THE INFLUENCE OF FILTER DEPTHS IN CAPTURING NUTRIENT CONTAMINANTS FOR NON-VEGETATED BIORETENTION COLUMN: A PRELIMINARY STUDY

HUSNA TAKAIJUDIN(1,2), HOW TION PUAY(1), AMINUDDIN AB. GHANI(1), NOR AZAZI ZAKARIA(1) & TZE LIANG LAU (1)

(1) *River Engineering and Urban Drainage Centre, Higher Institution Centre of Excellence (HICoE) for Service, Engineering Campus, Universiti Sains Malaysia, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia*
husna_takaijudin@petronas.com.my

(2) *Department of Civil Engineering, Faculty of Engineering, Universiti Teknologi PETRONAS, 31750, Tronoh, Perak, Malaysia*

ABSTRACT

Engineered soil media plays significant role in enhancing bioretention performance in terms of water quantity and quality aspects. There was limited research on hydraulic response in establishing design parameters such as soil depths. This paper presents a preliminary study on the evolution of hydraulic conductivity over time and examine the stormwater treatment efficiency for engineered soil media consisted of various depths. This study focused on three small-scale column namely C1,C2 and C3 with 74mm in diameter and 700 mm in height. Column C1,C2 and C3 comprise 500 mm, 400 mm, 300 mm deep engineered soil media, respectively. Soil composition of engineered soil media consists of 50% medium sand, 30% topsoil, and 20% organic leaf compost. Daily hydraulic conductivity was monitored over 10 weeks to observe the declination of this parameter over the time. Then, approximately 3.3 L collected 'dry' stormwater sample (no rain was observed during November- January 2013) were poured into each column. Both influent and effluent were collected and tested. Results found that C3 has the greater K_{sat} (280.2±63.4mm/hr) due to having narrow depth of filter media. However, C1 (88.2±36.7mm/hr) and C2 (74.6±15.1mm/hr) has lower hydraulic conductivity due to having deeper depth of filter media. Preliminary results illustrates that a declination in hydraulic conductivity very quick in the first two weeks progression in all cells then it tends slowly decreased at remain at one value. Besides, C1 has highest retention time was capable to remove total nitrogen (TN) pollutants with 52.2±8.5%. TN removal for C2 and C3 were slight lower than C1 which were 35.8±3.4% and 24.2±9.8%, respectively. Total phosphorus (TP) was treated well in all columns with C1 and C2 with 71.8±14.4% and 81.6±6.1%, respectively. C3 was ineffectively removing nutrient pollutants with less percentage of pollutant removal. It was probably C3 has narrow depth of engineered filter media which provide lesser treatment on stormwater pollutants due to insufficient retention time to soil microbes react with the contaminants. It was suggested that a minimum depth of 400 mm of engineered filter media capable to remove nutrient contaminant due to having longer retention time which giving more natural treatment processes to occur.

Keywords: nutrient pollutants, column study, engineered soil media, hydraulic conductivity, treatment efficiency.

1. INTRODUCTION

Bioretention is became more versatile as stormwater management practices over the world including Malaysia. This approach is widely used to minimize harmful impact of non-point source pollutants mainly from urban stormwater runoff related with impervious areas(Brown & Hunt, 2011). This system offers good function in flow management and also stormwater treatment across literature. Brander et al. (2004) compared bioretention system with other Best Management Practices (BMPs) such as detention pond and infiltration. They found that rain garden performed better than others which can optimize water to evapotranspirate with the presence of vegetation and also increase groundwater recharge(Brander et al., 2004).

Filter media is basically soil or sand-base media which major component of bioretention system. Engineered soil media plays important roles in peak flow attenuation through infiltration processes and efficiently removed Total Suspended Solids (TSS). This was agreed by many researchers where it successfully removed more than 90% TSS (Blecken et al., 2010; Guo et al., 2014; Lee et al.,2008). It also assists on treatment performance during plant reach to maturity age (Cizek & Hunt, 2013).

Filter media depth is the prime design specification element that need to be considered. This element was setup as the main design criteria but has not been thoroughly examined. In addition, this requirement kept changing which depending on the characteristics of plant, types of pollutants but not considering drainage area characteristics (Li & Davis, 2008; Brown & Hunt, 2011). Table 1 tabulates several recommended filter media depth according to varies guidelines all over the world. It can be summarized that the ranges between 300 -1000 mm is typically used for filter media for bioretention purposes. Li et al.(2009) explained that deeper filter media depth promotes more hydrological processes to occur mainly infiltration and evapotranpiration (ET) and it represented nearly to natural hydrological cycle (Li et al.,2009). Other researchers in 2009 examined the influence of temperature on bioretention depth. It was found that, deeper depth can remain constant temperature in longer period compared to shallower depth (Jones & Hunt, 2009). However, it might increased excavation and materials cost due to required higher volume of engineered soil media(Brown & Hunt, 2011). Conversely, bioretention which has shallower depth (below 0.6 m) can minimize the construction cost but in terms of flow and treatment performance are still questionable.

The responses on soil depth to the nutrient performance had been discussed. In 2006, Davis et al. (2006) examined nutrient performance mainly TP, and TN. It was indicated that 70-85% TP was captured at 60 to 80 cm depth in field studies. Besides, deeper depth (more than 90 cm depth) capable to remove 50 -80% TN pollutants which TN was controlled by total Kjeldahl nitrogen (TKN) (Davis et al., 2006). The investigation on soil depth influences was continued by Brown and Hunt (2011). The results reported that 75% TN contaminants was captured in 0.9 m depth of filter media compared to 0.6 m depth with only 21% removal. On the other hand, there was poor reduction on TP removal in both filter media depth which only 2% for 0.6 m depth and 19% for 0.9 m depth(Brown & Hunt, 2011). This is because TP inflow concentration was relatively low. Hence, this paper provides a preliminary study on the responses between hydraulic conductivity and nutrient contaminants in variation of filter depths.

Table 1. Recommended filter media depth across several national and international guidelines.

Guidelines	Country	Recommended filter media depths
Low Impact Development : Urban Design Tools (LID, 2007)	Maryland, USA	(1) recommended minimum depth of 600 mm to 760 mm without large tree plantings (2) if shallow rooted plants are used, soil depth may be reduced to 460 mm (3) recommended depth of 1200 mm to 1400 mm with large trees
North Shore City Bioretention Guidelines(North Shore City, 2008)	New Zealand	500 -1000 mm depth (minimum 300 mm for shrub and grass and maximum 1000 mm for trees
WSUD Engineering Procedures(Melbourne Water, 2005)	Australia	(1) Lined biofiltration system with submerged zone - 300 -500 mm (2) Standard lined biofiltration system - 400 – 700 mm
Bioretention Manual(The Prince george County, 2009)	North Carolina,USA	Min 18" (458 mm)
Engineering procedures for ABC Waters Design Features (PUB, 2011)	Singapore	Similar standard as recommended by FAWB (2009)
Stormwater Management Manual for Malaysia (MSMA)(DID, 2012)	Malaysia	450 -1000 mm for both permeable and impermeable bioretention system

2. MATERIALS AND METHODS

2.1 Column setup and configuration

Three (3) small-scale bioretention columns (diameter 74mm, height 700 mm) namely C1,C2 and C3 were setup in the Physical Modeling Laboratory, River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Penang, Malaysia. This setup is similar in previous study by Takaijudin et al.(2014) with designed scale of 1:20 from actual catchment area (Takaijudin et al., 2014). The configuration of the setup is tabulated in Table 2. Figure 1 illustrates the laboratory setup with 30 mm gravel as underdrain layer at the bottom to prevent movement of filter media layer (Kandra et al., 2014) and the engineered soil media were filled on top of the gravel layer with the different depth for each column ranged from 30 cm to 50 cm. C1 has 500 mm depth of engineered soil media, while C2 and C3 have 400 mm and 300 mm depth, respectively.

Table 2. Design and configuration of column setup (Takaijudin et al.,2014).

Design characteristics	Specification
Drainage area	0.04ha
Actual Peak Discharge	8.49L/s
Column diameter	74 mm
Column height	700 mm
Design Inflow	0.28 L/min
Filter media depth	300-500 mm
Engineered soil media composition	50% medium sand:30% topsoil:20% leaf compost
Gravel	6-8 mm grain size at 30 mm depth

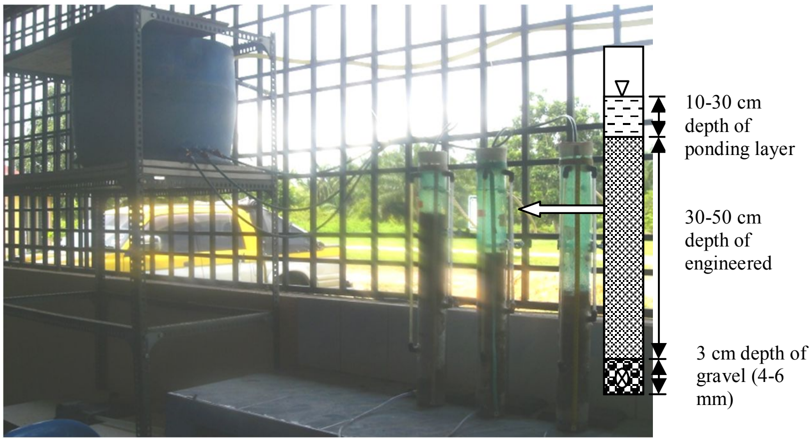


Figure 1. Small-scale column setup

2.2 Selection and Preparation of Engineered Soil Media

The engineered soil media consisted of 50% medium sand, 30% topsoil mainly loamy soil, and 20% organic leaf compost was chosen from previous study (Takaijudin et al., 2014) and also according to MSMA design requirement for engineered soil media (DID, 2012). Construction sand and topsoil were chosen due to its availability as a media type. Compost was obtained from local nursery. Construction sand and topsoil were dried at 105°C within 24 hours. Then, sand (D_{10} is 0.34 and D_{50} is 0.48) and topsoil (passing 2mm sieve) were selected by dry sieve method (BS 1377:Part 2:1990) (BSI, 1990) using mechanical shaker to obtain uniform size of media. The ratio of column diameter to the particle size of engineered soil media was exceeded 50 as recommended in previous literature to represent more practical scale (Bright et al., 2010; Le Coustumer et al., 2012).

2.3 Stormwater collection

Stormwater sample was collected at road side drain nearby Parit Buntar, Perak, Malaysia. This natural stormwater was used to obtain more representative stormwater characteristics (FAWB, 2009). Samples were collected during dry season within November to January 2013. It was observed no rainfall during that particular periods. Hence, it was expected higher pollutant concentration at that particular period. Baseline characteristics of stormwater pollutants are listed in Table 3.

Table 3. Baseline features of stormwater runoff.

Parameters	Unit	Values	Class*
Ammoniacal Nitrogen (NH_3-N)	mg/L	2.54±1.83	IV
Biochemical Oxygen Demand (BOD)	mg/L	6.15±1.03	IV
Chemical Oxygen Demand (COD)	mg/L	116.33±2.89	V
Dissolved Oxygen (DO)	mg/L	1.31±1.75	IV
pH		7.13±0.54	I
Total Suspended Solid (TSS)	mg/L	288.57±93.61	IV
Total Nitrogen (TN)	mg/L	5.58±4.03	
Total Phosphorus (TP)	mg/L	2.70±1.46	

2.4 Hydraulic conductivity test

Constant head conceptual was implemented for these column studies. It was modified by derivation of Darcy Law (Good et al., 2012). Tap water was used as the main source of water. Then, it will discharged to the cylindrical column through 6mm tubes in parallel condition. The inflow rate was adjusted using valves to obtain constant 100 mm ponding layer at the top of engineered soil media. Once ponding layer became steady (meeting saturated condition) within 24 hours, initial outflow rate were measured using stopwatch and 100ml of beacar (*n* =5 measurement for each column). Then, the measurements were continued until 70 days to observed the life span of hydraulic conductivity. Hydraulic conductivity was determined using Equation 1.

$$K_{sat} = \frac{Ql_s}{A \times (l_s + l_w)} \tag{1}$$

Where, K_{sat} = saturated hydraulic conductivity (mm/hr); Q = outflow rate (m^3/s); l_s = soil length (m); A = surface area of bioretention cell (m^2); and l_w = ponding depth (m).

2.5 Stormwater sampling and analyses

After completing hydraulic conductivity measurement using tap water, it was then flushed with natural stormwater runoff. Two (2) L influent stormwater sample was collected from the source tank. Approximately 4.1 L of natural stormwater sample (assuming bioretention size to 5% of impervious catchment area was discharged into each cell. Stormwater sample was conveyed into bioretention for six (6) hours measurement. Then, about two (2) L of treated stormwater sample was collected at outlet tubes for every two (2) hours. Four (4) repetition were completed with total stormwater samples, N = 48. TSS was analyzed by the gravimetric method and filtered using Whatman 47 mm diameter glass fibre filter papers (Guo et al., 2014). The nitrogen concentration was tested using the Persulfate Digestion Method (Hach Method 10071) where the unit is in mg/L N. Phosphorus concentration was tested using the USEPA PhosVer®3 with Acid Persulfate Digestion Method (Hach Method 8190) where the unit is in mg/L PO_4^{3-}.

3. RESULT AND DISCUSSION

3.1 Trends of hydraulic conductivity

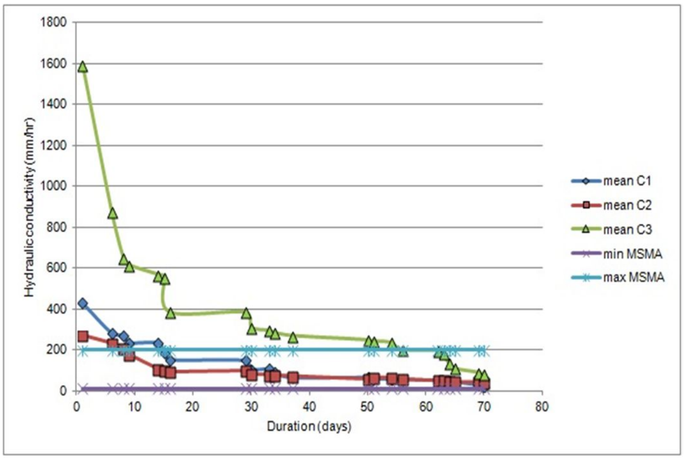


Figure 2. Evolution of hydraulic conductivity in different filter media depths.

The reduction is very quick in the first ten (10) days of experiments and then it tends to consistent at one value and slowly decreased at the end of monitoring period. Hydraulic conductivity values yet to stable at initial condition due to the soil movement that caused by water ponding pressure before it reached fully saturated condition. This phenomenon has good agreement with the results reported by Le Coustumer et al. (2007). However, continuous reduction of hydraulic conductivity in this study due to the absence of vegetation. Role of vegetation especially roots plant capable to maintain hydraulic conductivity values(Le Coustumer et al., 2007). The creation of macropores between particles size by roots might prevent clogging inside filter media system(Le Coustumer et al., 2012). Hence, it capable to maintain permeability rates in the soil system.

Figure 2 also explained the trends of hydraulic conductivity over time for different filter media depths. C1 with 500 mm soil depth generated greater hydraulic conductivity than C2 (400 mm depth) at the beginning period (from day 1 to day 30). However, it consistently obtained similar trends with C2 after day 30 onwards which illustrated that achieving a constant value with C2. In other words, the difference of 10 cm depth between C1(88.2±36.7 mm/hr) and C2 (74.6±15.1mm/hr) had little influence in hydraulic conductivity values. C3 performed the greatest values of hydraulic conductivity with 280.2±63.4 mm/hr from the beginning of observation period. C1 and C2 achieved the recommend values (13 – 200 mm/hr) of hydraulic conductivity after 10 and 15 days onwards, respectively (DID,2012).

3.2 Laboratory Study Results

Hydraulic conductivity measurement was carried out concurrently during stormwater sampling across six (6) hours experiment. This is essential to monitor the declination of hydraulic conductivity that caused by development of sediment layer on top of the soil media depth. Figure 3 demonstrates the behavior of hydraulic conductivity over six (6) hours measurement. A Kruskal Wallis Test revealed a statistically significant difference of hydraulic conductivity across the soil depth and also measurement periods($p<0.05$, $n=60$). C3 with 300 mm soil depth recorded the highest hydraulic conductivity than the other cells as presented in Figure 3. The discharge water released quickly through shallower soil depth due to smaller volume of filter media with similar pore sizes. The six (6) hour measurement period also significantly influenced the reduction of hydraulic conductivity with $p<0.05$ for all cells. In the first two (2) hours experiment, it was observed little sediment particles captured in the soil layer. After 4-6 hours observation, the sediment layer was started to develop at the top of soil depth with 2-5 mm depth. Potential clogging might occur at this stage by receiving higher concentration of sediment mainly for non-vegetated column. Hence, it can be prevented by the appearance of vegetated root which can create more macropores inside the soil media(Le Coustumer et al., 2012).

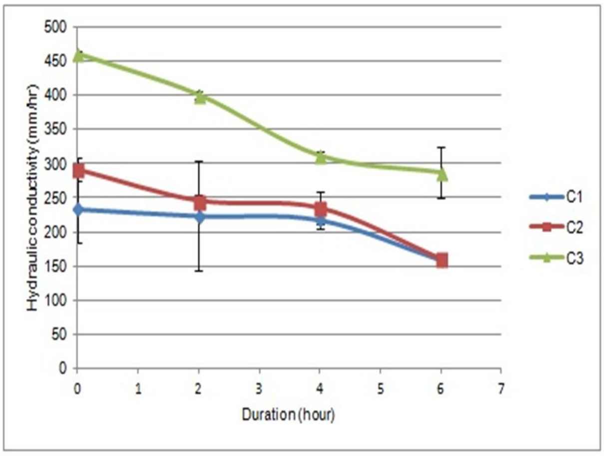
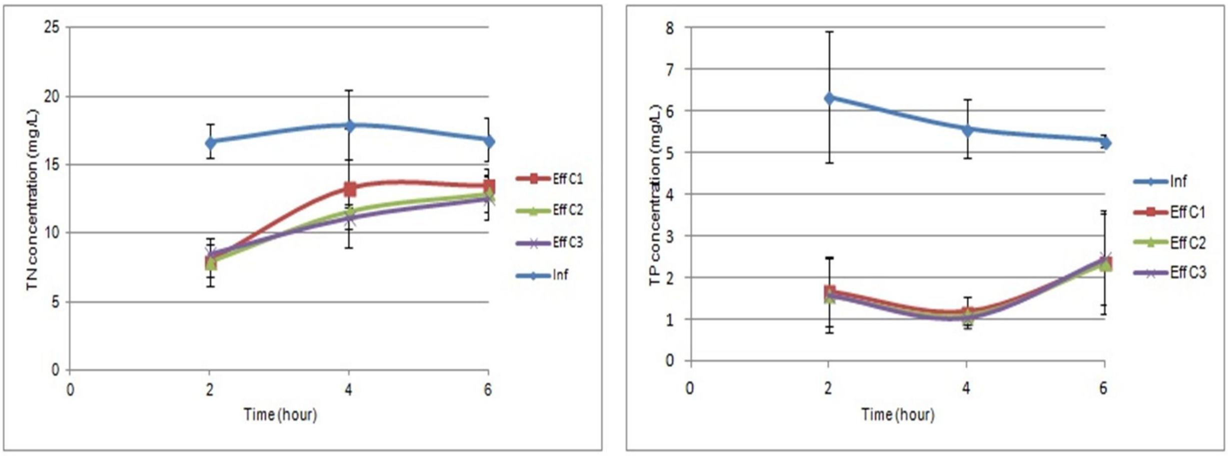


Figure 3. Hydraulic conductivity profiles during stormwater runoff application.

The water quality experiment was conducted simultaneously with hydraulic conductivity measurement to examine the inter-relation between nutrient treatment performance and hydraulic condition under variation soil media depth. Table 3 provides a summary of overall performance of hydraulic conductivity and stormwater treatment performance. Soil depth was correlated with the behavior of hydraulic conductivity and treatment performance(Davis et al., 2006; Brown & Hunt, 2011). It was explained by the shallower engineered soil which had greater hydraulic conductivity, might offers less treatment performance mainly TN and TP. Based on Table 3, all cells had reached to the target value of TP performance in local guidelines (>60%) (DID, 2012). Adequate treatment performance can be obtained at C1 and C2 which had moderate hydraulic conductivity at 500 mm and 400 mm depth, respectively. However, C2 performed better in treating TP compared to C1 which was contradict with the trends of other cells. This probably due to the composition of 20% compost in soil media system contribute to the effluent concentration. Higher soil depth provides higher volume of compost that been used in the mixture which might contain higher amount of phosphorus. Phosphorus was broke down by soil microbes using two (2) main mechanisms using by adsorption on soil particles or it can be transform to adsorbed phosphorus into mineral (Hou et al., 2013). TN reduction was poor for all cells. Only C1 achieved the targeted treatment performance (>50%)(DID, 2012). It has a good agreement with previous researchers where higher soil media depth offer better treatment performance compared to shallower depth (Davis et al., 2006; Brown & Hunt, 2011). Figure 4(a) and 4(b) show the nutrient performance over six (6) experiment. The effluent concentration for alls cell started to increase after four (4) hours sampling for both TN and TP. This was described the tendency of nutrient leaching probably occurred where the additional nutrient which came from engineered soil media accumulated with the effluent water. It was expected that leaching might be occur after six (6) based on the trends that have illustrated in Figure 4.

Table 3. Saturated hydraulic conductivity and treatment performance in natural stormwater runoff (influent) and treated water (effluent) from six (6) hour experiment (average±standard deviation)

		Effluent		
Mean values	**Influent**	**C1**	**C2**	**C3**
Hydraulic conductivity (mm/hr)				
Initial	NA	233±4	291±17	461±48
Final	NA	159±36	160±6	287±6
TP concentration (mg/L)	5.7±1.0	1.5±0.8	1.1±0.2	2.2±0.9
TP removal (%)	NA	71.8±14.4	81.6±6.1	58.0±19.2
TN concentration (mg/L)	17.2±1.7	8.6±0.8	11.4±0.7	13.3±0.6
TN removal (%)	NA	52.2±8.5	35.8±3.4	24.2±9.7

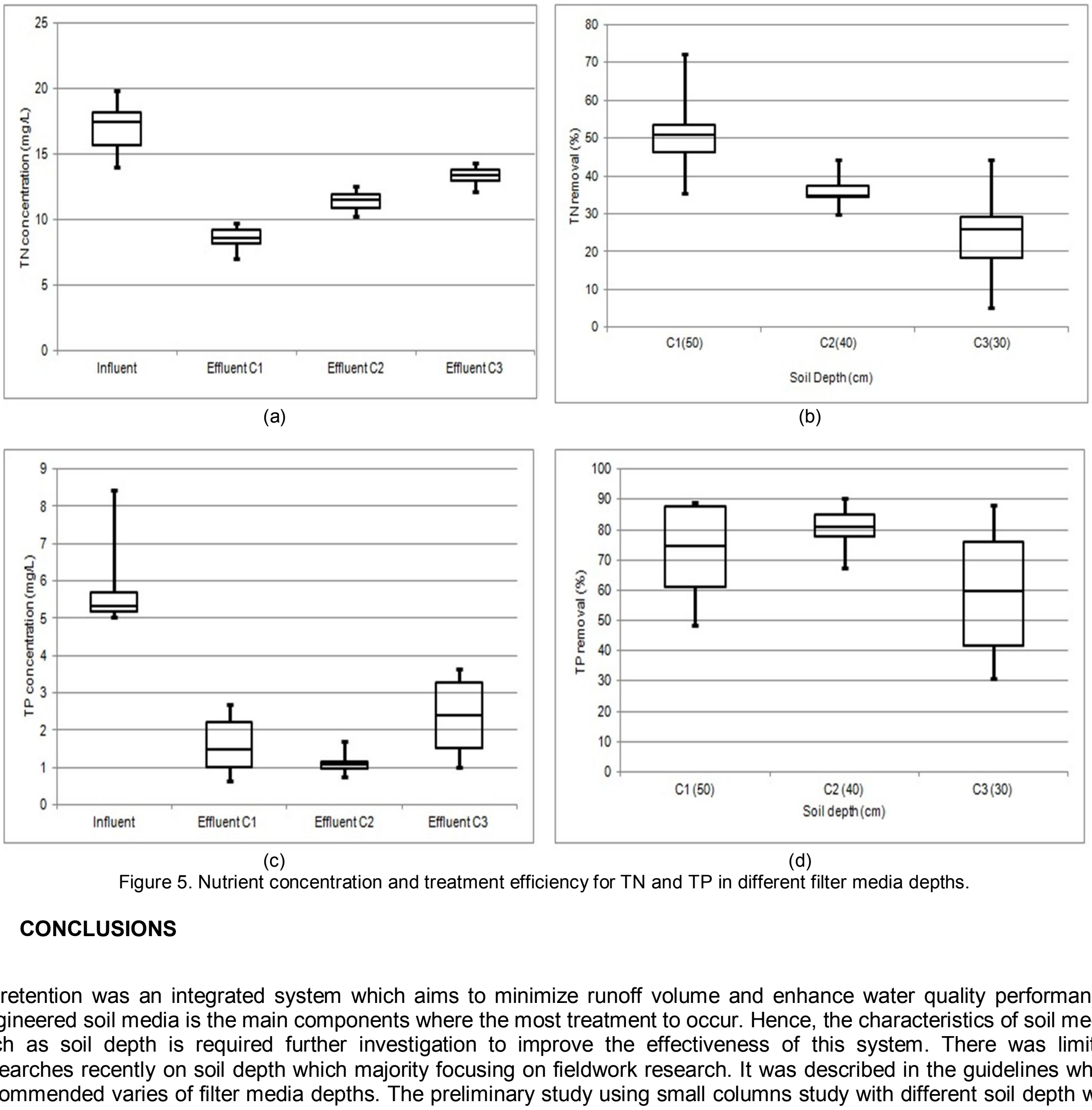


(a) (b)

Figure 4. Nutrient concentration performance during stormwater runoff application.

3.2 Engineered Soil Depth Effects

Pollutant removal data at the respective soil depths was evaluated to examine the effect of design media depth on nutrient removal (Davis et al., 2006). Box plot diagram of pollutant concentration and removal as expressed in Figure 5. Soil depth with 500 mm depth (C1) provide the best performance for TN and sufficient treatment for TP due to having longer retention time in deeper soil depth(Table 3 and Figure 5(b) and 5 (d). The median reduction of TN and TP at C1 were 50.9% and 74.5%,respectively.As per discussion earlier, TP was captured lower in C1 probably caused by the additional Phosphorus substances from compost in engineered soil media. Davis et al. (2006) reported that almost 50-80% of TN removal was presented at the highest depth. C2 showed adequate performance for TP pollutant with median removal were 80.8% exceeded the recommended value and moderate performance for TN with 34.9% removal. C3 had the poorest pollutant removal with median removal of TN and TP were 25.8% and 59.8% due to having shallower depth which capable to treat low volume of stormwater runoff with higher hydraulic conductivity. Hence, based on the study, it is suggested that 400 mm depth is the optimum depth to be used as a design filter media depth with a sufficient treatment performance mainly for nutrient pollutants.



(a) (b)

(c) (d)

Figure 5. Nutrient concentration and treatment efficiency for TN and TP in different filter media depths.

4. CONCLUSIONS

Bioretention was an integrated system which aims to minimize runoff volume and enhance water quality performance. Engineered soil media is the main components where the most treatment to occur. Hence, the characteristics of soil media such as soil depth is required further investigation to improve the effectiveness of this system. There was limited researches recently on soil depth which majority focusing on fieldwork research. It was described in the guidelines which recommended varies of filter media depths. The preliminary study using small columns study with different soil depth with range 300 – 500 mm depth. From the results, hydraulic conductivity was declined gradually over more than 2 months observation period for all cells. The reduction can be minimized using vegetated column with the presence of root that can create macropores between soil particles. C3 promoted the greatest hydraulic conductivity compared to the other cell due to shallower depth. C1 and C2 has little difference of hydraulic conductivity. In terms of responses of hydraulic conductivity on the nutrient removal, shallow soil depth (C3) generates greatest hydraulic conductivity but had poorest treatment performance. Conversely, lowest hydraulic conductivity provided by C1 has sufficient treatment performance for nutrient contaminant. C2 has slightly greater hydraulic conductivity than C1 achieved moderate nutrient removal by having 400 mm depth. Hence, the optimum depth of 400 mm was suggested in this study for the design purposes by considering water quality performance.

ACKNOWLEDGMENTS

This experimental work was funded by Ministry of Higher Education under Long Term Research Grant (LRGS) No. 203/PKT/672004 entitled Urban Water Cycle Processes, Management and Societal Interactions: Crossing from Crisis to Sustainability. The authors would like to acknowledge the financial assistance from Ministry of Education under HICoE's niche area Sustainable Urban Stormwater Management (Grant No. 311.PREDAC.4403901)., Universiti Teknologi PETRONAS (UTP) for giving fully support for the success of this project.

REFERENCES

Blecken, G.T., Zinger, Y., Deletić, A., Fletcher, T. D., Hedström, A., & Viklander, M. (2010). Laboratory study on stormwater biofiltration: Nutrient and sediment removal in cold temperatures. *Journal of Hydrology, 394*(3–4), 507-514.

Brander, K. E., Owen, K. E., & Potter, K. W. (2004). Modeled Impacts of Development Type on Runoff Volume and Infiltration Performance. *JAWRA Journal of the American Water Resources Association, 40*(4), 961-969.

Bright, T., Hathaway, J., Hunt, W., de los Reyes, F., & Burchell, M. (2010). Impact of Storm-Water Runoff on Clogging and Fecal Bacteria Reduction in Sand Columns. *Journal of Environmental Engineering, 136*(12), 1435-1441.

British Standard Institution (BSI), (1990). Methods of Test for Soils for Civil Engineering Purposes *Part 2:Classification Tests* (pp. 27-59). London: Board of BSI.

Brown, R. A., & Hunt, W. F. (2011). Impacts of Media Depth on Effluent Water Quality and Hydrologic Performance of Undersized Bioretention Cells. *Journal of Irrigation and Drainage Engineering, 137*(3), 132-143.

Cizek, A. R., & Hunt, W. F. (2013). Defining predevelopment hydrology to mimic predevelopment water quality in stormwater control measures (SCMs). *Ecological Engineering, 57*, 40-45.

Davis, A. P., Shokouhian, M., Sharma, H., & Minami, C. (2006). Water quality improvement through bioretention media: Nitrogen and phosphorus removal. *Water Environment Research, 78*(3), 284-293.

Department of Environmental Resources, The Prince George County, Maryland. (2009). The Bioretention Manual *Chapter 4:Sizing and Design Guidance* (pp. 48-68). Maryland: Environmental Services Division,Department of Environmental Resources, The Prince George's County, Maryland.

Department of Drainage and Irrigation of Malaysia (DID), (2012). Urban Stormwater Management Manual for Malaysia: Department of Irrigation and Drainage (DID)Malaysia

Facility for Advance Water Biofiltration (FAWB) (2009). Stormwater Biofiltration System Adoption Guidelines : Planning, Design and Practical Implementation (1 ed.). Monash University: Monash University.

Guo, H., Lim, F. Y., Zhang, Y., Lee, L. Y., Hu, J. Y., Ong, S. L., Yau, W.K.,Ong, G. S. (2014). Soil column studies on the performance evaluation of engineered soil mixes for bioretention systems. *Desalination and Water Treatment*, 1-7.

Hou, L., Liu, F., Feng, C., & Wan, L. (2013). Efficiencies of multilayer infiltration systems for the removal of urban runoff pollutants. [Evaluation Studies Research Support, Non-U.S. Gov't]. *Water Sci Technol, 67*(8), 1851-1858.

Jones, M. P., & Hunt, W. F. (2009). Bioretention impact on runoff temperature in trout sensitive waters. *Journal of Environmental Engineering, 135*(8), 577-585.

Kandra, H. S., McCarthy, D., Fletcher, T. D., & Deletic, A. (2014). Assessment of clogging phenomena in granular filter media used for stormwater treatment. *Journal of Hydrology, 512*, 518-527.

Le Coustumer, S., Fletcher, T. D., Deletic, A., & Barraud, S. (2007). Hydraulic performance of biofilters for stormwater management: first lessons from both laboratory and field studies. *Water Sci Technol, 56*(10), 93-100.

Le Coustumer, S., Fletcher, T. D., Deletic, A., Barraud, S., & Poelsma, P. (2012). The influence of design parameters on clogging of stormwater biofilters: a large-scale column study. [Research Support, Non-U.S. Gov't]. *Water Res, 46*(20), 6743-6752.

Lee, J. Y., Kim, H., & Han, M. (2008). The Evaluation of Bioretention Mesocosm for Treatment of Urban Stromwater Runoff. *International Journal of Urban Sciences, 12*(2), 116-128.

Li, H., & Davis, A. P. (2008). Heavy metal capture and accumulation in bioretention media. *Environmental science & technology, 42*(14), 5247-5253.

Li, H., Sharkey, L., Hunt, W., & Davis, A. (2009). Mitigation of Impervious Surface Hydrology Using Bioretention in North Carolina and Maryland. *Journal of Hydrologic Engineering, 14*(4), 407-415.

Low Impact Development (LID) Centre (2007). Urban Design Tools: Low Impact Development. *Bioretention Specifications* Retrieved 21 January 2015, 2015, from http://www.lid-stormwater.net/biohighres_specs.htm

Melbourne Water, (2005). WSUD Engineering Procedures: Stormwater: CSIRO PUBLISHING.

North Shore City (2008). North Shore City Bioretention Guidelines. Auckland, New Zealand.

PUB. (2011). Engineering procedures for ABC Waters Design Features *Chapter 7: Bioretention Basins* (pp. 1-42). Singapore.

Takaijudin, H., Ghani, A.Ab., Zakaria, N.A.,H.Md. Azamathulla. (2014). Preliminary Study on the Impacts of Variation Engineered Soil Composition in Bioretention on Hydraulic Performance. *Proceedings on 13th International Conference on Urban Drainage, Sarawak, Malaysia, 7-12 September 2014* 1-8.