PERFORMANCE OF GRASSED SWALE AS
STORMWATER QUANTITY CONTROL IN LOWLAND AREA

NURHAZIRAH BINTI MUSTAFFA

A thesis submitted in fulfillment of the requirement for the award of the
Degree of Master of Civil Engineering

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

APRIL 2018

ACKNOWLEDGEMENT

I would like to express deepest appreciation to my supervisor, Assoc. Prof. Dr. Mohd Adib Mohammad Razi, and my co-supervisor, Puan Noor Aliza Ahmad, for their expertise, assistance, and patience in guiding me in the completion of writing this thesis, regardless their time and place. Without their persistent help, this thesis would not have been possible.

I would like to extend my sincere gratitude to the staff from Faculty of Civil and Environmental Engineering and Center of Graduate Studies. My appreciation also goes to everyone involved directly or indirectly towards the completion of this thesis, especially to the examiners during the viva voce.

I am deeply thankful to Ministry of Higher Education Malaysia and Research, Innovation, Commercialization, and Consultancy Management Office of Universiti Tun Hussein Onn Malaysia for financially under FRGS Fund (Vot 1414) for supporting this study.

Last of all, special thanks to my beloved parents, Mustaffa Seth and Rogayah Mohd Saad, who have been remarkably supporting me in pursuing my dreams and ambitions, and also to my devoted husband, Azdzharulhisham Alwi, who has helped me a lot throughout the study process and always gives me encouragement, inspiration, and motivation.

ABSTRACT

Grassed swale is a vegetated open channel designed to attenuate stormwater through infiltration and conveying runoff into nearby water bodies, thus reduces peak flows and minimizes the causes of flood. UTHM is a flood-prone area due to located in lowland area, has high groundwater level and low infiltration rates. The aim of this study is to assess the performance of grassed swale as a stormwater quantity control in UTHM. Flow depths and velocities of swales were measured according to Six-Tenths Depth Method shortly after a rainfall event. Flow discharges of swales (Q_{swale}) were evaluated by Mean-Section Method to determine the variations of Manning's roughness coefficients ($n_{calculate}$) that results between 0.075 – 0.122 due to tall grass and irregularity of channels. Based on the values of Q_{swale} between sections of swales, the percentages of flow attenuation are up to 54%. As for the flow conveyance of swales, Q_{swale} were determined by Manning's equation that divided into $Q_{calculate}$, evaluated using $n_{calculate}$, and Q_{design}, evaluated using roughness coefficient recommended by MSMA (n_{design}), to compare with flow discharges of drainage areas (Q_{peak}), evaluated by Rational Method with 10-year ARI. Each site of study has shown Q_{design} is greater than Q_{peak} up to 59%. However, $Q_{calculate}$ is greater than Q_{peak} only at a certain site of study up to 14%. The values of Q_{design} also greater than $Q_{calculate}$ up to 52% where it shows that the roughness coefficients as considered in MSMA are providing a better performance of swale. This study also found that the characteristics of the studied swales are comparable to the design consideration by MSMA. Based on these findings, grassed swale has the potential in collecting, attenuating, and conveying stormwater, which suitable to be applied as one of the best management practices in preventing flash flood at UTHM campus.

ABSTRAK

Swale berumput adalah saluran terbuka tumbuhan yang direka untuk memperlahankan air ribut melalui penyusupan dan mengalirkan air larian ke saluran air berdekatan, lalu mengurangkan aliran puncak dan meminimumkan punca-punca banjir. UTHM adalah kawasan terdedah kepada banjir kerana terletak di kawasan tanah rendah, mempunyai paras air bawah tanah yang tinggi dan kadar penyusupan yang rendah. Tujuan kajian ini adalah untuk menilai prestasi *swale* berumput sebagai kawalan kuantiti air ribut di UTHM. Kedalaman aliran dan halaju *swale* diukur berdasarkan *Six-Tenths Depth Method*. Pelepasan aliran *swale* (Q_{swale}) dinilai oleh *Mean-Section Method* untuk menentukan variasi pekali kekasaran *Manning* ($n_{calculate}$) yang mana nilainya antara 0.075 – 0.122 disebabkan oleh rumput tinggi dan ketidakaturan saluran. Berdasarkan nilai-nilai Q_{swale} antara bahagian *swale*, peratusan pengecilan aliran adalah sehingga 54%. Bagi pengangkut aliran *swale*, Q_{swale} ditentukan oleh persamaan *Manning* yang dibahagikan kepada $Q_{calculate}$, dinilai dengan menggunakan $n_{calculate}$, dan Q_{design}, dinilai dengan menggunakan pekali kekasaran yang dicadangkan oleh MSMA (n_{design}), untuk dibandingkan dengan pelepasan aliran kawasan tadahan (Q_{peak}), dinilai oleh *Rational Method* dengan ARI 10 tahun. Setiap tapak kajian menunjukkan Q_{design} lebih besar daripada Q_{peak} sehingga 59%. Namun, $Q_{calculate}$ lebih besar daripada Q_{peak} hanya di tapak kajian tertentu sehingga 14%. Nilai-nilai Q_{design} juga lebih besar daripada $Q_{calculate}$ sehingga 52% di mana ia menunjukkan bahawa pekali kekasaran oleh MSMA menyediakan prestasi *swale* yang lebih baik. Kajian ini juga mendapati ciri-ciri *swale* yang dikaji adalah setanding dengan pertimbangan rekabentuk oleh MSMA. Berdasarkan dapatan kajian, *swale* berpotensi dalam mengumpul, memperlahankan, dan mengangkut air larian ribut, yang mana sesuai digunakan sebagai salah satu amalan pengurusan terbaik dalam mencegah banjir kilat di kawasan kampus UTHM.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Drainage area / Channel area
B	-	Bottom width
C_{avg}	-	Average runoff coefficient
cm	-	Centimeter
d	-	Storm duration
I	-	Infiltration rate
i	-	Average rainfall intensity
L_d	-	Channel length
L_o	-	Overland sheet flow path length
m	-	Meter
m^2	-	Meter square
m^3/s	-	Meter cube per second
mm	-	Millimeter
mm/hr	-	Millimeter per hour
n	-	Manning's roughness coefficient
n^*	-	Horton's roughness
$n_{calculate}$	-	Calculated value of Manning's
n_{design}	-	Designed value of Manning's
P	-	Wetted perimeter
Q_{swale}	-	Flow discharge of swale
Q_{peak}	-	Flow discharge of drainage area
R	-	Hydraulic radius
S_o	-	Longitudinal slope
T	-	Top width

t_c	-	Time of concentration
t_d	-	Drain flow time
t_o	-	Overland flow time
V	-	Velocity
y	-	Flow depth
y_{max}	-	Maximum flow depth
z	-	Side slope
ARI	-	Average Recurrence Interval
DID	-	Department of Irrigation and Drainage Malaysia
FKAAS	-	Faculty of Civil and Environmental Engineering
FPTV	-	Faculty of Technical and Vocational Education
HSG	-	Hydrologic soil group
IDF	-	Intensity-duration-frequency
MSMA	-	Urban Stormwater Management Manual for Malaysia
NCDA&CS	-	North Carolina Department of Agriculture & Consumer Service
NRCS	-	Natural Resources Conservation Service
ORICC	-	Office for Research, Innovation, Commercialization and Consultancy Management
PWD	-	Public Work Department of Malaysia
QUDM	-	Queensland Urban Drainage Manual
RECESS	-	Research Centre of Soft Soil Malaysia
SCS	-	Soil Conservation Service
USDA	-	United States Department of Agriculture
USEPA	-	United States Environmental Protection Agency
UTHM	-	Universiti Tun Hussein Onn Malaysia

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The United States Environmental Protection Agency or USEPA (2012) has defined grassed swale as vegetated open channel management practices primarily in attenuating and treating storm runoff for a specified water quantity and quality volume. As stated in the Stormwater Design and Specification Manual by City of Indianapolis (2009), swale is applicable in many urban settings such as street and parking, commercial and light industrial facilities, roads and highways, and residential developments.

Grassed swale is widely employed in urban areas to encourage ground infiltration and reduce storm runoff (Wilson, 2007). The establishment of swale is a potential solution whenever stormwater needs to be transported from impervious surfaces, infiltrated into soils, and conveyed into nearby streams thus reduced the peak flows and minimized the causes of flood.

Swale also serves as storm runoff treatment through filtration by the vegetation and the subsoil matrix of the channel or infiltration into the underlying soils. The vegetation functioned as filters any particles or pollutants as runoff passes through the channel. The pollutants are then incorporated within the soil where they may be immobilized or decomposed by plants and microbes (USEPA, 2012).

As compared to the conventional drainage ditch, a decent design of grassed swale to accommodate a predetermined storm event volume has resulted in a significant improvement in slowing and cleaning of water (Stevens, 2011). The maintenance for swale is required more frequently, but it is considerably less costly than curb and gutter systems maintenance (McKain, 2013). Besides that, swale is providing significant aesthetic benefit and conserving biodiversity with native plants (Clark and Acomb, 2008). In general, swale is an inexpensive sustainable drainage system that can work both as storm runoff conveyance and pollutant removal.

Universiti Tun Hussein Onn Malaysia (UTHM) has applied the grassed swales around the campus as an effort to curb the flash flood issue since UTHM is located in a lowland area. Figure 1.1 shows one of the grassed swales within UTHM campus. This study was carried out to access the performance of swales as a stormwater quantity control. The findings from this study implicate the flow discharge of swale and its hydraulic resistance, and provide the consideration design that can be use as reference for planning and construction of swale in the future.

Figure 1.1 : Grassed swale adjacent to parking lot in UTHM

1.2 Statement of Problem

In the end of 2006, Batu Pahat has been hit by a severe flood called as "banjir termenung" where UTHM was also affected as shown in Figure 1.2. As reported by

Department of Irrigation and Drainage Malaysia (DID), the flood occurred due to rainfall intensity was too high at Bekok Dam and Sembrong Dam with the average range of 229 mm/day – 247 mm/day. Furthermore, the storage capacity for stormwater was insufficient where the maximum water level has raised up to 12% - 14% at both dams (Musa *et al.*, 2009). During rainy season, UTHM is vulnerable to flood by an average water depth of 0.5 m and an average rainfall intensity of 2,400 mm/year (Tunji *et al.*, 2011).

Figure 1.2 : Flood at UTHM in the end of 2006

UTHM is located in Johor, which an undulating land dominated by a flat lowland area (Gharibreza and Ashraf, 2014). Lowlands are usually no higher than 100 m above mean sea level (Carating *et al.*, 2014) and UTHM has ground elevation ranged from 3 m – 14 m (Mazlan *et al.*, 2014). A flat topography has caused backwater from the main drain or stream that flows back into the drainage area. The existing detention is not effective to reduce the peak flow rate as the elevation gap between inflow and outflow is small (Tjahjanto *et al.*, 2008).

Based on the lithology logs and design of tube well in the Report on the Works of Tube Well (UTHM 1) Drilling, which prepared for the Research Centre of Soft Soil Malaysia (RECESS), UTHM has high groundwater level of 2.24 m as shown in Figure 1.3. UTHM also has low infiltration rate in the range of 0.004 mm/s – 0.007 mm/s that has caused the peak flow rate less decreased (Tjahjanto *et al.*, 2008).

This can be concluded that flood in UTHM was occurred due to high rainfall intensity, critical water level, low infiltration rate, and lack of proper drainage systems. Based on these problems, UTHM has implemented the sustainable drainage systems within the campus area such as swales, detention ponds, and engineered waterways to minimize the volume of storm runoff, decrease the peak flow, and thus prevent flash flood from occurred especially during the rainfall event. This study was conducted to evaluate the stormwater quantity control of grassed swales in UTHM to determine its efficacy in collecting, attenuating, and conveying storm runoff to the streams.

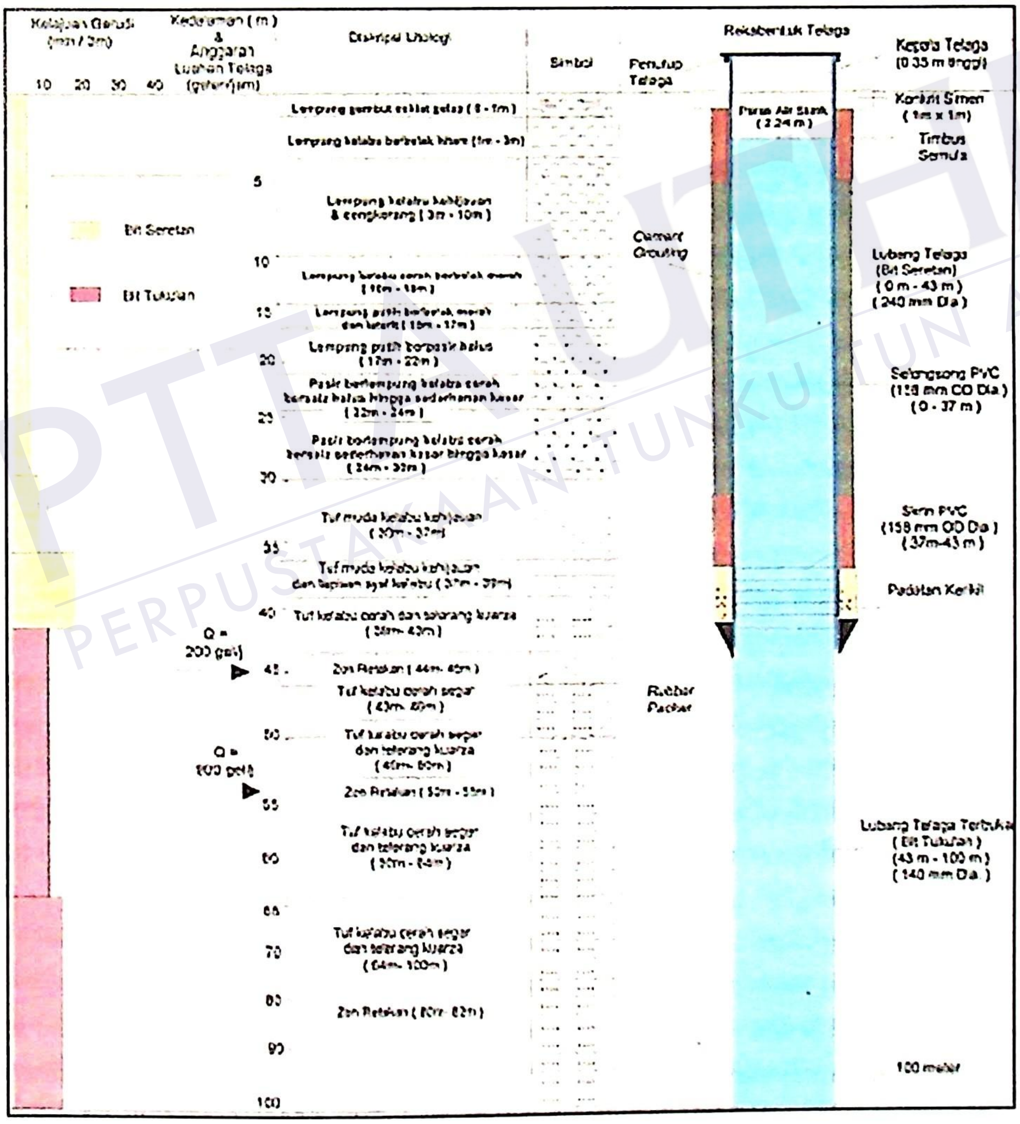

Figure 1.3 : Lithology logs of tube well in UTHM (Maju Teknik Kota Sdn. Bhd., 2007)

1.3 Aim of Study

The aim of this study is to determine the performance of grassed swales in the campus area of UTHM. The efficacy of swales as a stormwater quantity control was evaluated based on the flow discharges of swales and its hydraulic roughness coefficients. Apart from that, design of the grassed swales was compared to the specification as provided in Second Edition of Urban Stormwater Management Manual for Malaysia or MSMA by DID (2012).

1.4 Objectives of Study

This study was assessing the grassed swales potential in controlling the stormwater quantity, particularly in a lowland area. There are two objectives to be achieved in this study, which are :

1) To determine the variations of hydraulic roughness coefficients of swales.
2) To evaluate the flow attenuation and the flow conveyance capacity of swales.

1.5 Scope of Study

This study was conducted at four sites of study within UTHM. Site 1 and Site 2 were located at Faculty of Civil and Environmental Engineering (FKAAS) with areas of 0.55 ha and 0.62 ha respectively. Site 3 was located at Faculty of Technical and Vocational Education (FPTV) with an area of 0.76 ha while Site 4 was located at Office for Research, Innovation, Commercialization and Consultancy Management (ORICC) with an area of 0.85 ha. Figure 1.4 shows the location for the sites of study within the campus area of UTHM, which indicated by the red circles.

The lengths of grassed swales at Site 1 and Site 4 were 50 m while Site 2 and Site 3 were 100 m. Swales at Site 1 and Site 4 had two sections labeled as Section A and Section B while swales at Site 2 and Site 3 had three sections labeled as Section A, Section B, and Section C. These sections were represented as inflow and outflow of the swales. Three points of verticals were established on each section of swales labeled as left, center, and right to facilitate the measuring work for flow depth and velocity.

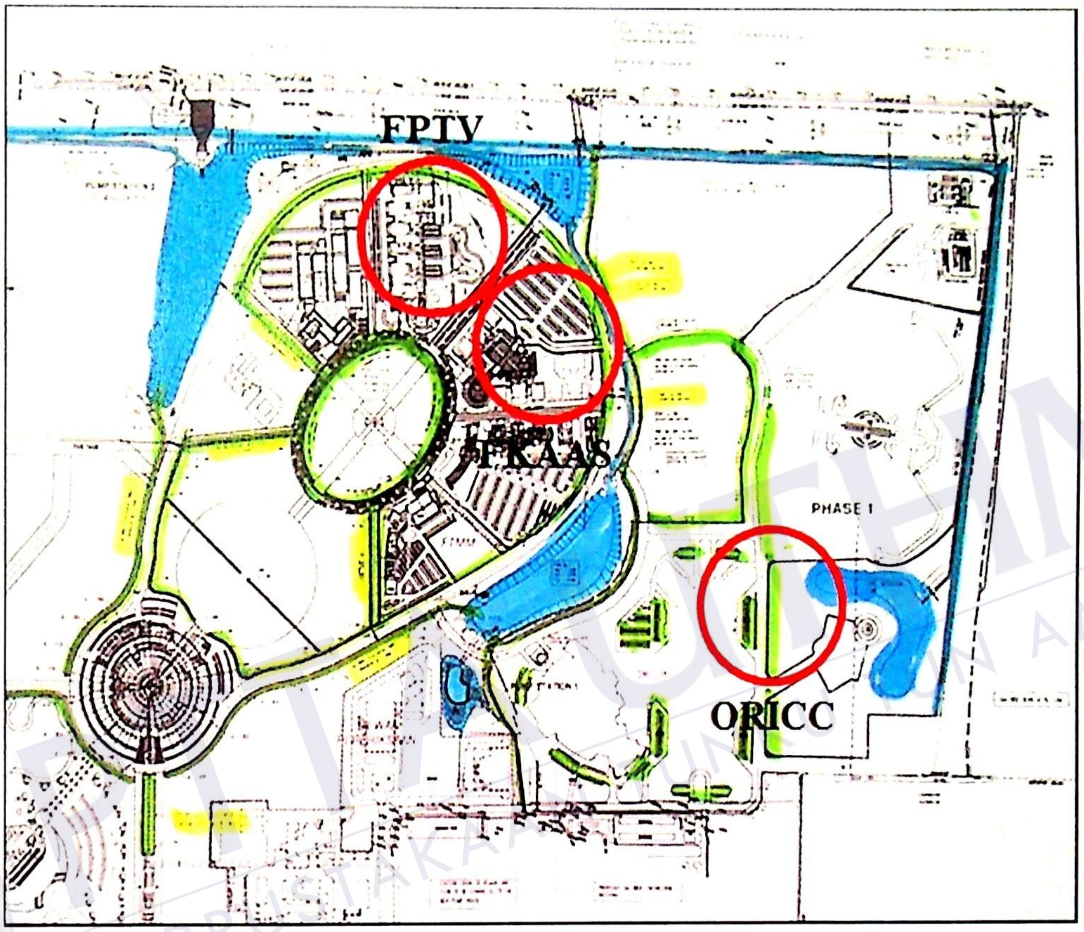

Figure 1.4 : Site plan of grassed swales within UTHM

Fieldwork was conducted on each section of swales to gather the hydraulic and hydrological data by first performing the levelling work. Based on the levelling data, the cross-sections of swales were plotted through the Microsoft Excel application. Flow depth and velocity were measured on each section of swales according to Six-Tenths Depth Method due to the studied swales in UTHM has flow depth less than 75 cm. Water that flows in the swales is conveyed to the detention ponds, which then released to the streams.

The selected swales at each site of study were identified as trapezoidal shaped with irregular perimeters. Therefore, the flow discharge of swales (Q_{swale}) was evaluated by Mean-Section Method to determine the percentage reductions of flow discharges between sections of swales and the variations of Manning's roughness coefficients ($n_{calculate}$). Q_{swale} were also divided into $Q_{calculate}$ and Q_{design} that derived from the Manning's equation by applying the maximum flow depth of swales (y_{max}). As for the roughness coefficients, $Q_{calculate}$ were using the values of $n_{calculate}$ while Q_{design} were using the recommended value of Manning's by MSMA (n_{design}).

The values of $Q_{calculate}$ and Q_{design} were compared to the flow discharge of drainage area (Q_{peak}) in order to estimate the capacity of flow conveyance. Q_{peak} was evaluated by the Rational Method for 10-year ARI since swale is categorized as a minor drainage system. $Q_{calculate}$ and Q_{design} shall be greater than Q_{peak}, which shows that the grassed swales are efficiently handling stormwater to prevent flash flood from occurred within the campus area of UTHM. The characteristics of studied swales were compared with the design consideration of swale as in MSMA.

1.6 Limitations of Study

This study was assessing the performance of grassed swales in UTHM based on its surface condition, which not including the subsurface as according to MSMA subsurface components are only added when swales have exceeded maximum permissible velocity. The catchment or drainage area for each site of study was plotted based on the overland slope through the Google Earth application and retrieved by the Earth Point application. The selected lengths of swales were 50 m and 100 m. However, the flow attenuation was evaluated as per 50 m between sections of the swales.

Three points of verticals at each section of swales were placed based on the minimum flow depth within the swales, which is at least 5 cm so that current meter is suitable to be used. This study does not set any specific time for collecting data. The measurements of flow depth and velocity of swales were taken shortly after rainfall events throughout the year of 2015 including dry season and rainy season.

In order to estimate the rainfall intensity, this study has used empirical equation and adopted constants from the nearest station to UTHM as applied by the consultant engineers, Perunding Azman, Ooi & Rao Sdn. Bhd., who had been designing the grassed swales in UTHM. Therefore, no rain gauge within UTHM campus was involved.

The variations of Manning's roughness coefficients were analyzed through the relationship between flow depth and grass cover within the swales. Grass cover was identified for its species and height, and not on the dense or loss of grass. The type of soil was identified through the infiltration rate at each site of study. The RECESS also has been providing data on soil type as well as groundwater level in UTHM. The methods and procedures that used throughout the study were based on MSMA.

1.7 Significance of Study

Water is an essential component for sustaining life. Therefore, water conservation should be implemented fundamentally through the drainage systems. The sustainable drainage systems such as grassed swales offer control-at-source solution where it does not only prevent the flash flood but also water pollution problems in the future. Malaysia has implemented sustainable drainage systems in new developments to achieve DID's aim of "Zero Flash Flood" and help preserving the natural characteristics of the existing streams in line with the national "Love Our Rivers Campaign" (Ghani *et al.*, 2004).

This study was carried out to assess the efficacy of grassed swales as a stormwater quantity control within the campus area of UTHM. UTHM is located in a lowland area, has low infiltration rate ranging from 0.004 mm/s – 0.007 mm/s (Tjahjanto *et al.*, 2008) and high groundwater level of 2.24 m with topsoil consist of sand to loam (Maju Teknik Kota Sdn. Bhd., 2007). The findings of study were unraveling the relevance of employing grassed swales in lowlands in terms of reducing the risks of flood by efficiently handling the stormwater runoff.

Based on the analysis through the division sections of the swales, this study was identifying the relationship between the variations of roughness coefficients with the features of grass, flow characteristics, and elements of the swales. The findings of study can be used as a reference resource for planning and designing the drainage systems in future instead of developing more conventional drainage systems in reducing peak flow and preventing flash flood.

This study also attempted to respond to the recommendations by previous studies where the study of Best Management Practices (BMP) should be extended. Stagge (2006) claimed that good performance data and mechanistic understanding of swale design parameters are not widely available. Meanwhile, in a floodplain-wetland restoration study, Shen *et al.* (1994) have pointed out the need for study on the variation of resistance coefficient with changes of flow depth and plant growth.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study was conducted to investigate the relevance of implementing grassed swales in lowland area to reduce peak flows and prevent flash flood from occurred. This chapter has discussed in depth about land topography included the characteristics of upland and lowland. As for the stormwater drainage systems, it is categorized into conventional and sustainable systems. Swales are one of the sustainable drainage systems that give significant improvement in stormwater issues when compared to the conventional systems. This study has evaluated the stormwater quantity control on flow discharge of swales and its roughness coefficients. MSMA was used throughout this study as a guideline for procedures, calculation, and design considerations.

2.2 Land Topography

The topographic term is used to describe the changes in elevation over a particular area resulting from two processes, which is deposition and erosion (Allmon *et al.*, 2000). Topography includes the physical features of earth such as altitude, slope, exposure, mountain chains, valleys, and plains. The diversity of land topography has distributed the earth's surface unevenly where can be categorized into upland and lowland. In geology, upland is generally considered to be land that is at a higher elevation than the stream terrace (alluvial plain), which is considered to be lowland (King *et al.*, 1975).

The topography of Peninsular Malaysia is characterized by a central spine (with ground elevations up to 2000 m above mean sea level) which slopes steeply to the relatively flatter undulating coastal plains on the eastern and western sides (Loi, 1996). In Johor region, a study on flood mapping of Sembrong River by Mazlan *et al.* (2014) found that in the study area including Parit Raja has low elevation ranged from 3 m – 14 m. Adib *et al.* (2011) claimed that about 60% of Kota Tinggi is undulating upland rising to 366 m height while the remainder is lowland and swampy. Meanwhile, in Pahang, the highest hills in Bera Lake are up to 140 m above mean sea level and the lowest elevation is 7 m (Gharibreza and Ashraf, 2014).

Carating *et al.* (2014) have characterized the lowland area where soils developed from alluvial deposits, slopes ranging from 0% - 8%, altitude of less than 100 m above mean sea level, and temperature of more than 25°C. Lowland rivers produced slower water flow with water ordinarily colored by sediment and organic matter, and lower force due to gradual drops of course in altitude. Meanwhile, upland rivers have rapid drops of course in altitude, which produced fast-flowing water and higher force. Upland areas have clearer water, rocky and coarse sediments, and cooler temperature than lowlands.

Further details on characteristics of upland and lowland were described by several previous studies such as Sun *et al.* (2002) have carried out study on the long-term hydrologic characteristics and found the inland upland watershed was significantly higher water yield when compared to the lower coastal plain due to topographic and climatic differences. In aiming at minimizing flood risks and improving natural and built environment conditions, Miguez *et al.* (2015) have discussed the lowland habitation and city sustainability regarding urban stormwater management, fluvial space, and river restoration.

REFERENCES

Ackerman, D. and Stein, E. D. (2008). *Evaluating the Effectiveness of Best Management Practices Using Dynamic Modeling*. Journal of Environment Engineering, ASCE 134 (8), 628 – 639.

Adib, M. R. M., Saifullizan, M. B., Wardah, T., Rokiah, D., and Junaidah, A. (2011). *Flood Inundation Modeling for Kota Tinggi Catchment by Combination of 2D Hydrodynamic Model and Flood Mapping Approach*. Lowland Technology International, International Association of Lowland Technology, 13 (1), 27 – 35.

Ahmad, N. A., Ghani, A. A., Zakaria, N. A., and Azamathullah, H. M. (2011). *Hydraulic Characteristic for Flow in Swales*. 3rd International Conference on Managing Rivers in the 21st Century, 183 – 189.

Ainan, A., Zakaria, N. A., Ghani, A. A., Abdullah, R., Sidek, L. M., Yusof, M. F., and Wong, L. P. (2003). *Peak Flow Attenuation Using Ecological Swale and Dry Pond*. Advances in Hydro-Science and Engineering, Vol VI.

Allmon, W. D., Babcock, S., De Groot, R., Duggan-Haas, D., Isacks, B., Kay, R., Parrish, J. T., and Wershow, H. (2000). *Topography of the Western US*. The Teacher-Friendly Guide to the Earth Science of the Western US. Retrieved from http://geology.teacherfriendlyguide.org/index.php/topography-w

Arcement, G. J. Jr. and Schneider, V. R. (1989). *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*. U. S. Geological Survey Water Supply Paper 2339. United States Government Printing Office, Washington.

Arish, N. A. M., Musa, S., and Ismail, K. N. (2016). *The Nature of Curve Infiltration Pattern Circumstantially in Parit Raja Using Tension Infiltrometer*. 2nd International Conference on Structural Architectural and Civil Engineering, 88 – 96.

Barber, M. E., King, S. G., Yonge, D. R., and Hathhon, W. E. (2003). *Ecology Ditch : A Best Management Practice for Storm Water Runoff Mitigation*. Journal of Hydrologic Engineering, 8 (3), 111 – 122.

Barnes, H. H. Jr. (1967). *Roughness Characteristics of Natural Channels*. U.S. Geological Survey Water Supply Paper 1849. United States Government Printing Office, Washington.

Barrett, M. E., Walsh, P. M., Malina, J. F., and Charbeneau, R. J. (1998). *Performance of Vegetative Controls for Treating Highway Runoff.* Journal of Environmental Engineering, ASCE 124 (11), 1121 – 1128.

Bressy, A., Gromaire, M., Lorgeoux, C., Saad, M., Leroy, F., and Chebbo, G. (2014). *Efficiency of Source Control Systems for Reducing Runoff Pollutant Loads : Feedback on Experimental Catchments within Paris Conurbation*. Water Research, 57, 234 – 246.

Carating, R. B., Galanta, R. G., and Bacatio, C. D. (2014). *The Soils of the Philippines*. Springer Science & Business.

Center for Watershed Protection. (2003). *Impacts of Impervious Cover on Aquatic Systems*. Ellicott City, MD.

Chang, C. K., Ghani, A. A., Zakaria, N. A, Yusof, M. F., Ayub, K. R., Hasan, A. M. M., Ainan, A., and Lai, S. H. (2008). *Rehabilitation of Ex-mining Pond and Existing Wetland for Integrated Stormwater Management*. 11th International Conference on Urban Drainage.

Chang, T. H., Huang, S. T., Chen, S., and Lai, J. C. (2010). *Estimation of Manning Roughness Coefficients on Precast Ecological Concrete Blocks*. Journal of Marine Science and Technology, 18 (2), 308 – 316.

Chow, V. T. (1959). *Open Channel Hydraulics*. McGraw-Hill Book Company. New York.

Chow, V. T. (1964). *Handbook of Applied Hydrology*. McGraw-Hill Book Company. New York.

City of Indianapolis. (2009). *Stormwater Design and Specification Manual*. Chapter 4.7 Swales. 104 – 112.

Clark, M. and Acomb, G. (2008). *Bioswales/Vegetated Swales*. Florida Field Guide to Low Impact Development. Program of Resource Efficient Communities. University of Florida.

Coombes, P. J., Babister, M., and McAlister, T. (2015). *Is the Science and Data Underpinning the Rational Method Robust for Use in Evolving Urban Catchments?* 36th Hydrology and Water Resources Symposium: The Art and Science of Water, 219.

Davis, A. P., Stagge, J. H., Jamil, E., and Kim, H. (2011). *Hydraulic Performance of Grass Swales for Managing Highway Runoff.* Water Research, 46 (20), 6775 – 6786.

Deletic, A. and Fletcher, T. D. (2006). *Performance of Grass Filters used for Stormwater Treatment – A Field and Modelling Study*. Journal of Hydrology, 317 (3), 261 – 275.

Department of Environmental Protection Pennsylvania. (2006). *Pennsylvania Stormwater Best Management Practices Manual*. BMP 6.4.8 : Vegetated Swale, 83 – 98.

Department of Irrigation and Drainage Malaysia (DID). (2000). *Urban Stormwater Management Manual for Malaysia*. Government of Malaysia.

Department of Irrigation and Drainage Malaysia (DID). (2012). *Urban Stormwater Management Manual for Malaysia*. Second Edition, Government of Malaysia.

Diaz, R. G. (2005). *Analysis of Manning Coefficient for Small-depth Flows on Vegetated Beds*. Hydrology Process 19, 3221 – 3233.

Dingman, S. L. (1993). *Physical Hydrology*. Macmillan, New York, 536 – 541.

Fathi-Maghadam, M. and Kouwen, N. (1997). *Nonrigid, Nonsubmerged, Vegetative Roughness on Floodplain*. Journal of Hydraulic Engineering, 123 (1), 51 – 57.

Fassman, E. A. and Liao, M. (2009). *Monitoring of a Series of Swales within a Stormwater Treatment Train*. 32nd Hydrology and Water Resources Symposium, Newcastle : Adapting to Change, 368.

Fenzl, R. N. (1962). *Hydraulic Resistance of Broad Shallow Vegetated Channels*. PhD Thesis, University of California, Davis, California.

Fischenich, C. (2001). *Stability Thresholds for Stream Restoration Materials*. DTIC Document.

Ghani, A. A., Zakaria, N. A., Abustan, I., Sidek, L. M., Abdullah, R., and Adlan, N. (2000). *New Ecological Drainage System – A New Approach to Reduce Flash Flood in Cities*. World Water Day Seminar.

Ghani, A. A., Zakaria, N. A., Abdullah, R., Yusof, M. F., Sidek, L. M., Kassim, A. H., and Ainan, A. (2004). *Bio-Ecological Drainage System (BIOECODS) : Concept, Design and Construction*. 6th International Conference on Hydroscience and Engineering.

Ghani, A. A., Zakaria, N. A., Chang, C. K., and Ainan, A. (2008). *Sustainable Urban Drainage System (SUDS) – Malaysian Experiences*. 11th International Conference on Urban Drainage.

Ghani, A. N. A., Shafiei, M. W., and Daud, M. Y. M. (2002). *The Impact of MSMA on Construction Costs – Small Scale Development*.

Gharibreza, M. and Ashraf, M. A. (2014). *Applied Limnology : Comprehensive View from Watershed to Lake*. Springer.

Goyen, A., Phillips, B. C., and Pathirajas, S. (2014). *Urban Rational Method Review*. Australian Rainfall and Runoff Revision Project 13, Engineers Australia, Canberra.

Grenz, N. S. (2007). *Efficiency of Bioswales in Positively Effecting Storm Water Quality*. Oregon State University, University Honors College.

Groves W. W., Hammer, P. E., Knutsen, K. L., Ryan, S. M., and Schlipf, R. A. (1999). *Analysis of Bioswale Efficiency for Treating Surface Runoff*. Master's Thesis. Donald Bren School of Environmental Science and Management. University of California, Santa Barbara.

Gulliver, J., Ahmed, F., Nieber, J., and Horwatich, J. (2014). *Infiltration into a Roadside Grassed Swale*. 13th International Conference on Urban Drainage.

Hin, L. S., Azamathullah, M. H., and Hasan, Z. A. (2009). *The Use of MSMA for Integrated Urban Drainage Management : Case Study in Ipoh and Melaka*. Short Term Research Fund.

Hoag, J. C. (2006). *Plant Fact Sheet – Creeping Spikerush, Eleocharis palustris (L.) Roemer and J. A. Schultes*. USDA-NRCS Aberdeen PMC, Aberdeen, ID.

Hunt, W. F., Lord, B., Loh, B., and Sia, A. (2015). *Plant Selection for Bioretention Systems and Stormwater Treatment Practices*. Springer Briefs in Water Science and Technology.

Jarvela, J. (2002). *Flow Resistance of Flexible and Stiff Vegetation : A Flume Study with Natural Plants*. Journal of Hydrology, 269, 44 – 54.

Khan, M. A., Mahmood, K., and Skogerboe, G. V. (1997). *Current Meter Discharge Measurements for Steady and Unsteady Flow Conditions in Irrigation Channels*. Report No. T-7, International Irrigation Management Institute, Pakistan.

Kibler, D. F. (1982). *Urban Stormwater Hydrology Monograph 7*. American Geophysical Union, Washington, D. C.

King, E. L., Dideriksen, R. I., and Fisher, C. S. (1975). *Soil Survey of Madison County, Iowa*. United States Soil Conservation Survey.

Kirby, J. T., Durrans, S. R., Pitt, R., and Johnson, P. D. (2005). *Hydraulic Resistance in Grass Swales Designed for Small Flow Conveyance*. Journal of Hydraulic Engineering 131 (1), 65 – 68.

Loi, H. K. (1996). *Flood Mitigation and Flood Risk Management in Malaysia*. International Workshop on Floodplain Risk Management, 205 – 216.

Lucke, T., Mohamed, M. A. K., and Tindale, N. (2014). *Pollutant Removal and Hydraulic Reduction Performance of Field Grassed Swales during Runoff Simulation Experiments*. Water, 6, 1887 – 1904.

Maju Teknik Kota Sdn. Bhd. (2007). *Laporan Kerja-kerja Pembinaan Telaga Tiub UTHM 1 di Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat, Johor.*

Mazlan, M., Adib, M. R. M., Adnan, M. S., Ahmad, M. A., and Tan, L. W. (2014). *Hydrodynamic Modelling and Flood Mapping of Sembrong Catchment Area.* 13th International Conference on Urban Drainage.

McKain, K. (2013). *Controlling Stormwater at the Source : Exploring Best Management Practices.* The Construction Specifier : The Official Magazine of CSI.

Miguez, M. G., Verol, A. P., de Sousa, M. M., and Rezende, O. M. (2015). *Urban Floods in Lowlands – Levee Systems, Unplanned Urban Growth and River Restoration Alternative: A Case Study in Brazil.* Sustainability, 7 (8), 11068 – 11097.

Musa, S., Zakaria, N. A., Tjahjanto, D., and Lai, S. H. (2009). *The Potential of Recharge Well System in Flat Area with Low Infiltration Rate.* International Conference on Water Resources.

Nara, Y. and Pitt, R. E. (2004). *Sediment Transport in Grass Swales.* University of Alabama, USA.

North Carolina Department of Agriculture & Consumer Services (NCDA&CS). (2013). *Community Conservation Assistance Program Design Manual.* 8.0 Vegetated Swale, 64 – 71.

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, 120 (1), 313 – 325.

Public Work Department of Malaysia (PWD). (2006). *Laporan Sistem Perparitan.* Cadangan Pembinaan Markas Pasukan Mencari dan Menyelamat Khas Malaysia (SMART) dan Institut Pengurusan dan Bencana (IPKBN) di Sepang, Selangor.

Queensland Urban Drainage Manual (QUDM). (2007). Volume I, Second Edition, Queensland Government, Australia.

Rhee, D. S., Woo, H., Kwon, B. A., and Ahn, H. K. (2008). *Hydraulic Resistance of Some Selected Vegetation in Open Channel Flows.* River Research and Applications, 24, 673 – 687.

Ruby, E. (2005). *How Urbanization Affects the Water Cycle.* California Water & Land Use Partnership. 1 – 4.

Rushton, B. (2002). *Infiltration Opportunities in Parking Lot Designs Reduce Runoff and Pollution*. 7th Biennial Stormwater Research and Watershed Management Conference.

Saybet, T. A. (2006). *Storm Water Management*. Wiley, John & Sons, 179 – 191.

Seilheimer, T. S., Wei, A., Chow-Fraser, P., 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 Ecosystems, 10 (3), 299 – 319.

Shen, H. W., Tabios III, G., and Harder, J. A. (1994). *Kissimmee River Restoration Study*. Journal of Water Resource Planning and Management, ASCE 120 (3), 330 – 349.

Shraideh, H. (2016). *Investigation of the Application of Open Channel Flow Concepts in Support of Wetland Reservoir Routing*. Doctoral dissertation, University of Missouri, Columbia.

Sidek, L. M., Zakaria, N. A., Ghani, A. A., and Abdullah, R. (2002). *Alternative Solutions to Conventional Drainage Systems Using Bio-Ecological Drainage Systems : Design and Concept (Part I)*. Buletin Ingenieur, 15, 46 – 51.

Stagge, J. H. (2006). *Field Evaluation of Hydrologic and Water Quality Benefits of Grass Swales for Managing Highway Runoff*. Thesis of Master of Science, Faculty of Graduate School, University of Maryland, College Park.

Stevens, D. (2011). *For Three Weeks I Owned the University of Illinois*. Lulu.com, 135 – 136.

Stevens, M. L. and Vanbianchi, R. (1993). *Restoring Wetlands in Washington : A Guidebook for Wetland Restoration, Planning, and Implementation*. Olympia : Washington State, Department of Ecology.

Sun, G., McNulty, S. G., Amatya, D. M., Skaggs, R. W., Swift Jr. L. W., Shepard, J. P., and Riekerk, H. (2002). *A Comparison of the Watershed Hydrology of Coastal Forested Wetlands and the Mountainous Uplands in the Southern*. Journal of Hydrology, 263, 92 – 104.

Temple, D. M., Robinson, K. M., Ahring, R. M., and Davis, A. G. (1987). *Agricultural Handbook No. 667 : Stability Design of Grass-lined Open Channels*. Agricultural Research Service, U.S. Department of Agriculture, Washington, D. C.

Tjahjanto, D., Musa, S., and Ridzuan, M. B. (2008). *A Study on Artificial Recharge Well as a Part of Drainage System and Water Supply in UTHM*. 1st National Seminar on Environmental, Development and Sustainability, 106 – 111.

Tunji, L. A. Q., Latiff, A. A. A., Tjahjanto, D., and Akib, S. (2011). *The Effectiveness of Groundwater Recharges Well to Mitigate Flood*. International Journal of Physical Sciences, 6 (1), 8 – 14.

United States Department of Agriculture (USDA). (1986). *Urban Hydrology for Small Watersheds*. 210-VI-TR-55, Second Edition.

United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS). (2012). *The PLANTS Database*. National Plant Data Team, Greensboro, NC 27401-4901 USA.

United States Environmental Protection Agency (USEPA). (2012). *Report of the Method 1664 Validation Studies*. EPA-821-R-95-036, U.S. Environmental Protection Agency, Washington, D.C.

Wilson, C. A. M. E. (2007). *Flow Resistance Models for Flexible Submerged Vegetation*. Journal of Hydrology, 342 (3), 213 – 222.

Wu, J. S., Allan, C. J., Saunders, W. L., and Evett, J. B. (1998). *Characterization and Pollutant Loading Estimation for Highway Runoff*. Journal of Environmental Engineering, ASCE 124 (7), 584 – 592.

Wu, F., Shen, H. W., and Chou, Y. (1999). *Variations of Roughness Coefficients for Unsubmerged and Submerged Vegetation*. Journal of Hydraulic Engineering, 125 (9), 934 – 942.

Yu, S. L., Kuo, J., Fassman, E. A., and Pan, H. (2001). *Field Test of Grassed Swale Performance in Removing Runoff Pollution*. Journal of Water Resources Planning and Management, ASCE 127 (3), 168 – 171.

Zakaria, N. A., Ghani, A. A., Abdullah, R., Sidek, L. M., Kassim, A. H., and Ainan, A. (2004). *MSMA – A New Urban Stormwater Management Manual for Malaysia*. Advances in Hydroscience and Engineering, Volume VI.

Zhao, M. and Fan, Z. (2017). *Hydrodynamic Characteristics of Submerged Vegetation Flow with Non-Constant Vertical Porosity*. PloS one, 12 (4), e0176712.