CNRGT54
SUBSURFACE DRAINAGE MODULE PERFORMANCE STUDY IN MANAGING URBAN STORMWATER (CASE STUDY: TAIPING HEALTH CLINIC TYPE 2)

Lai Sai Hin, KEE Li Choo*, Zakaria Nor Azazi, Ab Ghani Aminuddin, Chang Chun Kiat

River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia
*Email: lichoo.rem08@student.usm.my

ABSTRACT
A small-scaled Sustainable Urban Drainage System (SUDS) which consists of grassed swale with subsurface drainage module, on-site stormwater detention (OSD), porous pavement, dry pond and gross pollutant trap (GPT), was constructed in 2005 for Taiping Health Clinic Type 2. The aim of this study is to investigate the performance of subsurface drainage module in managing urban stormwater runoff in the clinic compound. This subsurface drainage module is integrated with grassed swale in parallel arrangement as the main stormwater runoff conveyance conduit. The methodology in obtaining hydrological and hydraulic data used in analyzing subsurface drainage module performance is presented. A total number of four rainfall events have been analyzed. Results show that the subsurface drainage module is effective in reducing peak flow of surface runoff as well as in enhancing groundwater recharge in the study area.

Keywords: *SUDS, grassed swale, subsurface drainage module, peak flow.*

INTRODUCTION
Over the past several decades, concerns over the environment have embraced the notion that one of the most important indicators of health of our natural resources is the quality of water. However, rapid development has increased the amount of land surface imperviousness which increases stormwater runoff and surface water pollution to rivers, lakes, streams, ponds and wetlands. Increment in the frequency and magnitude of flooding as well as degradation of aquatic ecosystem are the most significant impacts result from urbanization [1-3]. As a result from this, a large number of casualties, disease epidemics, property and crop damages and other intangible losses had been recovered annually [4]. Regarding to the problems stated previously, it is obvious that a long term environmental friendly and sustainable technique of drainage system is needed which can reduce the impacts of urbanization in terms of quantity and quality issues. Best Management Practices (BMPs) and Sustainable Urban Drainage System (SUDS) are two popular concepts widely implemented currently [5-7]. In Malaysia, the handling of project in stormwater management is referred to Urban Stormwater Management Manual for Malaysia (MSMA) which promotes sustainable urban drainage design and practising [8]. Several projects which referred to MSMA includes the pilot project of Bio-Ecological Drainage System (BIOECODS) completed at the end of 2002 at USM Engineering Campus [9-10], Taiping Health Clinic Type 2 completed in year 2005 [11], and DID Mechanical Section Ipoh where rehabilitation of existing wetlands and mining ponds have been done [12].

This paper will focus on the study of grassed swale system in Taiping Health Clinic Type 2. This grassed swale is designed for 5-year Average Recurrence Interval (ARI). The longitudinal slope of the grassed swale is 1:500. The design of grassed swale in this project consists of a surface swale and subsurface drainage module in parallel arrangement. The subsurface drainage module is enclosed within geotextile to prevent fines from entering the drainage system. It is overlaid by a layer of porous media (gravel) with clean river sand at both sides and bottom part as well as a layer of top soil for grass planting. Figure 1 shows the isometric view of grassed swale system.

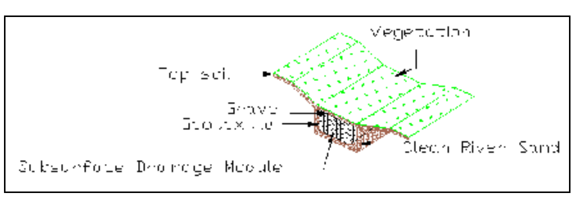


Figure 1: Isometric view of grassed swale system

At the beginning of rainfall, the first drop of water is intercepted by leaves and stems of vegetation. This is referred as interception storage. As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage). When depression storage is filled, water will start to flow and downstream runoff is thus generated [13-14]. Both the surface runoff and subsurface drainage module flow will finally being conveyed to the outlet. Meanwhile, water inside the subsurface drainage module will seep into surrounding soil which contributes to groundwater recharge.

The objective of the present paper is to examine the performance of the subsurface drainage module under different rainfall intensity events. The grassed swale with subsurface drainage module system needs a good understanding of its operation and performance in stormwater management.

BACKGROUND OF THE STUDY AREA

Taiping Health Clinic Type 2 and its infrastructure have been constructed on an area of approximately 2.2 hectare in Larut & Matang District, Perak [11]. This clinic is officially functioning since May 2008. The soil profile for overall project area is consistent, from silty sand at the first 10 m depth to hard layer of silty clay. Groundwater level is observed at 0.95 m to 1.35 m depth from the original ground surface. The location of this project is shown in Figure 2.

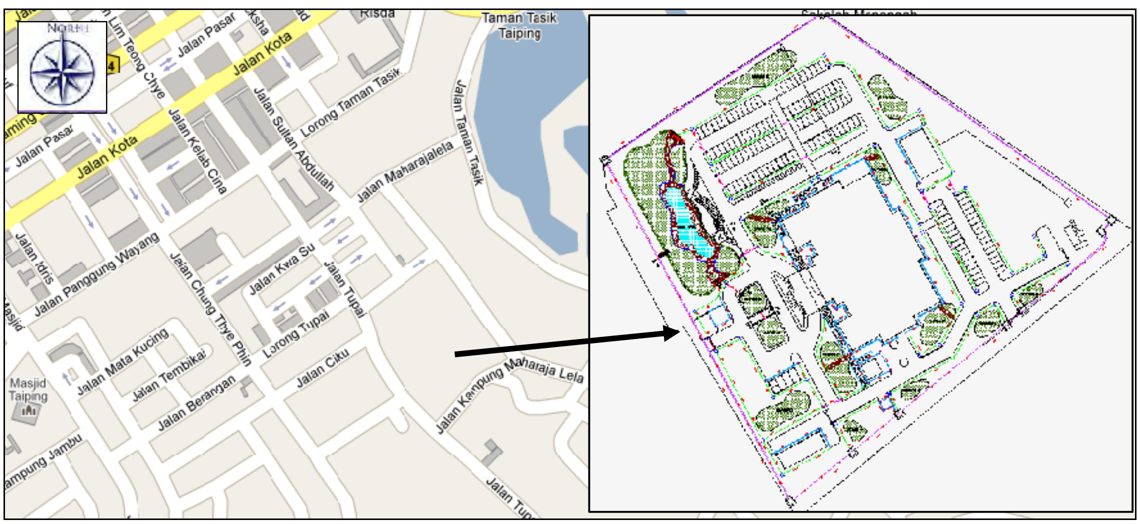


Figure 2: Location of Taiping Health Clinic Type 2 (from Google Map)

The field study is carried out in a selected sub-catchment with area of approximately 4,318 m^2. This sub-catchment area consists of stormwater devices such as grassed swale with subsurface drainage module, concrete drain and crossing. Landuse types of this area are described in Table 1.

Table 1: Landuse of selected sub-catchment

Landuse Type	Component	Percentage (%)
Pervious	Grassed swale, permeable pavement and grass area	28.4
Impervious	Concrete pavement, concrete drain and building	71.6

From upstream catchment, stormwater runoff from concrete pavement and permeable pavement will flow into grassed swale and concrete drain through road inlet pipe. There is a building area in this sub-catchment where concrete drain will receive stormwater runoff from the building. The monitoring point will finally receive stormwater runoff for the whole selected sub-catchment. Figure 3 shows the detail sub-catchment selected and the stormwater flow direction in this study.

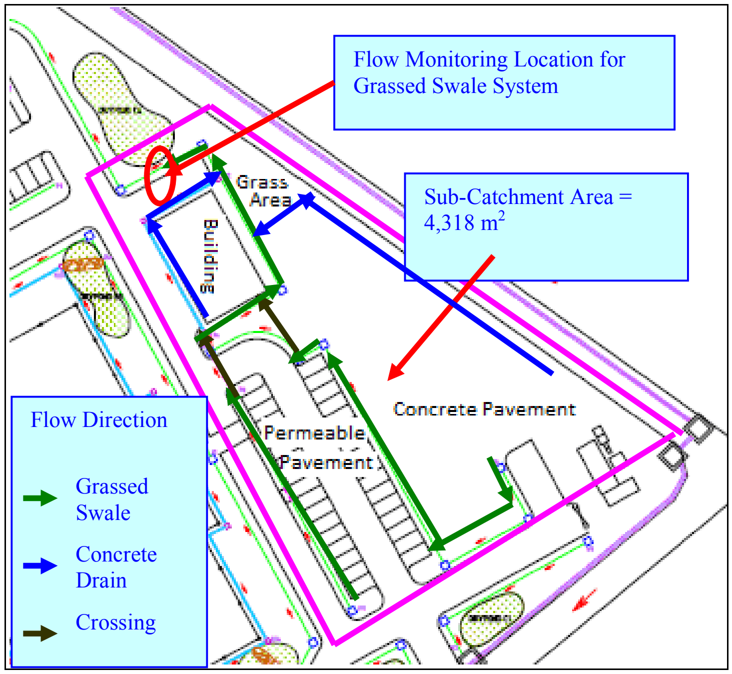


Figure 3: Flow direction in selected sub-catchment

MATERIAL AND METHODS

In order to investigate the performance of subsurface drainage module, there are some parameters which need to be determined. The detail field data measurement methods and related theories are described in the following sections.

Measurement

During rainfall event, measurement of grassed swale surface flow velocity and corresponding water depth has been taken manually by using electromagnetic current meter. The time interval for obtaining these data is fixed to be 5 minutes. Apart from this, the subsurface drainage flow velocity and water depth is recorded by an automatic gauging system with 1-minute interval.

Precipitation Data

The 5-minute interval precipitation data has been obtained from the rain gauge installed in the study area. The rainfall intensity for the duration from 30 minutes until 240 minutes and various Average Recurrence Interval (ARI) values for Bagan Serai have been calculated as shown in Table 2 [8]. These values are then used to estimate the ARI for rainfall events occurred in the study area.

Table 2: Summary of rainfall intensity for study area

Rainfall Duration	1-month ARI	3-month ARI	6-month ARI	1-year ARI	2-year ARI	5-year ARI	10-year ARI
30	31.84	39.80	47.76	63.68	79.60	94.04	107.28
45	25.29	31.62	37.94	50.59	63.24	74.99	85.45
60	21.04	26.30	31.56	42.08	52.60	62.75	71.60
90	15.84	19.80	23.76	31.67	39.59	47.78	54.71
120	12.76	15.95	19.14	25.52	31.90	38.86	44.63
150	10.72	13.39	16.07	21.43	26.79	32.89	37.85
180	9.26	11.57	13.89	18.52	23.14	28.59	32.94
240	7.31	9.14	10.97	14.62	18.28	22.78	26.28

In this study, rainfall-runoff relationship for grassed swale with subsurface drainage module has been analysed for 4 rainfall events in the month of March 2010. The rainfall depth (P_d) recorded is converted to rainfall intensity (I) by dividing it by the rainfall duration (d) [8].

$$I = \frac{P_d}{d} \tag{1}$$

The area which contributes to the runoff at the monitoring point is estimated to be around 4,318 m^2. Therefore, the total rainfall volume (V) which falls onto the catchment area (A) has been determined as follow:

$$V = P_d \times A \tag{2}$$

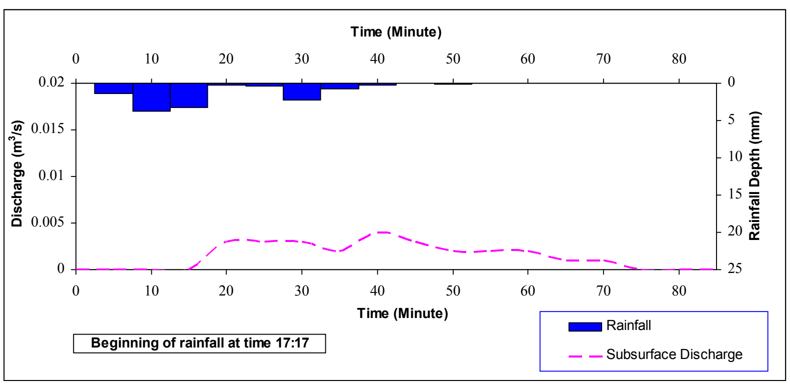
Finally, the ARI for the 4 rainfall events has been determined by using Table 2. The detail descriptions of each rainfall event are summarized in Table 3.

Table 3: Detail description of rainfall events

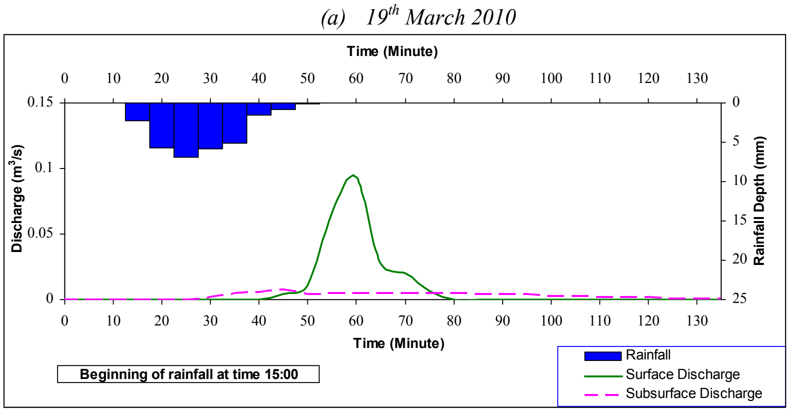
Date	Rainfall Intensity (mm/hr)	Rainfall Duration (min)	Total Rainfall Volume (m^3)	Average Recurrence Interval (ARI)
19th March 2010	16.26	45	52.68	(<) 1-month
21st March 2010	45.73	37	121.78	6-month
25th March 2010	28.76	58	120.05	3-month
26th March 2010	8.24	83	49.23	(<) 1-month

DATA ANALYSIS

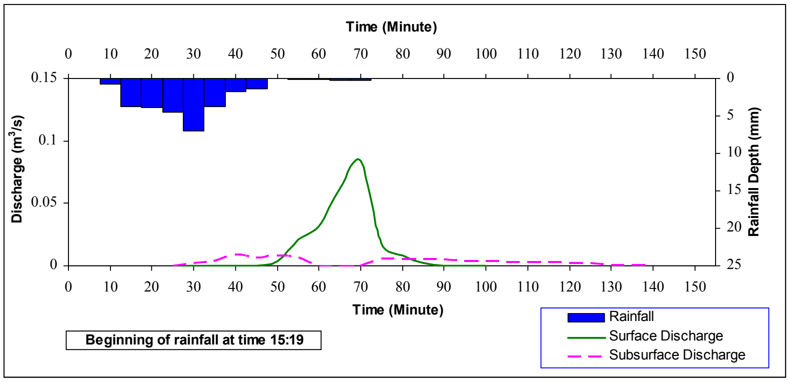
Figure 4 shows the grassed swale and subsurface drainage module hydrographs plotted for the 4 rainfall events. All the stormwater received in grassed swale has infiltrated into the subsurface layer for rainfall events less than 1- month ARI. The area under the graph represents the runoff volume received at the monitoring point.



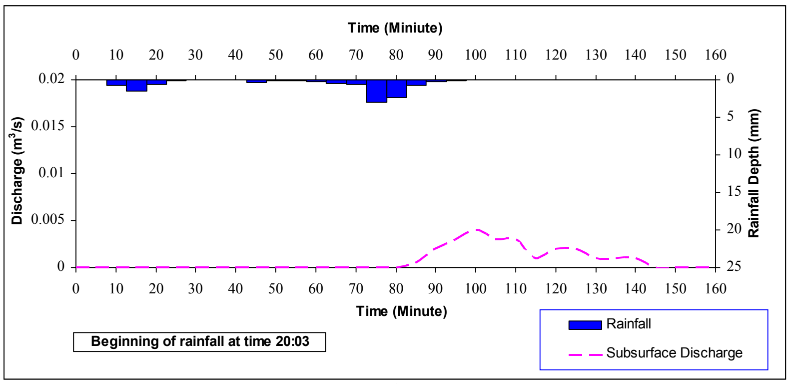
(a) 19th March 2010



(b) 21st March 2010



(c) 25th March 2010



(d) 26th March 2010

Figure 4: Hydrograph for grassed swale system for rainfall event: (a) 19th March 2010 (b) 21st March 2010 (c) 25th March 2010 (d) 26th March 2010 (continued)

From the data measured, peak flow and peak flow occurring time for grassed swale surface as well as subsurface drainage module are summarized in Table 4.

Table 4: Peak flow and peak flow occurring time for grassed swale surface and subsurface drainage module

Date	Rainfall Start	Grassed Swale Surface		Subsurface Drainage Module	
		Peak Flow (m^3/s)	Occuring Time	Peak Flow (m^3/s)	Occuring Time
19th March 2010	17:17	-	-	0.004	17:55
21st March 2010	15:00	0.094	15:45	0.008	15:30
25th March 2010	15:19	0.084	16:20	0.009	15:50
26th March 2010	20:03	-	-	0.004	21:35

Table 5 summarizes the percentage of runoff volume distribution for grassed swale surface and subsurface drainage module. The percentage of loss volume estimated in Table 5 represents the loss resulted from interception storage, absorption by porous media, depression storage, and groundwater recharge.

Table 5: Percentage of runoff volume distribution in grassed swale system.

Date	Total Rainfall Volume	Surface Flow Volume		Subsurface Flow Volume		Estimated Loss Volume	
	(m^3)	(m^3)	%	(m^3)	%	(m^3)	(%)
19th March 2010	52.68	0	0	8.16	15.5	44.62	84.5
21st March 2010	121.78	68.42	56.2	19.39	15.9	33.97	27.9
25th March 2010	120.05	69.11	57.6	24.66	20.5	26.28	21.9
26th March 2010	49.23	0	0	7.50	15.2	41.73	84.8

CONCLUSIONS

The subsurface drainage module which integrated with grassed swale is able to cater a percentage of surface runoff volume approximately 15.2% to 20.5% for rainfall events of less than 6-month ARI. This subsurface drainage module is proved to be able to improve groundwater recharge as the module allows seepage of water into the soil surrounding. Therefore, this grassed swale system is effective in managing the stormwater runoff in Malaysia as most of the rainfall events in Malaysia are less than 3-month ARI.

ACKNOWLEDGEMENT

The authors wish to gratefully acknowledge the USM-RU-PRGS grant no. 8032054 and Short Term Grant no. 6035263 provided by Universiti Sains Malaysia as well as the support of Universiti Sains Malaysia Fellowship for the financial commitment. Apart from this, the authors would like to convey their appreciation to Leow Cheng Siang and Dr. Darrien Mah Yau Seng in giving valuable advice for completing this research study.

REFERENCES

[1] Barber, M.E., King, S.G., Tonge, D.R., and Hathhorn, W.E. (2003) Ecology Ditch: A Best Management Practice for Storm Water Runoff Mitigation. Journal of Hydrologic Engineering, Vol. 8, No. 3, May 1, 2003. pp. 111-122.
[2] Ouyang, T., Zhu, Z., and Kuang, Y. (2006) Assessing Impact of Urbanization on River Water Quality in the Pearl River Delta Economic Zone, China. Environmental Monitoring and Assessment (2006) 120: 313–325.
[3] Seilheimer, T.S., Wei, A. Fraser, P.C., and Eyles, N. (2007) Impact of urbanization on the water quality, fish habitat, and fish community of a Lake Ontario marsh, Frenchman's Bay. Urban Ecosystem 10:299–319.
[4] Liu, P-S. & Chan, N.W. (2003) The Malaysian Flood Hazard Management Program. Int. J. Emergency Management, Vol. 1, No. 3, 2003.
[5] Ciria, Sustainable Drainage System, http://www.ciria.org.uk/suds/index.html. (accessed: 6 Nov 2009).
[6] International Stormwater BMP Database, http://www.bmpdatabase.org/. (accessed: 6 Nov 2009).
[7] The Low Impact Development Center, http://www.lowimpactdevelopment.org/index.html. (accessed: 6 Nov 2009).
[8] Department of Irrigation and Drainage Malaysia or DID (2000) Urban Stormwater Management Manual for Malaysia.
[9] Zakaria, N.A., Ab. Ghani, A., Abdullah, R., Mohd Sidek, L., Ainan, A. (2003) Bio-Ecological Drainage Syetem (BIOECODS) for Water Quantity and Quality Control. International Journal of River Basin Management, IAHR & INBO, Vol., 1, No. 3 (2003), pp. 237 – 251.
[10] Ab. Ghani, A., Zakaria, N.A., Abdullah, R., Yusof, M. F., Mohd Sidek, L., Kassim, A. H. & Ainan, A. (2004) Bio-Ecological Drainage System (BIOECODS): Concept, Design and Construction. 6th International Conference on Hydroscience and Engineering (ICHE-2004), May 30-June 3, Brisbane, Australia.
[11] Ab. Ghani, A., Zakaria, N.A., Chang, C.K. & Ainan, A. (2008) Sustainable Urban Drainage System (SUDS) - Malaysian Experiences. 11th International Conference on Urban Drainage, Edinburgh, UK, 31st August - 5th September.
[12] Chang, C.K., Ab. Ghani, A., Zakaria, N.A., Yusof, M.F., Ayub, K.R., Lai, S.H.,. Hasan, A.M.M., Ainan, A. (2008) Rehabilitation of Ex-Mining Pond and Existing Wetland for Integrated Stormwater Management. 11th International Conference on Urban Drainage, Edinburgh, UK, 31st August - 5th September.
[13] Deletic, A. (2001) Modeling of water and sediment transport over grassed areas. Journal of Hydrology 248 (2001) 168 – 182.
[14] Kamphorst, E.C., Chasoeuf, J., Jetten, V., and Gue´rif, J. (2005) Generating 3D Soil Surfaces from 2D Height Measurements to Determine Depression Storage. Catena 62 (2005) 189–205.

NOMENCLATURE

I	rainfall intensity (mm/hr)
P_d	rainfall depth (mm)
d	duration (min)
V	total rainfall volume (m^3)
A	catchment area (m^2)