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HYDRAULIC PERFORMANCE OF GRASSED SWALE AS STORMWATER QUANTITY CONTROL

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ABSTRACT

Grassed swales are widely employed to encourage ground infiltration and reduce storm runoff in urban areas. Precipitation that infiltrated into surrounding soils is collected and conveyed by swales into nearby water bodies to prevent localized flooding. Swales are one of the means to decrease the velocity, to reduce the peak flows, and minimize the causes of flood. However, a well functioned swale requires a systematic planning of construction. This study presents the determination of flow velocity for grassed swale in Universiti Tun Hussein Onn Malaysia (UTHM) and how its efficiency based upon the varied swale profile. Data collection was conducted on the grassed swale with the total length of swale is 100 meters. The swale is divided into three sections, where every section has three points. The measurements of flow velocity have been taken three times at each point after a rainfall event by using the current meter flow. As a preliminary work, levelling has been done on the swale beforehand to obtain the swale profile. The results showed various values of flow velocity according to the swale profile and its flow depth. The cross-sectional area of swale is in the range of 0.285 m^2 to 0.496 m^2. Meanwhile, the flow velocity observed from the swale is in the range of 0.027 m/s to 0.080 m/s. As a result, there are differences in flow discharge occurred, which in the range of 0.012 m^3/s to 0.023 m^3/s. An effective swale must have a suitable swale profile that could decrease the flow velocity and reduce the flow discharge of the swale.

Keywords: grassed swale, swale profile, hydraulic parameters, stormwater quantity control.

INTRODUCTION

Grassed swale is a vegetated, open channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality and quantity volume (US EPA, 2012). Establishment of grassed swale is a potential solution wherever stormwater needs to be transported from impervious surfaces, slowed down, and allowed to infiltrate into soils. When properly designed to accommodate a predetermined storm event volume, a grassed swale results in a significant improvement over the traditional drainage ditch in both slowing and cleaning of water (Stevens, 2001). In general, the swales work as decreasing the velocity of flow, acting as storm runoff detention facilities, and pollutant removal.
The urbanization has caused an increment in the imperviousness which produced increased peak flow and more runoff volume (Barber *et al*., 2003; Seilheimer *et al*., 2007; Ouyang *et al.*, 2006), as shown in Figure-1. As indicated in Figure 1, the percent of time that runoff rate exceeds a certain value generally increases after urban development. Thus, urbanization not only increases runoff rate and volume but also their frequency. The frequency of runoff rate has a direct impact on erosion and sediment transport of a channel.

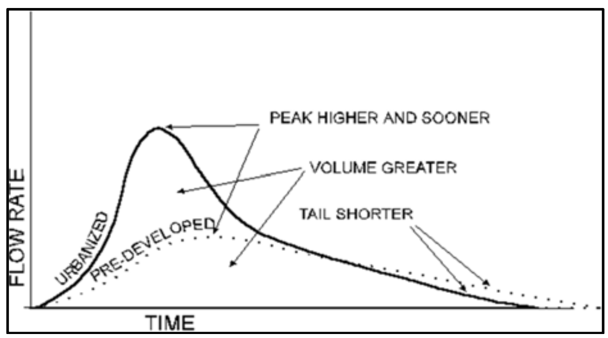

Figure-1. Runoff hydrographs before and after development (Li J, 2015).

In Malaysia, the conventional drainage systems (concrete drains) have been widely used. However, this practice brings a significant impact on the environment as a whole (Hin *et al*., 2009). The concrete drains tend to cause flooding as runoff is being conveyed to watercourses directly in shorter duration and have less infiltration into the ground. Besides, the conventional drainage systems are highly exposed to clogging problems. As a result, water cannot flow properly to the catchment area. When heavy rain occurs, it can result in high water volume and spills out of the drains and then cause flooding.

High water volume that caused by impervious surfaces may lead to more diverse pollutants and reduced pollutant removal during overland flow. Swales are designed to treat stormwater runoff through filtration by the vegetation in the channel, filtering through a subsoil matrix, or infiltration into the underlying soils. The vegetation above the ground part is to filter any particles and their associated pollutants as runoff passes through slowly and evenly the channel. The pollutants are then incorporated into the soil where they may be immobilized or decomposed by plants and microbes (US EPA, 2012).

Swale is treating water quality and quantity control only using cheap and readily available materials, which are soil, vegetation, and microbes. This will lead to reduce the cost of water treatment process, since swales are inexpensive relative to the conventional curb and gutter treatment or underground stormwater systems. The maintenance for swale is required more frequently but it is considerably less costly than curb and gutter systems maintenance (McKain, 2013).

Besides, swale comes with lots of water protection benefits. Swales are designed to capture and retain runoff in recessed drainage, which typically does not need irrigation beyond plant establishment. These areas can provide significant aesthetic benefit while avoiding water requirements associated with other landscape types. They can also conserve biodiversity when native plants are used (Clark *et al*., 2008).

Grassed swale is widely applied in the campus of Universiti Tun Hussein Onn Malaysia (UTHM). Swales are environmentally-friendly drainage system, which is derived from the Manual SaliranMesraAlam Malaysia (MSMA). MSMA is required in order to provide a systematic construction so that the swales can be function properly to reduce the risk of flooding. This study was conducted at the UTHM campus and focus on the flow velocity for grassed swale. The hydraulic parameters involved in this study are cross-sectional area of swale, flow velocity, flow depth, and flow discharge. The objectives for this study are to determine the flow velocity for grassed swale in UTHM based upon the swale profile and to determine its effectiveness on reducing flow discharge of the swale.

Stormwater quantity control

Stormwater drainage systems can be categorized into two types, which are the conventional drainage systems and the sustainable drainage systems. The conventional drainage is often unable to manage the quantity of rain that falls during heavy rains or storms. The idea behind the sustainable drainage systems is to counter the effects of conventional drainage systems that often allow for flooding and water pollution (Center for Neighborhood Technology, 2013). St. Johns River Water Management District (2015) stated that the sustainable drainage systems were designed to resemble the natural processes and come in a variety of shapes, sizes, and forms. Basically there are four types of sustainable drainage systems, which are retention basin, swale, dry detention, and wet detention. In this case of study, UniversitiTun Hussein Onn Malaysia (UTHM) has implemented the sustainable drainage systems, where mainly can be found at the new development of university campus. UTHM has applied swales (in lieu of the concrete drains), detention ponds, and engineered waterways. Figure-2 shows the grassed swale in UTHM.

Figure-2. Grassed swale in UTHM.

According to the City of Columbia Public Works Department (2015), there are two main issues concerned that related to stormwater, which is the volume and timing of runoff (flood control and water supplies), and the potential contaminants carried by the water (water pollution). In terms of quantity control, Yu *et al*. (2007) has claimed that swales significantly reduced total volume and flow magnitudes generally during events with rainfall less than 3 cm. From a water balance perspective, the swales are expected to have a decreasing capacity for infiltration storage, with the maximum infiltration rate decaying asymptotically towards the saturated hydraulic conductivity of the soil. Once precipitation exceeds the maximum infiltration rate, surface flow, storage, and eventual discharge from the swale will result. Stored water will infiltrate, which should beneficially contribute to groundwater recharge and base flow, and some will evapotranspirate (Davis, 2011).

Design considerations for grassed swale

Grassed swales are used to collect and transport stormwater runoff. Grassed swales can help maintain the flow rate and volume of the stormwater when receiving runoff from less than 1,400 m^2. The side and longitudinal slopes are used to control water flow (Grenz, 2007). It is commonly with a minimum longitudinal slope of 0.5% and a maximum of 5%.15 cm to 30 cm of water can be stored within the swale. This storage is used prevent the stormwater from entering the detention system all at once. The important factor in designing a grassed swale is to maintain the flow velocity of the swale. A high flow velocity can cause the grass to be pushed down, thus losing the filter aspect of the swale (Grenz, 2007). A 4 m swale can reduce the volume of runoff from a typical local road to about 25% of total rainfall; even the soils have very poor hydraulic conductivity (1 mm/h) (British Colombia, 2002).

Swales are impractical for areas with very flat grades or steep slopes, and should be used to serve areas of less than 4 ha. Swales should not be installed in areas with high water tables where groundwater reaches the

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bottom of the swale (Clark *et al*., 2008). In each swale the water is stored to a level of approximately 0.25 meters, a level designed to be exceeded only once every two years. Once every twenty-five years the water level in the swale reaches a depth of 0.35 meters. Above this level the water is discharged into the next swale and, in the end, into the surface water.

The preferred shapes for swales are shown in Figure-3a trapezoidal shaped which commonly used in Universiti Tun Hussein Onn Malaysia (UTHM). A trapezoidal section may be used for additional capacity or to limit the depth of the swale. The depth of a grassed swale shall include a minimum freeboard of 50 mm above the design stormwater level in the swale to allow for blockages (DID, 2012). The flow path shall not exceed 0.9 m. The average flow velocity in a swale shall not exceed 2 m/s. If this is not practical, an underground pipeline, lined open drain, or grass reinforcement system should be provided (DID, 2012).

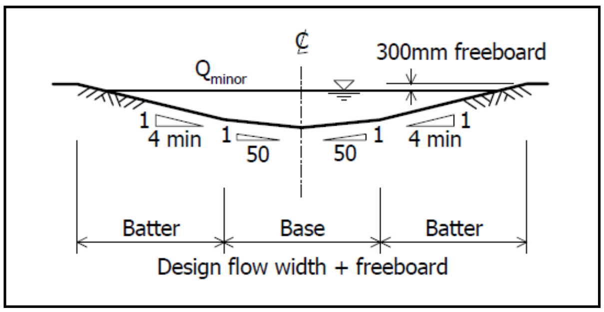

Figure-3. Swale in trapezoidal shaped.

Materials and Methods

Data collection was conducted at grassed swale in Universiti Tun Hussein Onn Malaysia (UTHM) campus, which measurement was made after the rainfall event. The equipment used are the current meter flow to measure the flow velocity, the levelling instrument to measure the cross section of swale in order to develop the swale profile, and the measuring tape to measure the width and depth of surface drainage.

The length of swale is 100 meters and was divided into three sections, which are Section A, Section B, and Section C. The distance from Section A to Section B is 50 meters and distance from Section B to Section C is also 50 meters. Figure 4shows the cross sections of swale at Section A, Section B, and Section C. The data obtained from the swale are the flow depth of swale (Y), the flow velocity in the swale (V), and the top width of swale (T). This data are important to determine the effectiveness of the swale in terms of its hydraulic parameters, which are the cross-sectional area of swale (A) and the flow discharge of swale (Q).

The methodology of this study are similar with previous study by Afzalimehr *et al*., (2010), where at each cross section, three points were made to measure the flow velocity. The velocities have been measured at each point thrice, with the average of these three values taken as representative of the actual velocity for that point. The discharge was calculated by using the continuity equation Q = AV.

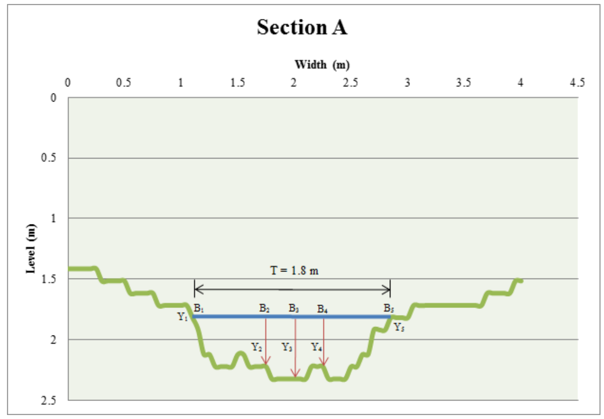

Figure-4. Cross section of swale for Section A, B, and C.

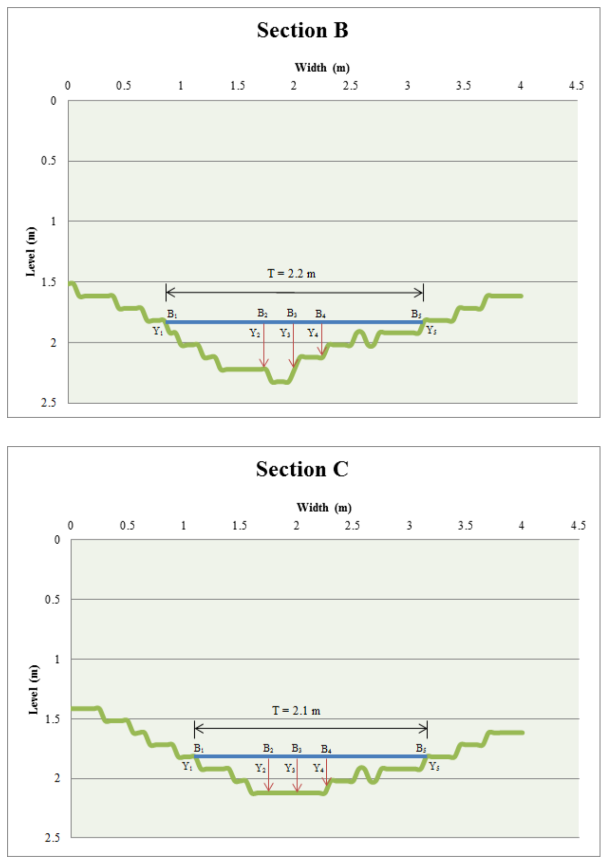

Figure-5. Cross section of swale for Section A, B, and C (continued).

RESULTS AND DISCUSSIONS

Table-1 shows the flow depth and top width of the swale at three sections for three days. Each section is divided into three points, which labeled as Left, Center, and Right, so that the flow depth can be measured accurately along the cross sections of swale.

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Table-1. Flow depth and top width of the swale at three sections for three days.

Section	Date	Flow depth, Y (m)			Top width, T (m)
		Left	Center	Right	
A	31 March 2015	0.360	0.390	0.385	1.8
	02 April 2015	0.290	0.270	0.235	1.6
	03 April 2015	0.175	0.240	0.230	1.5
B	31 March 2015	0.375	0.380	0.320	2.2
	02 April 2015	0.210	0.215	0.195	1.5
	03 April 2015	0.190	0.250	0.180	1.7
C	31 March 2015	0.210	0.225	0.205	2.1
	02 April 2015	0.075	0.095	0.080	1.9
	03 April 2015	0.070	0.085	0.065	1.8

Based on Table-1, the flow depth at three sections of swale on 31st March 2015 has the highest value compared to the other two days. The cross-sectional area of swale is determined based on the flow depth and the top width of swale by using the suitable hydraulic equation. The average value of flow velocity in each section is calculated to determine the flow discharge of swale.

Table-2 shows the cross-sectional area, the average value of flow velocity, and the flow discharge at three sections of the swale for three days. Since the data on 31st March 2015 has the highest value among the other days, the analysis will be focused on that date for each section of the swale.

Table-2. Cross-sectional area, flow velocity, and flow discharge at three sections of swale for three days.

Section	Date	Area, A (m^2)	Velocity, V (m/s)	Flow discharge, Q (m^3/s)
A	**31 March 2015**	**0.452**	**0.0270**	**0.012**
	02 April 2015	0.291	0.0013	3.783×10^{-4}
	03 April 2015	0.224	0.0037	8.288×10^{-4}
B	31 March 2015	0.496	0.0340	0.017
	02 April 2015	0.216	0.0050	10.8×10^{-4}
	03 April 2015	0.252	0.0033	8.316×10^{-4}
C	31 March 2015	0.285	0.0800	0.023
	02 April 2015	0.102	0.0017	1.734×10^{-4}
	03 April 2015	0.086	0.0030	2.58×10^{-4}

Based on Table-2, Section B has the largest cross-sectional area of swale which is 0.496 m^2, and Section C has the smallest cross-sectional area which is 0.285 m^2. However, Section C has shown that it has the highest value of flow discharge, which is 0.023 m^3/s that occurred at 0.080 m/s of flow velocity. Meanwhile, Section A has shown that it has the lowest flow discharge, which is 0.012 m^3/s that occurred at 0.027 m/s of flow velocity.

From this analysis, Section C shown that the smallest cross-sectional area has the highest value of flow velocity thus increased the flow discharge. Nevertheless, it doesn’t mean the largest cross-sectional area will decreased the flow velocity and flow discharge of the swale. As can be seen on the table, the cross-sectional area for Section B is larger than Section A. Even so, Section A has the lowest value of flow velocity thus decreased the flow discharge of swale. The results showed probable that Section A has the most appropriate design characteristics. This may be due to several factors in terms of the swale profile, the hydraulic parameters, the distance between section of the swale, and the type of vegetation that grew at each section of the swale.

Stormwater design criteria are provided to prevent increased flooding, to protect the water quality, to preserve the baseflow characteristics, to limit undesirable geomorphic changes in watercourses, and to maintain the groundwater quality. The quantity control criteria have been established in order to protect downstream properties from flooding due to upstream change in land use caused by development (Ganaraska Region Conservation Authority, 2014). Swale is considered can provide control of certain peak runoff rates by retarding and impounding stormwater, thus conveying it downstream at velocities low enough to protect against channel and streambank erosion. Roesner *et al*. (2001) found that the higher frequency of the peak flow causes the stream to cut a deeper and wider channel. The study by Ainan *et al*. (2003) has showed the percentage reduction of volume and peak flow based on the flow attenuation for swale. The percentage reduction of peak flow for swale surface is in the range of 28.9% to 55.9%. Meanwhile, the percentage reduction of volume is between 19.4% and 69.8%. This percentage shows the effectiveness of swale in controlling the stormwater quantity. The study on stormwater quantity control can be further explored with the quantity design fundamentals, which included the rainfall and peak discharge estimation by using the Rational Method.

CONCLUSIONS

This study can be concluded that the flow velocity in a swale is affected by the cross section of the swale. Based on the results, it shows that if the swale is appropriately designed with the suitable hydraulic parameters, then the swale will be functional as an effective drainage system. An effective grassed swale would convey the stormwater runoff to the detention pond or river, which then prevent flooding from occurred. Swales should be able to carry their design flow without overtopping or eroding. If the flow velocity is too high for grass cover in the swale but the slope and cross section cannot be adjusted, the swale can be reinforced with rip-rap or turf reinforcement matting, which can withstand a higher flow velocity. Vegetation also plays an important role in the effectiveness of the swale, which act as an agent to slow down the flow velocity, thus reduced the flow discharge. Maintenance of grassed swale is required to ensure that the intended use of swale can be achieved, which are controlling volume of stormwater runoff and avoiding flood.

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