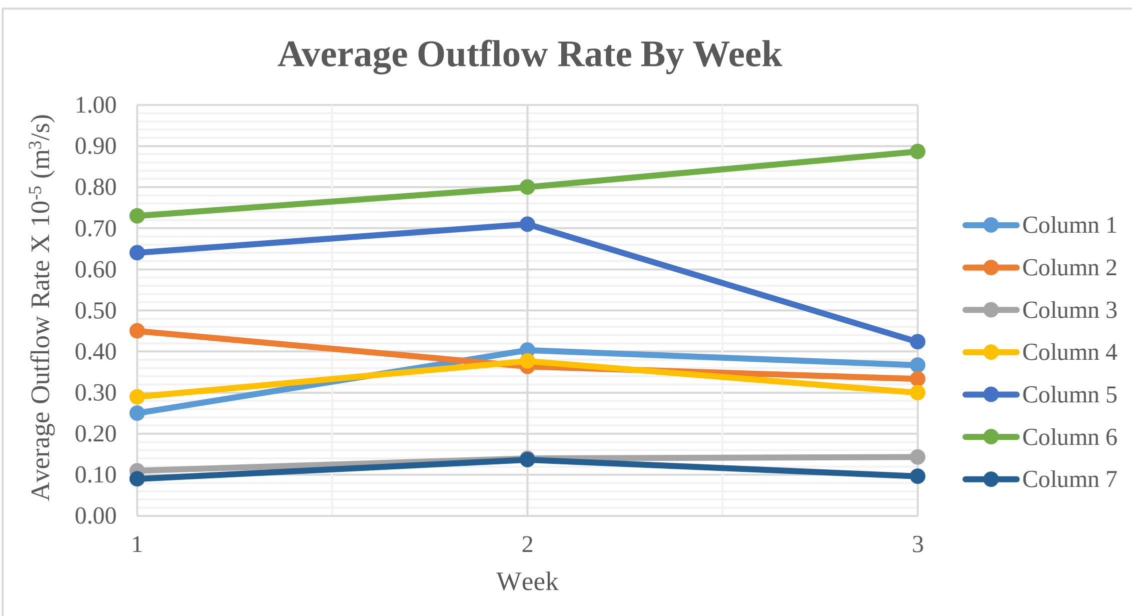


Figure 4.2: Graph of Average Outflow Rate by Week during Stabilization Phase

Meanwhile according to Figure 4.2, it can be seen that the outflow rate for each soil columns and each week varies from each other. Column 6 has the highest average outflow rate from Week 1 until Week 3 which is 0.73 X 10^{-5} m^3/s, 0.80 X 10^{-5} m^3/s and 0.89 X 10^{-5} m^3/s respectively. It has no mixture of compost in the soil medium used, thus, the water can move through the soil easily as soil has high permeability rate. Meanwhile the lowest average outflow rate throughout all the stabilization phase is Column 3 and

Column 7 which range from 0.09 X 10^{-5} m^3/s until 0.14 X 10^{-5} m^3/s. Unlike the other columns which used course sand size, both of Column 3 and 7 used medium sand size. Since the sand is in smaller size, thus it have smaller voids between the sand particles, making the water hard to flow through the sand layer. For Column 2 and Column 5, the average outflow rate is decreasing throughout the time, varying from 0.33 X 10^{-5} m^3/s to 0.64 X 10^{-5} m^3/s. Presence of moss can be observe at the outlet pipe of both columns starting from Week 2. This might affect the outflow rate of each columns because the moss might be blocking the outlet valve from inside of the columns. Lastly for Column 1 and Column 4, the average outflow rate trend can be observed to be increasing at Week 2 but starting to decrease at Week 3. The mixture of soil and compost particle might be settle and filling the voids between them by end of Week 2, causing the water hard to flow through, thus reducing the outflow rate of each columns.

4.3.2 Flow Reduction

From the recorded inflow and outflow rate, the flow reduction for each soil column can be determined. Flow reduction is one of the important aspect to be monitored as the main function of bioretention basin is to reduce the stormwater runoff flow during storm event. A good bioretention system should have a good flow reduction and at the same time have enough time to flush all the water retained to get ready for the next storm event. In this project, the average percentage of flow reduction for each soil columns can be summarized as in Table 4.7.

Table 4.7: Average Flow Reduction Percentage by Week during Stabilization Phase

Week	**1**	**2**	**3**
	Average Flow Reduction (%)		
Column 1	90.3	84.17	85.26
Column 2	82.8	85.10	86.91
Column 3	95.6	94.64	94.25
Column 4	89.1	85.30	88.42
Column 5	76.2	71.99	83.79
Column 6	75.5	68.17	63.73
Column 7	96.6	94.81	96.19

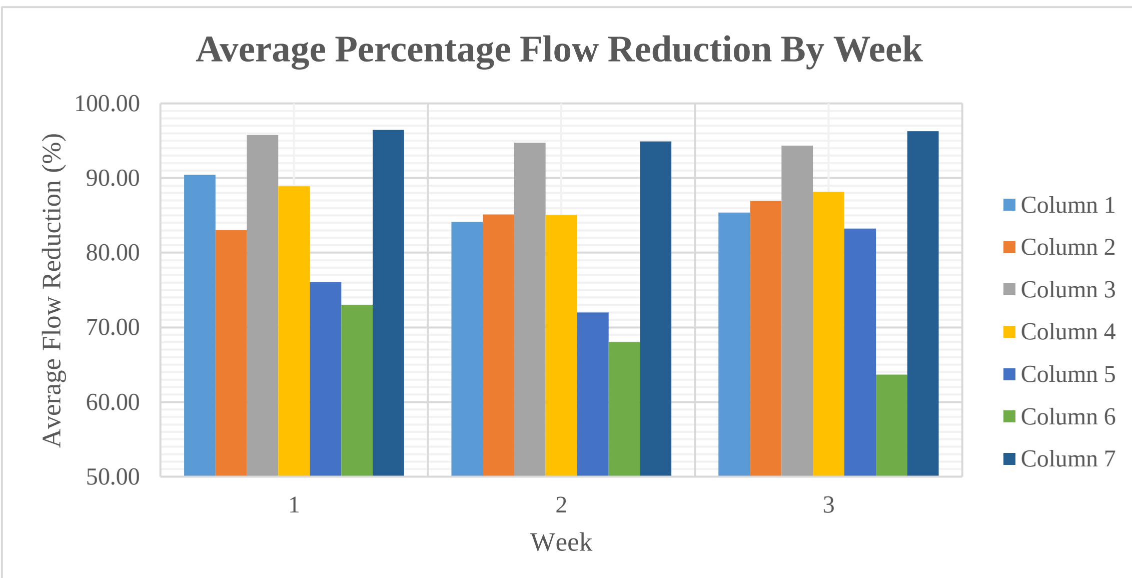


Figure 4.3: Graph of Average Percentage Flow Reduction by Week during Stabilization Phase

Following the outflow rate, the flow reduction for each soil columns will also varies from each other. The highest flow reduction percentage is from Column 3 and Column 7 which varies from 94.25% until 96.0%. This is because the sand used as the transition layer in these columns are medium size, hence, the porosity of the sand is lower due to smaller voids between the sand particles making the water hard to flow through the sand layer. The trend for Column 1, Column 4 and Column 5 is decreasing by Week 2 and starting to increase by Week 3. The mixture of soil and compost particle might be settle and filling the voids between them by end of Week 2, causing the water hard to flow, thus increasing the quantity of water retained and increase the percentage of flow reduction of each column. For Column 2, the average percentage flow reduction keep increasing throughout week 1 until Week 3 with values of 82.8%, 85.10% and 86.91% respectively. Column 2 consist of mixture of soil and compost, thus throughout the time, the mixture of soil and compost might be settle well, filling the voids between them and making the water hard to filtrate. Meanwhile for Column 6, the average flow reduction percentage keep decreasing throughout the period from Week 1 until Week 3 with values of 75.5%, 68.17% and 63.73% respectively. Although there is no mixture of soil and compost in Column 6, but the soil settle well and filling the voids between them. This eventually not affect the filtration rate of the water because soil is highly permeable and can allow the filtration to occur without any problem.

4.3.3 Water Ponding Volume

Water ponding volume is depend to the capability of the soil to filtrate the water. If the soil have high porosity and can filtrate the water easily, the water ponding volume will be lesser. Meanwhile if the soil have difficulty to filtrate the water, the water ponding volume will be higher as the water flow really slowly throughout the soil medium layer.

Table 4.8: Average Water Ponding Volume by Week during Stabilization Phase

Week	**1**	**2**	**3**
	Average Water Ponding Volume (m^3)		
Column 1	0.0049	0.0098	0.0106
Column 2	0.0064	0.0099	0.0111
Column 3	0.0067	0.0105	0.0106
Column 4	0.0053	0.0097	0.0108
Column 5	0.0046	0.0082	0.0116
Column 6	0.0042	0.0055	0.0053
Column 7	0.0092	0.0115	0.0119

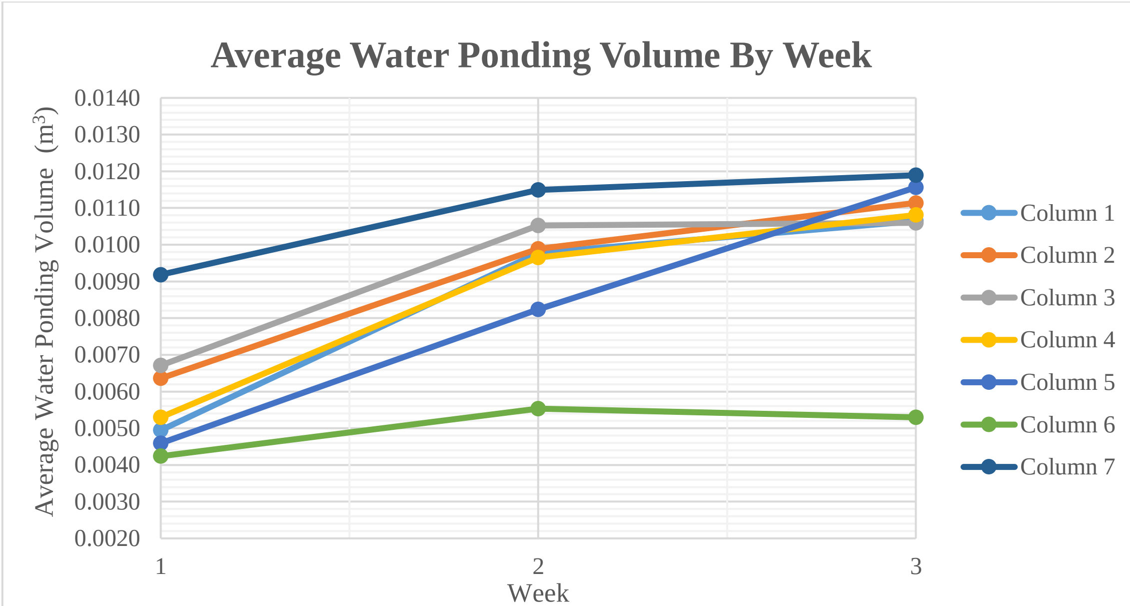


Figure 4.4: Graph of Average Water Ponding Volume by Week during Stabilization Phase

Supposedly, the water ponding volume should be increasing by time because as the time passing by, the soil and sand layer will settle, making the water hard to filtrate through them. Thus, there will be high amount of water ponding height at the top surface of bioretention basin. All columns except Column 6 follows this trend accordingly. By time passing by, their water ponding volume increasing, varying from 0.0046 m^3 to 0.0119 m^3. However for Column 6, the water ponding volume increasing and then decreasing from Week 1 until Week 3 with values of 0.0042 m^3, 0.0055 m^3 and 0.0053 m^3 respectively. This shows that the water is not retained in long time by the soil as time passing by. The water just filtrate through the soil and sand layer without any retaining occur during the process.

4.3.4 Hydraulic Retention Time (HRT)

Hydraulic retention time is the length of time that the water remains in the storage basin. To design a good bioretention basin with purpose to prevent flood from happening at the down drift area, it must have a good hydraulic retention time. A good hydraulic retention time does not always mean to have a long retention time. Instead, it must have a good length of time enough to retain the water within the soil for a while and later get ready to flush all the water out from the soil to cater for the next storm event.

Table 4.9: Average Hydraulic Retention Time by Week during Stabilization Phase

Week	1	2	3
	Average Hydraulic Retention Time (hour)		
Column 1	0.2969	0.2253	0.2885
Column 2	0.2653	0.3169	0.3409
Column 3	0.8319	0.4915	0.4508
Column 4	0.2953	0.1605	0.2789
Column 5	0.1747	0.2272	0.2294
Column 6	0.2325	0.1590	0.1481
Column 7	0.7297	0.6099	0.6291

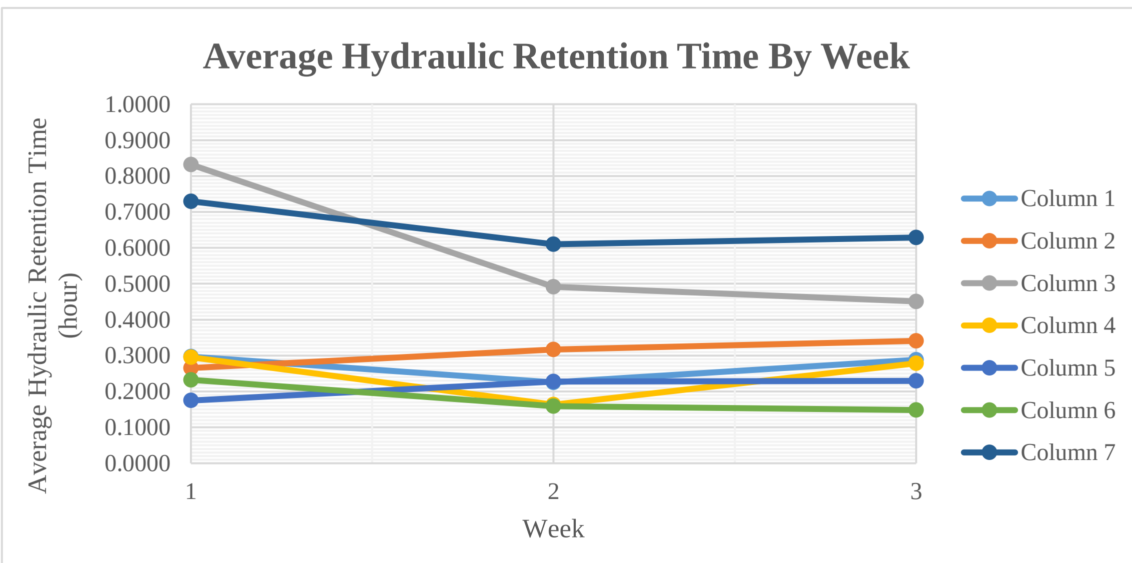


Figure 4.5: Graph of Average Hydraulic Retention Time by Week during Stabilization Phase

According to Figure 4.5, the hydraulic retention time for each columns is almost in the same range, varying from 0.2325 hour until 0.3409 hour except for Column 3 and Column 7. Column 3 and Column 7 both used the medium sand size as the transition layer, thus it might affecting the hydraulic retention time of the soil during this study. The trend of hydraulic retention time for Column 2 and Column 5 keep increasing throughout the stabilization phase. This shows that across the time, the flow of water through that soil mixtures with rabbit's manure compost is quiet slow. Meanwhile for Column 1 and Column 4, which consist the mixture of soil with organic compost also shows the same trend of their hydraulic retention time, decreasing at Week 2 and then increasing by Week 3. Unlike Column 6, the average hydraulic retention time keep decreasing by Week 1 until Week 3 with values of 0.7297 hour, 0.6099 hour and 0.6291 hour respectively. This illustrate that the soil with no compost has no capability to retain water as time passing by.

4.3.5 Saturated Hydraulic Conductivity (*Ksat*)

Saturated hydraulic conductivity (*Ksat*) describes as the movement of water through the saturated media. During this phase, the reading for saturated hydraulic conductivity is taken twice in a week. The author did not manage to take any reading of saturated hydraulic retention time in Week 1.

Table 4.10: Average Saturated Hydraulic Conductivity by Week during Stabilization Phase

Week	**2**	**3**
	Average Saturated Hydraulic Conductivity (mm/hr)	
Column 1	286.90	254.19
Column 2	199.15	198.72
Column 3	82.90	86.02
Column 4	131.00	171.68
Column 5	131.77	164.76
Column 6	579.63	661.67
Column 7	72.11	75.68

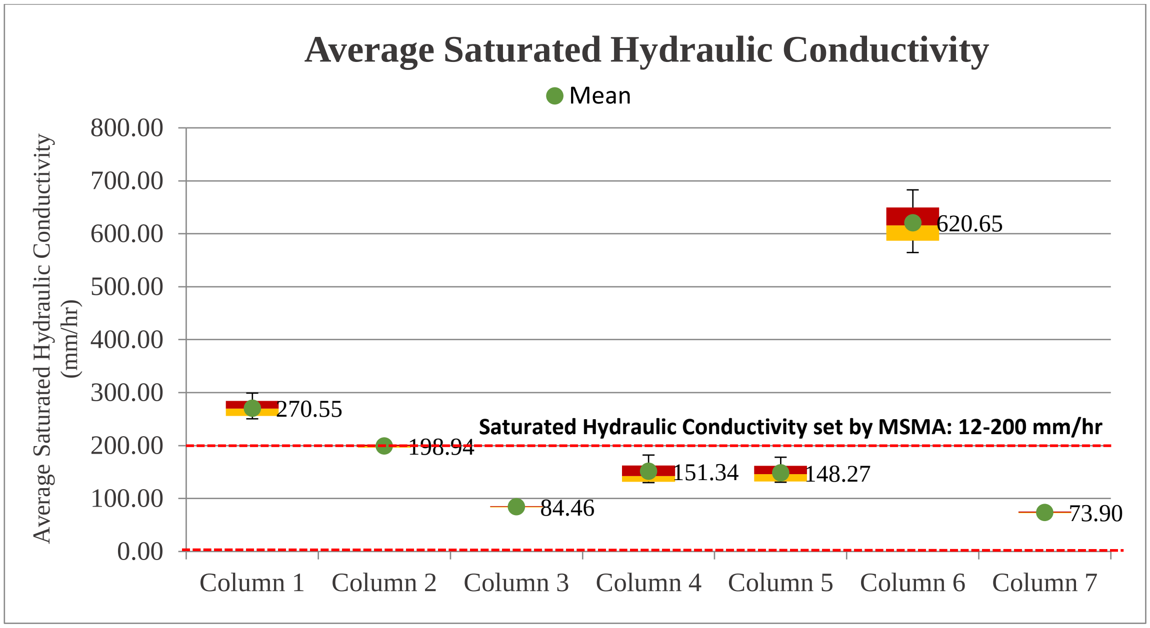


Figure 4.6: Graph of Average Saturated Hydraulic Conductivity during Stabilization Phase

The saturated hydraulic conductivity (*Ksat*) set by MSMA to be used in bioretention system is in range from 12 mm/hr to 200 mm/hr. According to MSMA (2012), the maximum saturated hydraulic conductivity (*Ksat*) 200 mm/hr is the sufficient soil moisture needed by the system to sustain vegetation growth. If the saturated hydraulic conductivity (Ksat) is too much or too less, it is not good for the plant growth. Other than that, saturated hydraulic conductivity *(Ksat)* also describe the moisture content in the soil mixture. If the saturated hydraulic conductivity *(Ksat)* is higher, it shows that the moisture content in the soil mixture is also higher. Thus, potential for clogging to happen in the system is lower because the water can flow easily in saturated condition. Potential for clogging to happen is higher if the saturated hydraulic conductivity *(Ksat)* is lower because even in saturated condition, the water still have difficulty to flow through the soil.

From Figure 4.6, it can be conclude that the average saturated hydraulic conductivity *(Ksat)* from Column 1 and Column 6 is already out from the range set by MSMA. This shows that the moisture content in both column is not suitable to sustain the plant growth. The lowest average saturated hydraulic conductivity is coming from Column 3 and Column 7 with values of 84.46 mm/hr and 73.90 mm/hr respectively. This is because the sand used in the transition layer is in medium size. Thus, the flow of the water in saturated soil condition might be affected due to smaller sand size particle. Column 1 and Column 4 which consist organic compost have higher average saturated hydraulic conductivity *(Ksat)* compared to Column 2 and Column 5 which have rabbit's manure compost. This shows that organic compost is more permeable and can retain the water more compared to rabbit's manure thus increasing the moisture content and the saturated hydraulic conductivity *(Ksat)* of the soil mixture.

4.3.6 Evaporation Rate

Evaporation rate at UTP's Sewerage Treatment Plant (STP) is also being monitored. This test is done to see if evaporation process does really have significant effect affecting the water ponding build up at the top surface in bioretention basins. Factors that might affecting the evaporation rate include of concentration and humidity of the air, the temperature of the surrounding, the air flow rate, the pressure at that area and also the surface area of the basin. The reduction of water level in evaporation rate basin test is observed weekly. The evaporation rate basin test area is 350 mm x 250 mm.

Table 4.11: Average Evaporation Rate by Week during Stabilization Phase

Week	Evaporation Rate (m^3/week)
1	0.0009
2	0.0013
3	0.0011

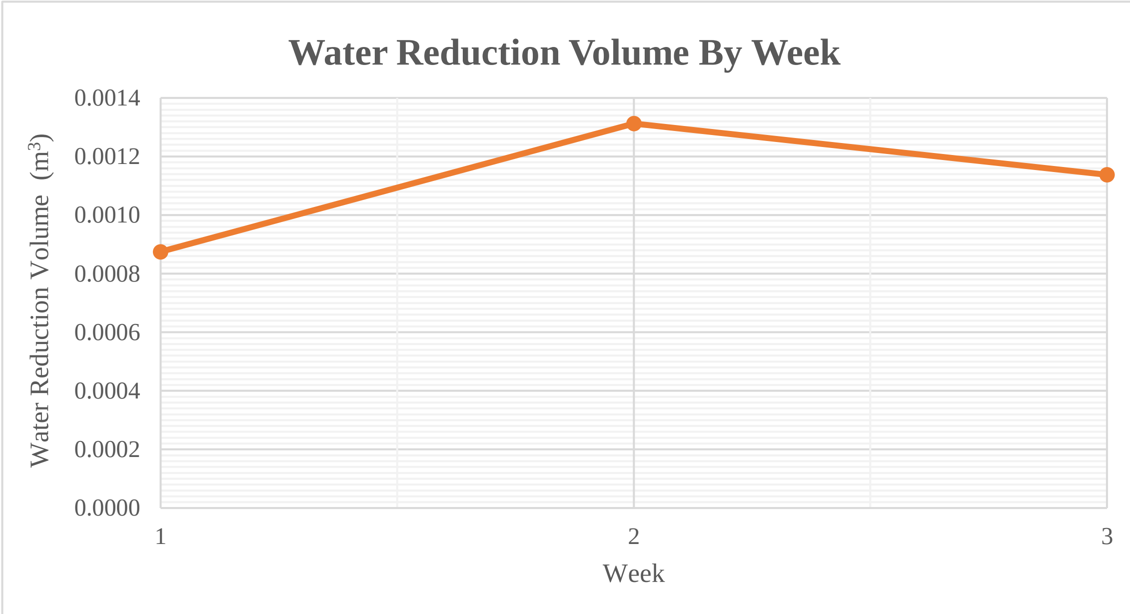


Figure 4.7: Graph of Average Evaporation Rate by Week during Stabilization Phase

The highest evaporation rate during stabilization phase is in Week 2 with an average water reduction volume about 0.0013 m^3/week. During that time, the surrounding temperature is very high. Meanwhile the lowest evaporation rate during the phase is in Week 1 with an average water reduction volume of 0.0009 m^3/week. In Week 1, almost every evening was raining at Seri Iskandar, thus reducing the surrounding temperature and the air humidity. Week 3 has average evaporation rate with value of water reduction volume by 0.0011 m^3/week.

4.4 Correlation between Hydraulic and Hydrologic Parameters during Stabilization Phase

Correlations

		Inflow_Rate	Outflow_Rate	Percentage_Flow_Reduction	Water_Ponding_Volume	Hydraulic_Retention_Time	Saturated_Hydraulic_Conductivity	Evaporation_Rate
Inflow_Rate	Pearson Correlation	1	-.186	.248	-.047	.135	.030	-.619
	Sig. (2-tailed)		.201	.086	.746	.354	.881	.575
	N	49	49	49	49	49	28	3
Outflow_Rate	Pearson Correlation	-.186	1	-.997**	-.688**	-.724**	.068	.885
	Sig. (2-tailed)	.201		.000	.000	.000	.730	.308
	N	49	49	49	49	49	28	3
Percentage_Flow_Reduction	Pearson Correlation	.248	-.997**	1	.674**	.717**	-.059	-.941
	Sig. (2-tailed)	.086	.000		.000	.000	.764	.219
	N	49	49	49	49	49	28	3
Water_Ponding_Volume	Pearson Correlation	-.047	-.688**	.674**	1	.424**	-.367	.763
	Sig. (2-tailed)	.746	.000	.000		.002	.055	.447
	N	49	49	49	49	49	28	3
Hydraulic_Retention_Time	Pearson Correlation	.135	-.724**	.717**	.424**	1	-.174	-.976
	Sig. (2-tailed)	.354	.000	.000	.002		.376	.139
	N	49	49	49	49	49	28	3
Saturated_Hydraulic_Conductivity	Pearson Correlation	.030	.068	-.059	-.367	-.174	1	.265
	Sig. (2-tailed)	.881	.730	.764	.055	.376		.829
	N	28	28	28	28	28	28	3
Evaporation_Rate	Pearson Correlation	-.619	.885	-.941	.763	-.976	.265	1
	Sig. (2-tailed)	.575	.308	.219	.447	.139	.829	
	N	3	3	3	3	3	3	3

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.8: Correlation between Hydraulic and Hydrologic Parameters during Stabilization Phase

Analysis on the correlation between the hydraulic and hydrologic parameters have been done by using SPSS software. Usually, values ranging from 0.8-1.0 shows that the parameters been analyze have strong correlation. Meanwhile range of 0.5-0.7 shows that the parameters have intermediate correlation and values less than 0.5 shows that the parameters being observe have weak correlation between each other. From Figure 4.8, it can be observe that outflow rate and percentage of flow reduction have the highest correlation with values of -0.997. Negative sign shows the inverse relation between them which mean that the higher the outflow rate, the lesser the percentage flow reduction produced by the soil column system. This is because as the flow rate of the runoff is higher, the water is less retained in the soil mixture because the soil does not retain and absorb the water, thus the flow reduction will be lesser. Meanwhile the lowest correlation is between the inflow rate and saturated hydraulic conductivity *(Ksat)*. Saturated hydraulic conductivity *(Ksat)* of the soil does not depend on the inflow rate. In fact, the filtration rate of the soil does affect the saturated hydraulic conductivity *(Ksat)*. In this case, the water ponding volume and the hydraulic retention time of the system is most likely relatable to illustrate the infiltration rate of the soil.

4.5 Physical Condition of Plants and Soil Column Structures throughout Stabilization Phase

Throughout the stabilization phase, the physical condition of the plant and the changes of soil column structure is also being observed. The plants is observed if they can grow healthily and can adopt well to the soil. Intentionally, there is no addition of fertilizers to the plant to analyze the capability of the plant in growing in natural condition. Meanwhile for the soil column structure, any physical changes that might happened is also being monitored. For instance, if there is any leaking occurs at the outlet valve of the column or any other environment effect happening at the column structure by time passing by.

4.5.1 Condition of Plants

Throughout the stabilization phase, the plant is observe to grow healthily and can adopt well to the soil mixture used. Hibiscus plant in Column 1, 2 and 3 is observed to grow healthily and they produced a lot of leaf and sometimes also producing bud and flowers. Same observation goes to Column 4, 5 and 6 where the Ixora plant is planted. They grow healthily without any sign to go wild. Thus, the stabilization phase is shorten from four (4) weeks to three (3) weeks only.

(a) Column 1

(b) Column 2

(c) Column 3

(d) Column 4

(e) Column 5

(f) Column 6

Figure 4.9: Physical Condition of Plants by the End of Stabilization Phase

4.5.2 Condition of Soil Column Structures

Throughout the stabilization phase, there is no significant leaking occurs at the outlet valve of the columns. Unfortunately, there is presence of moss occurring at the outlet pipeline at Column 2 and Column 5. Moss likely to occur at that area due to cool and moist condition. By time passing by, the presence of moss will increase and eventually will affect the flow rate of water. If the condition become worsen, clogging might happen because the moss is blocking the outlet valve of the column.

(a) Column 2

(b) Column 5

Figure 4.10: Presence of Moss at Outlet Pipeline at Column 2 and Column 5

Figure 4.11: Soil Column 1 Until 7

4.6 Test Run Phase

Test run in this study have been done in six (6) weeks time. The amount of inflow intake for each soil column have been done according in Table 4.12. Same as in stabilization phase, throughout this six (6) weeks period, the inflow and outflow rate, the flow reduction, water ponding volume, hydraulic retention time (HRT), the saturated hydraulic conductivity (K_{sat}) for each soil column and the evaporation rate at Sewerage Treatment Plant (STP) area are also being monitored and observed.

Table 4.12: Designed Inflow Intake for Each Soil Column during Test Run

Week	Inflow Intake	Purpose
Week 1 and 2	Four (4) times a week	To illustrate wet condition (raining everyday)
Week 3 and 4	Three (3) times a week	To illustrate normal condition
Week 5 and 6	Once (1) a week	To illustrate dry condition (rarely raining)

4.6.1 Inflow and Outflow Rate

Same as during stabilization phase, about 14 liter of synthetic stormwater is used for each of the soil column as the inflow volume. Table 4.13 and Figure 4.12 shows the trend of weekly inflow rate meanwhile Table 4.14 and Figure 4.13 shows the trend of weekly outflow rate for each of soil column throughout the test run period

Table 4.13: Average Inflow Rate by Week during Test Run Phase

Week	**1**	**2**	**3**	**4**	**5**	**6**
	Average Inflow Rate X 10^{-5} (m^3/s)					
Column 1	6.08	5.98	6.07	6.05	6.06	6.03
Column 2	5.94	6.02	6.04	6.08	6.11	5.91
Column 3	5.98	6.03	6.02	6.05	6.06	5.83
Column 4	5.94	5.97	6.06	5.96	5.96	5.91
Column 5	5.90	5.90	5.99	6.03	5.96	5.86
Column 6	6.04	5.98	6.02	5.87	6.09	6.06
Column 7	6.00	5.99	5.96	5.96	6.03	6.09

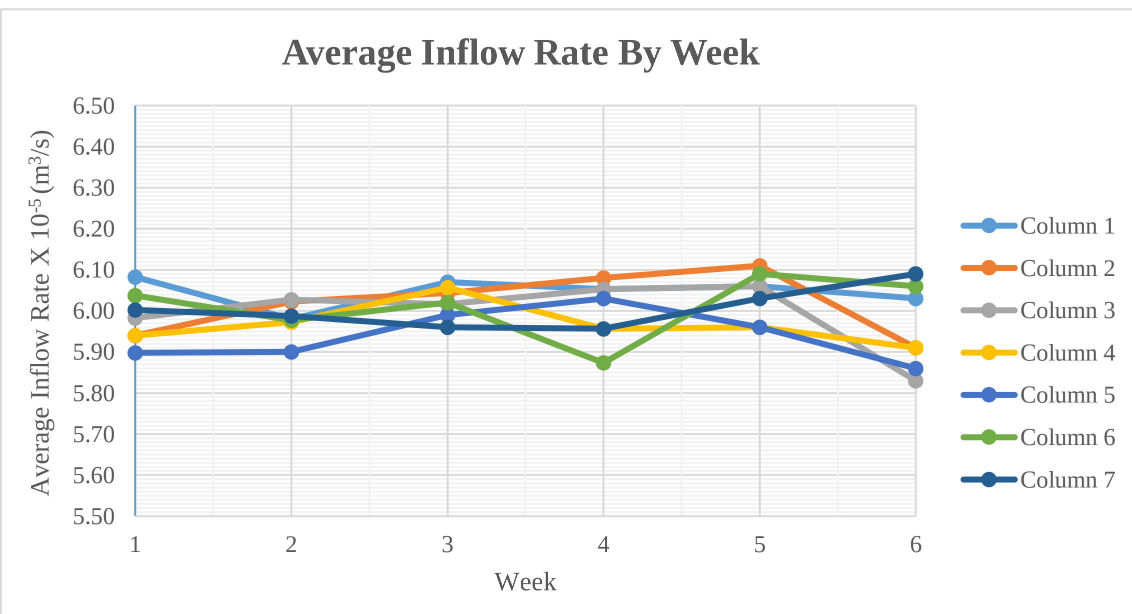


Figure 4.12: Graph of Average Inflow Rate by Week during Test Run Phase

From Table 4.13 and Figure 4.12, there is no dramatic changes can be observed for the inflow rate of all columns throughout the six (6) weeks period. The inflow rate for all columns only varies in small range which is from 5.87 X 10^{-5} m^3/s to 6.11 X 10^{-5} m^3/s. This is because the author control the inflow rate for all columns.

Table 4.14: Average Outflow Rate by Week during Test Run Phase

Week	**1**	**2**	**3**	**4**	**5**	**6**
	Average Outflow Rate X 10^{-5} (m^3/s)					
Column 1	0.48	0.46	0.48	0.47	0.50	0.50
Column 2	0.53	0.48	0.54	0.53	0.55	0.55
Column 3	0.23	0.19	0.22	0.22	0.23	0.23
Column 4	0.49	0.49	0.52	0.51	0.52	0.51
Column 5	0.71	0.67	0.70	0.81	0.83	0.81
Column 6	0.67	0.66	0.72	0.77	0.77	0.75
Column 7	0.16	0.14	0.15	0.15	0.16	0.15

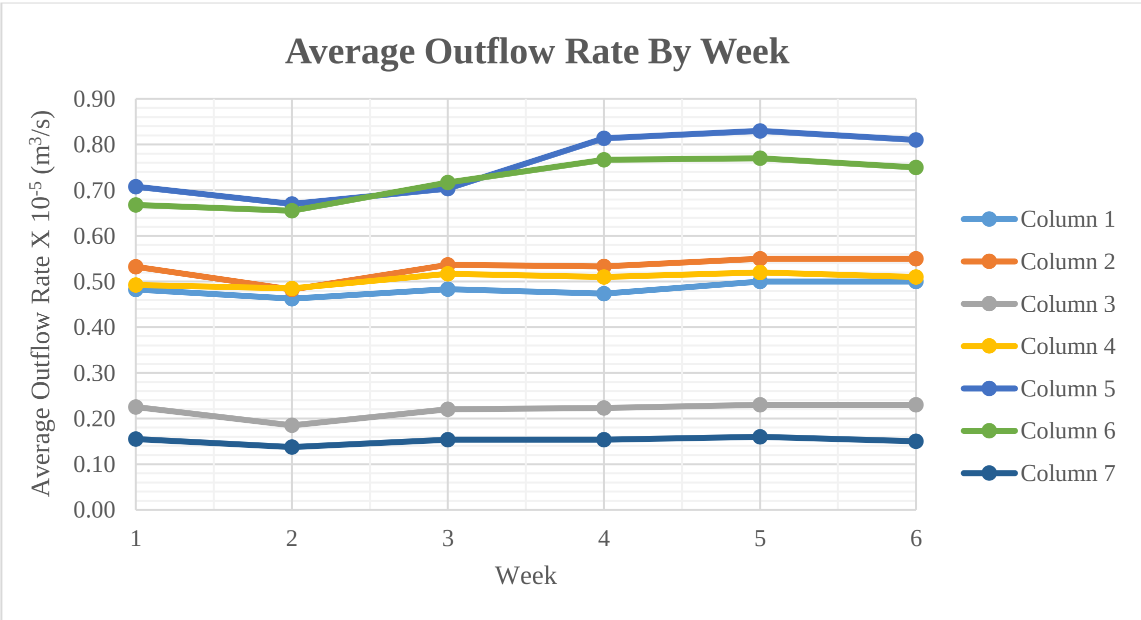


Figure 4.13: Graph of Average Outflow Rate by Week during Test Run Phase

In contrast with inflow rate, the outflow rate for each of the soil columns is varies from one another. This is because the outflow rate depend onto the permeability and porosity of the soil mixture with compost. According in Figure 4.14, the lowest outflow rate throughout the test run phase is coming from Column 3 and Column 7 with value of 0.22 m^3/s and 0.15 m^3/s respectively. This is because the sand used as the transition layer in both soil columns are medium sand size. Thus, the water cannot flow and filtrate easily in both columns compared to other columns that used course sand size as the transition layer. For Column 1 and Column 4 which have organic compost, they have slightly small outflow rate with values 0.48 m^3/s and 0.51 m^3/s respectively compared to Column 2 (0.53 m^3/s) and Column 5 (0.76 m^3/s) that have rabbit's manure compost. This is mainly because the organic compost have smaller particle size compared to rabbit's manure compost, thus they have less porosity which will lead to difficulty for the water to flow through and give the smaller outflow rate result. Meanwhile for rabbit's manure compost which have bigger particle size, the porosity of the soil mixture is higher, then enhancing the water to flow easily through the soil layer. In addition, it also can be conclude that the permeability of the organic compost is higher than rabbit's manure compost. Due to higher permeability, the water takes time to flow through the soil mixture layer because the soil mixtures first will absorb the water before let them flow through.

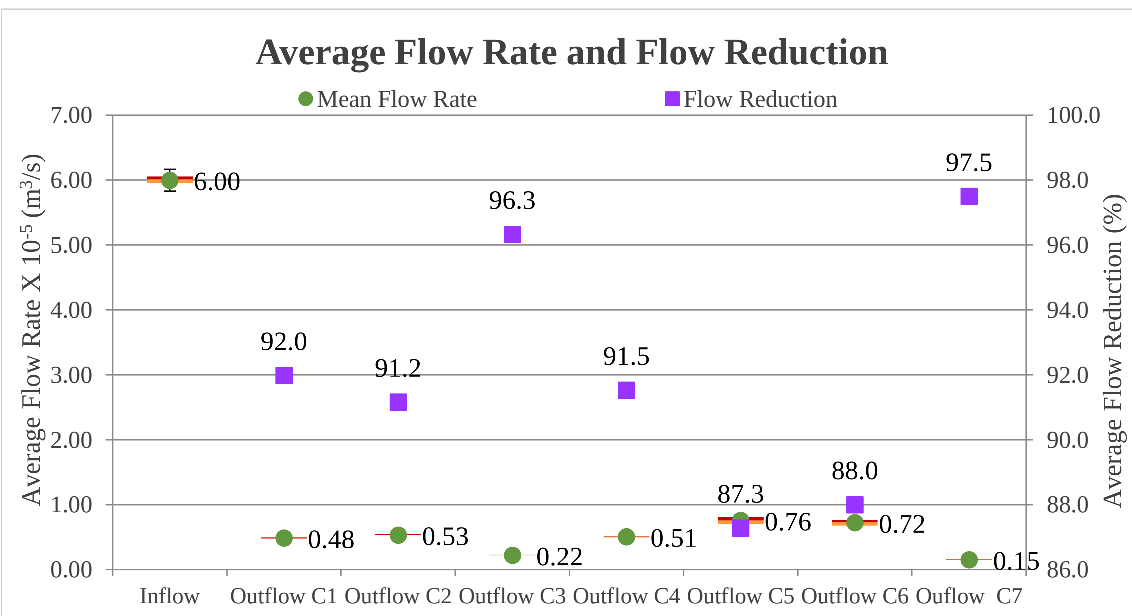


Figure 4.14: Graph of Average Flow Rate and Flow Reduction throughout Test Run Phase

4.6.2 Flow Reduction

Table 4.15: Average Flow Reduction by Week during Test Run Phase

Week	1	2	3	4	5	6
	Average Flow Reduction (%)					
Column 1	92.1	92.3	92.0	91.9	91.8	91.8
Column 2	91.1	92.0	91.1	91.2	91.0	90.6
Column 3	96.3	96.9	96.3	96.4	96.1	96.0
Column 4	91.7	91.9	91.5	91.4	91.3	91.3
Column 5	88.0	88.7	88.3	86.4	86.1	86.2
Column 6	88.9	89.0	88.1	87.0	87.4	87.6
Column 7	97.4	97.7	97.5	97.4	97.4	97.5

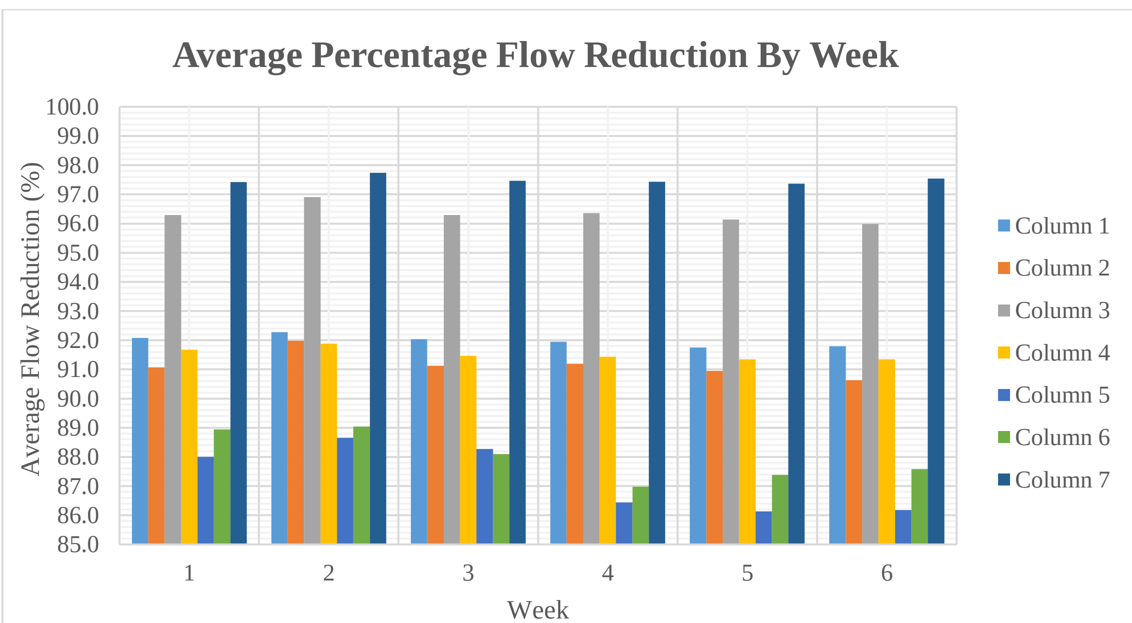


Figure 4.15: Graph of Average Flow Reduction by Week during Test Run Phase

Flow reduction of the soil columns depend on their outflow rate. If the outflow rate is lower, then the flow reduction of the soil column will be higher. As in Figure 4.15, Column 3 and Column 7 have the highest flow reduction which are 96.3% and 97.5% respectively. This is mainly because the sand used as the transition layer is in medium size thus reducing the porosity of the sand layer. Meanwhile for Column 1 and Column 4, they have slightly higher flow reduction throughout the test run phase which is 92% and 91.5% compared to Column 2 and Column 5 which have values of flow reduction 91.2% and 87.3% respectively. This is because the organic compost contained in Column 1 and Column 4 have higher permeability and lower porosity. Lastly for Column 2 and Column 5, the flow reduction is lower due to rabbit's manure compost have less permeability and higher porosity thus enhancing the flow rate of the water in both columns.

4.6.3 Water Ponding Volume

Water ponding happened in each soil column is depend on the infiltration rate of soil. Infiltration describe the process for the water on the ground surface to enter the soil. Table 4.16 and Figure 4.16 describe the trend of weekly water ponding volume for each soil column.

Table 4.16: Average Water Ponding Volume by Week during Test Run Phase

Week	**1**	**2**	**3**	**4**	**5**	**6**
	Average Water Ponding Volume (m^3)					
Column 1	0.0101	0.0123	0.0133	0.0134	0.0134	0.0135
Column 2	0.0094	0.0116	0.0129	0.0131	0.0131	0.0132
Column 3	0.0104	0.0130	0.0141	0.0143	0.0143	0.0143
Column 4	0.0110	0.0133	0.0144	0.0146	0.0146	0.0146
Column 5	0.0092	0.0118	0.0135	0.0141	0.0138	0.0140
Column 6	0.0082	0.0111	0.0123	0.0126	0.0124	0.0124
Column 7	0.0120	0.0136	0.0151	0.0150	0.0150	0.0152

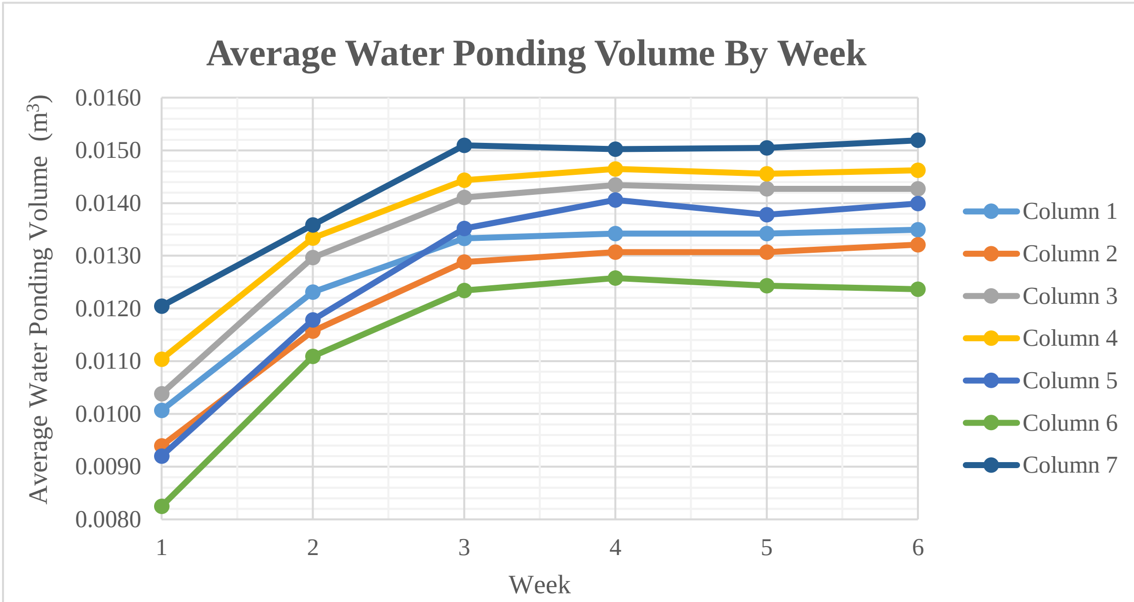


Figure 4.16: Graph of Average Water Ponding Volume by Week during Test Run Phase

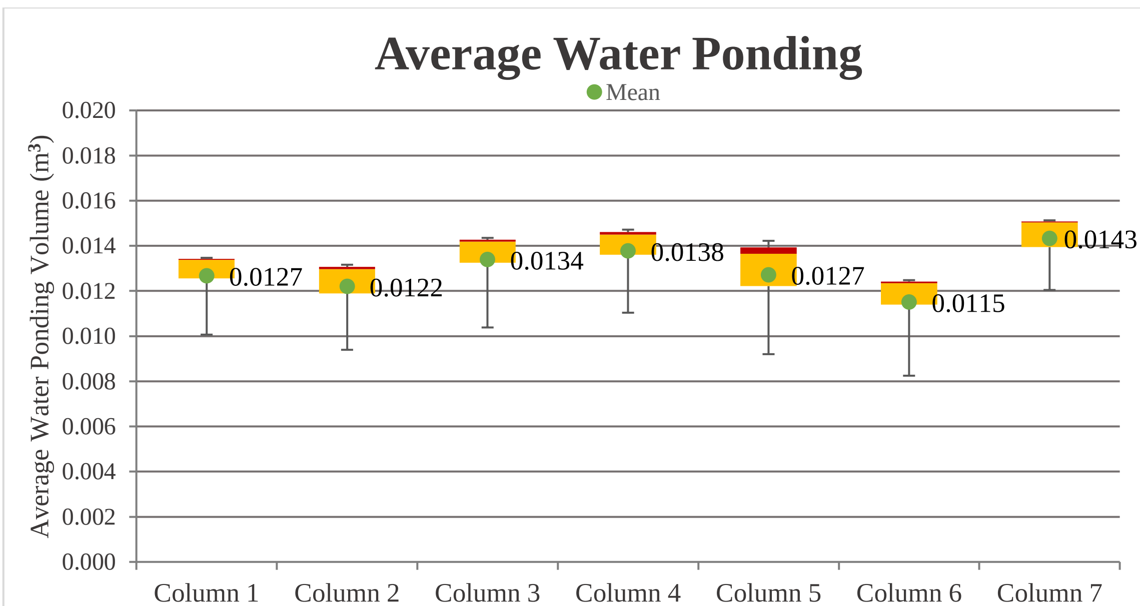


Figure 4.17: Graph of Average Water Ponding Volume throughout Test Run Phase

According to Figure 4.17, throughout the test run phase, the water ponding volume in Column 7 have the highest value which is 0.0143 m^3. Since Column 7 is the control column, it have no presence of plant thus decreasing the infiltration rate of the system. Vegetation in bioretention system will increase the infiltration rate because of the root action that will loosen up the soil around the root area and thus will increase the porosity of the soil. Meanwhile for Column 1 and Column 4, they have slightly larger amount of water ponding compared to Column 2 and Column 5 with values of 0.0127 m^3 and 0.0138 m^3 respectively. As stated before, organic compost contained in Column 1 and Column 4 have smaller particle size thus, providing less porosity to the soil mixture in both columns. As rabbit's manure compost contained in Column 2 and Column 5 have bigger particle size, they provide larger porosity to the soil mixture thus, producing less amount of water ponding volume with values of 0.0122 m^3 and 0.0127 m^3 respectively. Lastly Column 3 and Column 6 have no present of compost in the soil mixture. The porosity and permeability does not affected by the compost. Since the soil mixture in both column just consist of top soil and sand, the higher permeability coming from top soil and sand did not have much permeability to contribute to the system since it does not really absorb and retain water. Due to that, water can filtrate easily through the soil mixture layer and producing less water ponding volume. Unfortunately, since Column 3 used medium sand size as the transition layer, it does affecting the flow of the water then, increasing the water ponding volume with average of 0.0134 m^3 throughout the six weeks period.

4.6.4 Hydraulic Retention Time (HRT)

Table 4.17: Average Hydraulic Retention Time by Week during Test Run Phase

Week	**1**	**2**	**3**	**4**	**5**	**6**
	Average Hydraulic Retention Time (hour)					
Column 1	0.2981	0.2832	0.2898	0.2930	0.2953	0.2958
Column 2	0.2935	0.2791	0.2979	0.3087	0.3097	0.3108
Column 3	0.3808	0.3311	0.3505	0.3581	0.3592	0.3606
Column 4	0.3310	0.2958	0.3239	0.3420	0.3422	0.3433
Column 5	0.3300	0.2922	0.3069	0.3251	0.3231	0.3244
Column 6	0.3194	0.2784	0.2980	0.3165	0.3158	0.3164
Column 7	0.5422	0.4526	0.4657	0.4728	0.4731	0.4742

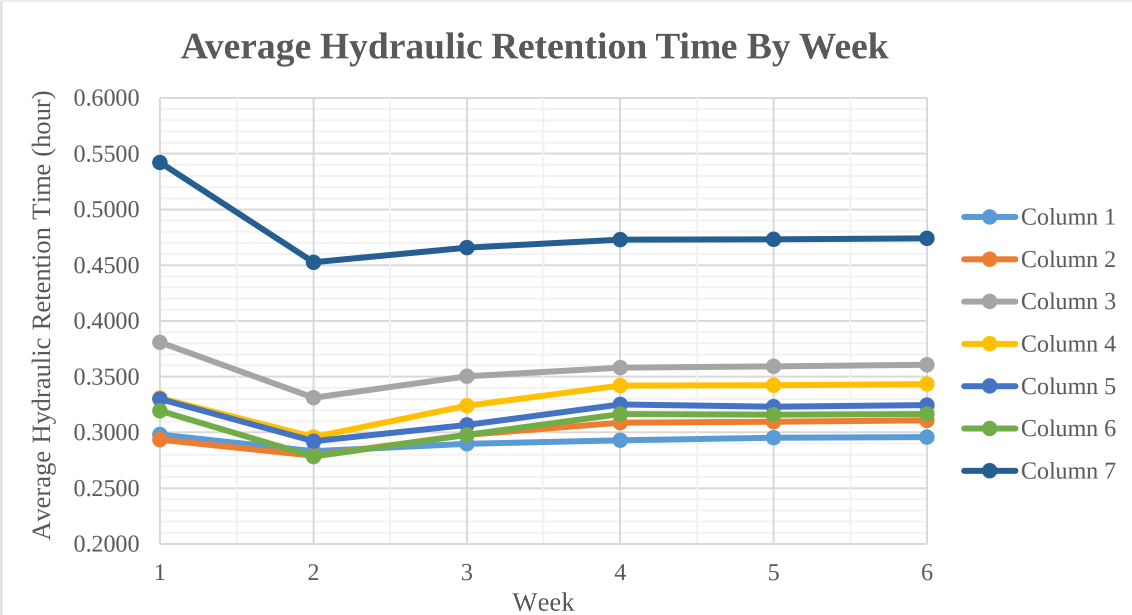


Figure 4.18: Graph of Average Hydraulic Retention Time by Week during Test Run Phase

According to Figure 4.18, the hydraulic retention time for each column is almost in the same range, varying from 0.2791 hour to 0.3433 hour except for Colum 3 and Column 7. Unlike other columns hat used coarse sand size, Column 3 and Column 7 used medium sand size as the transition layer, thus it might affect the hydraulic retention time for both columns. This is because the water have difficulty to flow through the smaller size of sand particle. Meanwhile for other columns, the trend for the hydraulic retention time is decreasing at Week 2 but increasing slightly starting from Week 3 until Week 6. This shows that when the storm event happened everyday which designed to be in Week 1 and Week 2, the system does not have enough time to flush all the water retained and to cater for the next storm event. In long term, it will affect the performance of the system and will not be able to reduce the peak runoff flow as its purpose of design.

4.6.5 Saturated Hydraulic Conductivity (*Ksat*)

Table 4.18: Average Saturated Hydraulic Conductivity by Week during Test Run Phase

Week	1	2	3	4	5	6
	Average Saturated Hydraulic Conductivity (mm/hr)					
Column 1	149.68	145.76	143.42	140.48	138.09	133.14
Column 2	126.18	121.70	119.74	117.99	117.37	113.20
Column 3	37.58	37.25	36.98	36.82	36.71	36.29
Column 4	102.65	99.34	97.17	96.33	95.10	92.34
Column 5	360.28	320.94	309.75	295.43	287.75	263.92
Column 6	378.09	341.90	318.60	301.42	289.62	267.08
Column 7	28.75	28.04	27.88	27.75	27.65	27.38

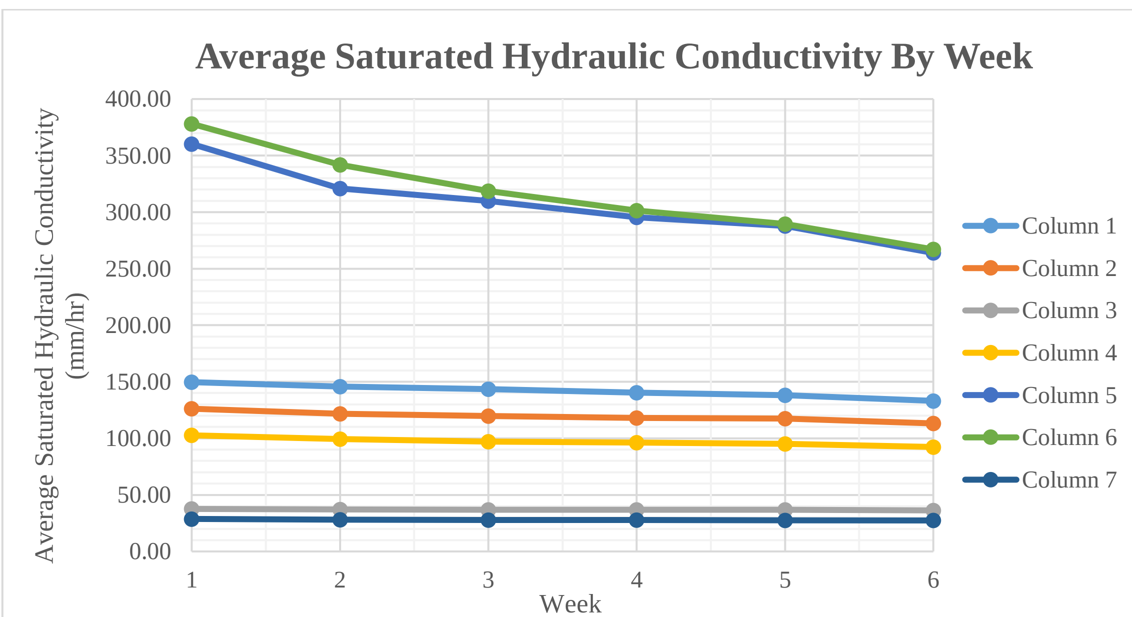


Figure 4.19: Graph of Average Saturated Hydraulic Conductivity by Week during Test Run Phase

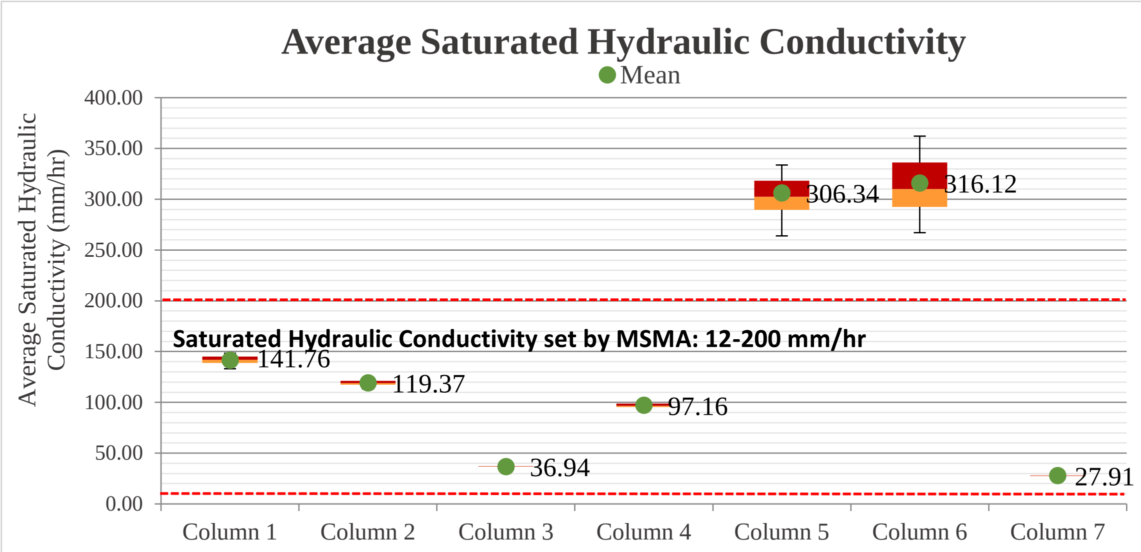


Figure 4.20: Graph of Average Saturated Hydraulic Conductivity throughout Test Run Phase

From Figure 4.20, throughout the test run phase, it can be seen that the average saturated hydraulic conductivity (*Ksat*) for Column 5 and Column 6 is out from the range set by MSMA. Thus, the mixture of soil and designed used in both Column5 and Column 6 is not suitable to be used in bioretention system because it is not good for the plant growth. The highest average saturated hydraulic conductivity *(Ksat)* that lies within the range set by MSMA is from Column 1 with values 141.76 mm/hr which consist mixtures of soil with organic compost. Organic compost is more permeable and can retain water more thus increase the moisture content of the soil mixture in the column. Meanwhile for Column 2 which consist mixtures of soil with rabbit's manure compost, the average saturated hydraulic conductivity *(Ksat)* is slightly lower from Column 1 with value of 119.37 mm/hr. This shows that rabbit's manure compost is less permeable compared to organic compost, hence can retain water lesser. Thus, the moisture content in Column 2 is also lesser, eventually leading to lower saturated hydraulic conductivity *(Ksat)* value. The lowest average saturated hydraulic conductivity *(Ksat)* is from Column 3 and Column 7 with values of 36.94 mm/hr and 27.91 mm/hr respectively. There is no presence of compost in both columns. The permeability of soil mixtures is only depend from sand and top soil. Since sand have lower moisture content, thus only top soil provide the moisture content to the system. This eventually led to the lowest saturated hydraulic conductivity *(Ksat)* value. Both of the columns is not suitable to be used as bioretention system because clogging might happened at the system by time passing.

4.6.6 Evaporation Rate

The reduction of water level in evaporation rate basin test is observed weekly. The evaporation rate basin test area is 350 mm x 250 mm.

Table 4.19: Average Evaporation Rate by Week during Test Run Phase

Week	Evaporation Rate (m^3/week)
1	0.0011
2	0.0011
3	0.0009
4	0.0008
5	0.0004
6	0.0004

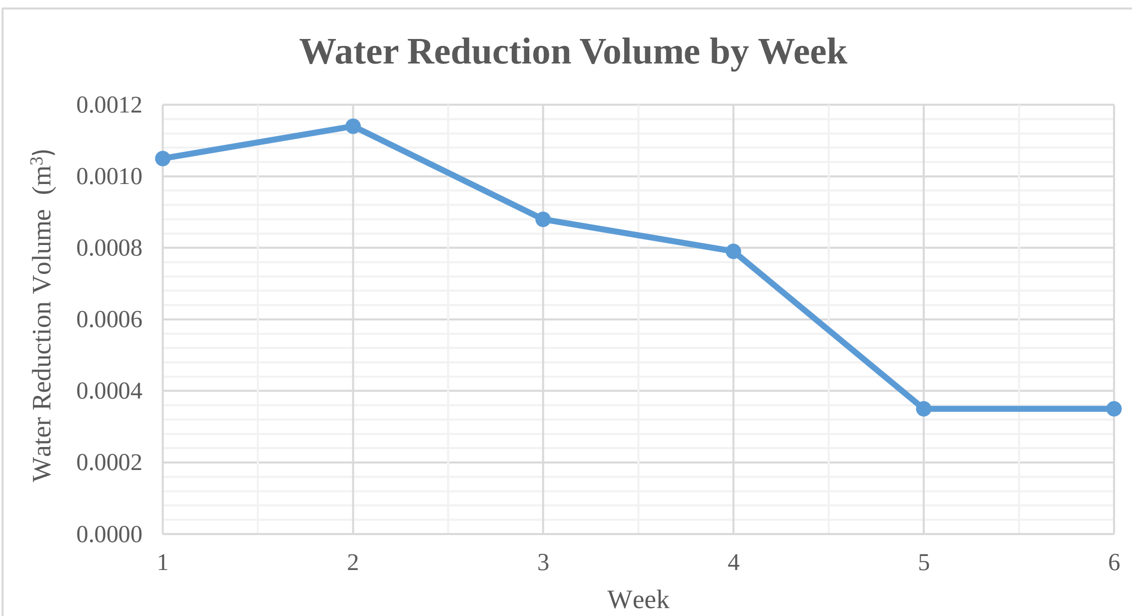


Figure 4.21: Graph of Average Evaporation Rate by Week during Test Run Phase

The evaporation rate keep decreasing throughout the test run phase because almost every day was raining at Seri Iskandar area. During that time, the surrounding temperature as the air humidity is low, thus reducing the evaporation rate at that area.

4.7 Correlation between Hydraulic and Hydrologic Parameters during Test Run Phase

Correlations

		Inflow_Rate	Outflow_Rate	Percentage_Flow_Reduction	Water_Ponding_Volume	Hydraulic_Retention_Time	Saturated_Hydraulic_Conductivity	Evaporation_Rate
Inflow_Rate	Pearson Correlation	1	-.382*	.380*	-.142	.198	-.255	-.113
	Sig. (2-tailed)		.012	.013	.368	.210	.103	.832
	N	42	42	42	42	42	42	6
Outflow_Rate	Pearson Correlation	-.382*	1	-.999**	-.337*	-.698**	.887**	-.641
	Sig. (2-tailed)	.012		.000	.029	.000	.000	.170
	N	42	42	42	42	42	42	6
Percentage_Flow_Reduction	Pearson Correlation	.380*	-.999**	1	.331*	.695**	-.886**	.638
	Sig. (2-tailed)	.013	.000		.032	.000	.000	.173
	N	42	42	42	42	42	42	6
Water_Ponding_Volume	Pearson Correlation	-.142	-.337*	.331*	1	.361*	-.482**	.570
	Sig. (2-tailed)	.368	.029	.032		.019	.001	.238
	N	42	42	42	42	42	42	6
Hydraulic_Retention_Time	Pearson Correlation	.198	-.698**	.695**	.361*	1	-.539**	-.233
	Sig. (2-tailed)	.210	.000	.000	.019		.000	.657
	N	42	42	42	42	42	42	6
Saturated_Hydraulic_Conductivity	Pearson Correlation	-.255	.887**	-.886**	-.482**	-.539**	1	-.837*
	Sig. (2-tailed)	.103	.000	.000	.001	.000		.038
	N	42	42	42	42	42	42	6
Evaporation_Rate	Pearson Correlation	-.113	-.641	.638	.570	-.233	-.837*	1
	Sig. (2-tailed)	.832	.170	.173	.238	.657	.038	
	N	6	6	6	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.22: Correlation between Hydraulic and Hydrologic Parameters during Test Run Phase

From Figure 4.22, it can observed that the highest correlation is between the outflow rate and percentage flow reduction with values of -0.999. When the outflow rate is lower, the percentage flow reduction eventually will be higher. This is because when the water retained and absorbed by the soil mixtures, the water will have difficulty to flow through the soil easily, thus, decreasing the flow rate of stormwater runoff. Meanhile the lowest correlation is between inflow rate and the evaporation rate parameters. This two parameters is not relatable to each other. Evaporation rate is only affected by the surrounding temperature and humidity of air. Meanwhile the inflow rate only describe the speed of stormwter runoff to flow into the system in time. .

CHAPTER 5

CONCLUSION

As conclusion, based on the literature review and experiment that have been done by the author, it is proven that bioretention system are able to reduce peak stormwater runoff. Overall, type of compost used in the soil mixture does affect the hydraulic and hydrologic performance of the system. Each of the compost have different characteristic such as the permeability, porosity and the hydraulic conductivity. Hence, each of the compost produced different performance in term of hydraulic and hydrologic.

Based on the analysis that have been done in Chapter 4, it can be conclude that Column 4 which consist the mixture of medium soil with organic compost give the best performance in term of hydraulic and hydrologic. In both runoff intake condition which is either using tap water or synthetic stormwater, Column 4 produced the best saturated hydraulic conductivity *(Ksat)* that lies within the range set by MSMA with values of 151 mm/hr and 97 mm/hr respectively. This shows that the moisture content in the soil mixture is sufficient enough to sustain the vegetation growth in the system. Furthermore, the potential for clogging to happen in the system is lesser since the value of saturated hydraulic conductivity *(Ksat)* for both runoff intake condition is not too low.

Then, the water ponding volume in Column 4 for both runoff intake condition is in the good range with values of 0.0086 m^3 and 0.0138 m^3 respectively. The water ponding volume produced in Column 4 is not too much, showing that the soil layer in the system have good infiltration rate. This is a good sign because potential for flooding to happen at the upstream area of the system due to bad infiltration rate can be avoided.

Next, Column 4 served the purpose of bioretention system quite well which is to reduce the peak runoff flow rate during storm event. From the analysis that have been done, Column 4 produced a good percentage of flow reduction for both runoff intake condition which is either using tap water or synthetic stormwater with values of 87% and 92% respectively. Thus, it can be conclude that Column 4 which consist the mixture of medium soil with organic compost able to prevent the flooding from happening either in the upstream or downstream area of the system.

Lastly for the correlation between the hydraulic and hydrologic parameters, strong relationship is coming between the outflow rate and percentage flow reduction of the system. Percentage flow reduction also describe how much the water is retained in the soil layer. When the stormwater runoff is absorb by the soil and when the permeability of the soil is higher, the outflow rate of the runoff will be lower since it cannot flow through the soil mixture easily. In addition, the relationship between the outflow rate and the saturated hydraulic conductivity *(Ksat)* is also quite high. Saturated hydraulic conductivity *(Ksat)* describe the easiness of water to flow in saturated soil condition. When the stormwater runoff can flow easily in the saturated soil, the outflow rate will eventually will increase.

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APPENDICES

APPENDIX 1:

RESULTS DURING STABILIZATION PHASE

Inflow Rate

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		INFLOW RATE X 10^{-5} (m^3/s)						
1	4	2.57	2.62	2.52	2.65	2.69	2.72	2.65
2	7	2.47	2.38	2.61	2.41	2.69	2.66	2.75
	9	2.63	2.43	2.71	2.56	2.46	2.55	2.74
	11	2.55	2.61	2.52	2.60	2.43	2.39	2.39
3	14	2.50	2.49	2.52	2.50	2.61	2.49	2.60
	16	2.44	2.65	2.42	2.60	2.47	2.35	2.51
	18	2.53	2.50	2.56	2.50	2.49	2.50	2.49

Outflow Rate

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		OUTFLOW RATE X 10^{-5} (m^3/s)						
1	4	0.25	0.45	0.11	0.29	0.64	0.73	0.09
2	7	0.47	0.44	0.16	0.39	0.80	0.61	0.18
	9	0.46	0.46	0.13	0.38	0.86	0.89	0.13
	11	0.28	0.19	0.13	0.36	0.47	0.90	0.10
3	14	0.34	0.32	0.13	0.28	0.30	0.95	0.10
	16	0.40	0.35	0.16	0.30	0.56	0.88	0.10
	18	0.36	0.33	0.14	0.32	0.41	0.83	0.09

Flow Reduction

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		FLOW REDUCTION (%)						
1	4	90.43	83.02	95.78	88.91	76.08	73.02	96.44
2	7	80.85	81.51	93.91	83.98	70.37	77.13	93.51
	9	82.67	81.27	95.24	85.32	64.98	64.89	95.42
	11	88.83	92.62	95.04	86.00	80.67	62.16	95.81
3	14	86.40	87.13	94.77	88.82	88.68	61.88	96.29
	16	83.82	86.79	93.55	88.47	77.40	62.33	96.03
	18	85.90	86.88	94.71	87.26	83.63	66.77	96.54

Water Ponding Volume

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		WATER PONDING VOLUME (m^3)						
1	4	0.0049	0.0064	0.0067	0.0053	0.0046	0.0042	0.0092
2	7	0.0092	0.0088	0.0092	0.0085	0.0061	0.0057	0.0117
	9	0.0102	0.0095	0.0117	0.0099	0.0078	0.0067	0.0113
	11	0.0099	0.0113	0.0107	0.0106	0.0108	0.0042	0.0115
3	14	0.0104	0.0106	0.0106	0.0109	0.0117	0.0049	0.0117
	16	0.0110	0.0113	0.0106	0.0106	0.0113	0.0053	0.0117
	18	0.0106	0.0115	0.0106	0.0110	0.0117	0.0057	0.0124

Hydraulic Retention Time (HRT)

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		HYDRAULIC RETENTION TIME (hour)						
1	4	0.2969	0.2653	0.8319	0.2953	0.1747	0.2325	0.7297
2	7	0.1961	0.2339	0.3800	0.1742	0.1483	0.1658	0.5256
	9	0.2272	0.2933	0.6253	0.2636	0.1911	0.1694	0.6694
	11	0.2525	0.4236	0.4692	0.0519	0.3422	0.1417	0.6347
3	14	0.2722	0.3458	0.2325	0.2953	0.2433	0.1592	0.6239
	16	0.3364	0.3383	0.7467	0.3111	0.2497	0.1408	0.6517
	18	0.2569	0.3386	0.3733	0.2303	0.1953	0.1444	0.6117

Saturated Hydraulic Conductivity (*Ksat*)

WEEK	DAY	Col. 1	Col. 2	Col.3	Col.4	Col. 5	Col. 6	Col. 7
		SATURATED HYDRAULIC CONDUCTIVITY (mm/hr)						
2	9	282.29	196.48	82.60	130.03	130.80	594.69	71.82
	11	291.51	201.82	83.21	131.96	132.74	564.58	72.41
3	16	257.81	195.62	86.27	152.75	170.24	686.18	76.77
	18	250.57	201.82	85.77	190.61	159.29	637.17	74.58

APPENDIX 2:

RESULTS DURING TEST RUN PHASE

Inflow Rate

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		INFLOW RATE X 10^{-5} (m^3/s)						
1	1	6.14	5.86	5.93	6.11	5.91	6.19	6.09
	2	5.91	5.83	5.93	5.88	5.79	6.09	5.96
	3	6.19	6.09	5.93	5.86	5.83	5.91	5.93
	4	6.09	5.98	6.14	5.91	6.06	5.96	6.03
2	1	5.86	5.93	5.83	5.91	5.76	6.14	5.98
	2	5.91	5.96	6.11	6.09	6.03	5.96	5.93
	3	6.19	6.14	6.06	5.91	5.93	5.98	6.03
	4	5.96	6.06	6.11	5.98	5.88	5.83	6.01
3	1	6.09	6.14	5.98	5.91	5.93	6.09	5.96
	2	6.09	6.03	6.14	6.17	6.06	6.09	5.96
	3	6.03	5.96	5.93	6.09	5.98	5.88	5.96
4	1	6.14	6.06	5.96	5.91	6.09	5.88	5.98
	2	5.96	6.01	6.09	5.98	6.09	5.91	5.96
	3	6.06	6.17	6.11	5.98	5.91	5.83	5.93
5	1	6.06	6.11	6.06	5.96	5.96	6.09	6.03
6	1	6.03	5.91	5.83	5.91	5.86	6.06	6.09

Outflow Rate

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		OUTFLOW RATE X 10^{-5} (m^3/s)						
1	1	0.50	0.54	0.23	0.51	0.73	0.67	0.16
	2	0.48	0.56	0.22	0.51	0.71	0.64	0.16
	3	0.48	0.52	0.22	0.48	0.70	0.70	0.15
	4	0.47	0.51	0.23	0.47	0.69	0.66	0.15
2	1	0.49	0.52	0.20	0.50	0.70	0.65	0.14
	2	0.44	0.50	0.18	0.45	0.66	0.63	0.13
	3	0.46	0.46	0.18	0.47	0.65	0.69	0.14
	4	0.46	0.45	0.18	0.52	0.67	0.65	0.14
3	1	0.51	0.55	0.24	0.53	0.85	0.78	0.17
	2	0.47	0.52	0.21	0.51	0.64	0.69	0.15
	3	0.47	0.54	0.21	0.51	0.62	0.68	0.14
4	1	0.48	0.53	0.22	0.50	0.80	0.77	0.15
	2	0.48	0.54	0.23	0.52	0.83	0.77	0.15
	3	0.46	0.53	0.22	0.51	0.81	0.76	0.16
5	1	0.50	0.55	0.23	0.52	0.83	0.77	0.16
6	1	0.50	0.55	0.23	0.51	0.81	0.75	0.15

Flow Reduction

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		FLOW REDUCTION (%)						
1	1	91.90	90.83	96.19	91.59	87.65	89.19	97.34
	2	91.89	90.42	96.30	91.28	87.74	89.44	97.34
	3	92.30	91.47	96.36	91.86	88.01	88.13	97.48
	4	92.21	91.55	96.29	91.98	88.61	88.99	97.52
2	1	91.66	91.17	96.63	91.62	87.93	89.41	97.73
	2	92.62	91.57	97.03	92.55	89.04	89.42	97.81
	3	92.57	92.56	96.93	92.07	89.02	88.49	97.67
	4	92.26	92.64	97.04	91.30	88.64	88.83	97.75
3	1	91.63	91.04	95.93	91.06	85.71	87.19	97.22
	2	92.25	91.41	96.50	91.74	89.51	88.73	97.45
	3	92.22	90.93	96.44	91.58	89.61	88.36	97.73
4	1	92.05	91.22	96.38	91.52	86.67	86.94	97.43
	2	91.60	90.98	96.26	91.30	86.32	86.97	97.52
	3	92.19	91.37	96.42	91.46	86.32	87.01	97.36
5	1	91.75	90.95	96.13	91.34	86.13	87.38	97.37
6	1	91.79	90.63	95.98	91.35	86.18	87.58	97.54

Water Ponding Volume

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		WATER PONDING VOLUME (m^3)						
1	1	0.0092	0.0085	0.0088	0.0099	0.0078	0.0067	0.0117
	2	0.0097	0.0088	0.0099	0.0110	0.0088	0.0078	0.0119
	3	0.0102	0.0097	0.0110	0.0113	0.0097	0.0088	0.0120
	4	0.0111	0.0106	0.0119	0.0120	0.0105	0.0097	0.0126
2	1	0.0113	0.0105	0.0119	0.0122	0.0106	0.0102	0.0127
	2	0.0122	0.0113	0.0127	0.0132	0.0116	0.0110	0.0134
	3	0.0127	0.0120	0.0134	0.0138	0.0122	0.0113	0.0139
	4	0.0131	0.0125	0.0138	0.0141	0.0127	0.0119	0.0143
3	1	0.0132	0.0127	0.0139	0.0143	0.0134	0.0122	0.0148
	2	0.0134	0.0129	0.0141	0.0145	0.0135	0.0124	0.0152
	3	0.0134	0.0130	0.0143	0.0145	0.0136	0.0124	0.0153
4	1	0.0134	0.0129	0.0141	0.0144	0.0136	0.0124	0.0148
	2	0.0134	0.0131	0.0144	0.0147	0.0141	0.0127	0.0150
	3	0.0135	0.0132	0.0146	0.0148	0.0145	0.0127	0.0152
5	1	0.0134	0.0131	0.0143	0.0146	0.0138	0.0124	0.0150
6	1	0.0135	0.0132	0.0143	0.0146	0.0140	0.0124	0.0152

Hydraulic Retention Time (HRT)

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		HYDRAULIC RETENTION TIME (hour)						
1	1	0.2950	0.2892	0.3664	0.3300	0.3269	0.3111	0.5419
	2	0.3006	0.2922	0.3889	0.3356	0.3336	0.3217	0.5472
	3	0.2939	0.2914	0.3772	0.3336	0.3303	0.3297	0.5275
	4	0.3028	0.3011	0.3908	0.3247	0.3292	0.3153	0.5519
2	1	0.2833	0.2786	0.3361	0.3019	0.2919	0.2786	0.4542
	2	0.2825	0.2769	0.3211	0.2786	0.2833	0.2742	0.4461
	3	0.2828	0.2806	0.3303	0.3014	0.2967	0.2803	0.4539
	4	0.2842	0.2803	0.3369	0.3014	0.2967	0.2806	0.4564
3	1	0.2847	0.2806	0.3417	0.3042	0.2981	0.2806	0.4561
	2	0.2908	0.3050	0.3494	0.3328	0.3072	0.3053	0.4692
	3	0.2939	0.3081	0.3603	0.3347	0.3153	0.3081	0.4719
4	1	0.2922	0.3083	0.3572	0.3408	0.3222	0.3153	0.4722
	2	0.2928	0.3081	0.3581	0.3425	0.3272	0.3175	0.4714
	3	0.2939	0.3097	0.3592	0.3428	0.3258	0.3167	0.4747
5	1	0.2953	0.3097	0.3592	0.3422	0.3231	0.3158	0.4731
6	1	0.2958	0.3108	0.3606	0.3433	0.3244	0.3164	0.4742

Saturated Hydraulic Conductivity (*Ksat*)

WEEK	DAY	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
		SATURATED HYDRAULIC CONDUCTIVITY (mm/hr)						
1	1	150.68	127.43	37.58	103.01	374.80	384.50	28.78
	2	148.67	124.93	37.58	102.30	345.75	371.68	28.72
	3	146.24	122.53	37.32	99.56	325.56	348.45	28.10
	4	145.28	120.87	37.17	99.12	316.32	335.35	27.98
2	1	143.88	120.22	37.01	97.17	311.90	320.88	27.89
	2	142.95	119.26	36.95	97.17	307.60	316.32	27.86
	3	141.14	118.31	36.86	96.75	299.34	305.49	27.79
	4	139.82	117.68	36.77	95.92	291.51	297.35	27.70
3	1	138.09	117.37	36.71	95.10	287.75	289.62	27.65
	2	133.14	113.20	36.29	92.34	263.92	267.08	27.38
	3	150.68	127.43	37.58	103.01	374.80	384.50	28.78
4	1	148.67	124.93	37.58	102.30	345.75	371.68	28.72
	2	146.24	122.53	37.32	99.56	325.56	348.45	28.10
	3	145.28	120.87	37.17	99.12	316.32	335.35	27.98
5	1	143.88	120.22	37.01	97.17	311.90	320.88	27.89
6	1	142.95	119.26	36.95	97.17	307.60	316.32	27.86