THE EFFECTIVENESS OF ON-SITE DETENTION FOR WATER QUANTITY CONTROL IN TAMAN ILMU USING STORMWATER MANAGEMENT MODEL (SWMM)

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By

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ABSTRAK

Perbandaran pesat meningkatkan risiko banjir akibat kawasan permukaan yang tidak telap air. Storan tahanan tapak (OSD) diperkenalkan sebagai mitigasi banjir dalam kajian ini. Objektif kajian ini adalah menggunakan Model Pengurusan Air Ribut (SWMM) untuk permodelan sistem saliran Taman Ilmu dan menilai keberkesanan OSD. OSD adalah salah satu fasiliti pengurusan air ribut yang mengurangkan puncak aliran dan menangguhkan tempoh. SWMM ialah satu program yang digunakan secara meluas untuk perancangan, analisis dan reka bentuk yang berkaitan sistem saliran iaitu kawalan kuantiti dan kualiti di kawasan bandar. Taman Ilmu telah dipilih sebagai kawasan kajian kerana kawasan itu berada di tepi Sungai Kerian yang mempunyai risiko untuk berlaku banjir apabila masa hujan monsoon serta air pasang. Dalam kajian ini, tempoh 1 jam telah digunakan untuk mereka bentuk keamatan hujan dan 79.03 mm/jam untuk 10 tahun kala kembali didapati. Selepas pemasangan OSD dalam setiap sub-tadahan, pengecilan aliran dalam setiap sub-tadahan terdapat dari 22.5 % hingga 89.2 %. Hal ini demikian kerana perbezaan antara kawasan yang tidak telap dan isipadu OSD dalam setiap sub-tadahan. Sebanyak 48 % pengecilan puncak aliran didapati dari 2.189 m^3/s berkurang ke 1.137 m^3/s di alir keluar Taman Ilmu. Selain itu, bilangan dan lokasi menjadi faktor-faktor yang boleh mempengaruhi keberkesanan OSD. Lokasi OSD di kawasan hiliran lebih berkesan daripada hulu. Aliran pengecilan meningkat apabila jumlah OSD meningkat tetapi kos pemasangan dan penyelenggaraan juga meningkat

ABSTRACT

Rapid urbanisation causes the risk of flood to increase due to large impervious surface area. On-site detention is introduced as a flood mitigation in this study. The objectives of the study are to model Taman Ilmu drainage system using Stormwater Management Model and to evaluate the effectiveness of on-site detention. On-site detention is one of stormwater management device which detained the runoff to reduce the peak discharges and delay the flood. Stormwater Management Model is a widely used program for planning, analysis and design related to drainage systems of runoff quantity and quality in urban areas. Taman Ilmu is chosen as a study area because it is located beside the Kerian River which has the risk of flood occurring due to monsoon rain incorporate with rising tide. Over this study, 1 hour storm duration is used for design rainfall intensity and 79.03 mm/hr for 10 year ARI is calculated. After installation of OSD in each sub-catchment, the range of flow attenuation is from 22.5% to 89.2% due to different impervious area and volume of OSD. The results show that 48% attenuation of peak discharge from 2.189 m^3/s to 1.137 m^3/s at outlet of Taman Ilmu. The location and number are factors that can affect the effectiveness of OSD. Location of OSD at upstream area more effective than downstream. The number of OSD increase, the flow attenuation increase but the cost of installation and maintenance increase as well.

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LIST OF ABBREVIATIONS

ARI	**A**verage **R**ecurrence **I**nterval
BMPs	**B**est **M**anagement **P**ractices
CMS	**C**ubic **M**eter Per **S**econd
EL	**E**levation **L**evel
EPA	**E**nvironmental **P**rotection **A**gency
DID	**D**epartment of **I**rrigation and **D**rainage
HED	**H**igh **E**arly **D**ischarge
IDF	**I**ntensity-**D**uration-**F**requency
MSMA	**M**anual **S**aliran **M**esra **A**lam
OSD	**O**n-Site **D**etention
PSD	**P**ermissible **S**ite **D**ischarge
SSR	**S**ite **S**torage **R**equirements
SWMM	**S**torm **W**ater **M**anagement **M**odel
USEPA	**U**nited **S**tates **E**nvironmental **P**rotection **A**gency
UPVC	**U**nplasticized **P**oly**v**inyl **C**hloride

NOMENCLATURES

C	Runoff Coefficient
Q	Peak Flow
A	Drainage Area
i	Average Rainfall Intensity
n*	Horton's Roughness Value for Surface
d	Storm Duration
n	Manning's Roughness Coefficient
R	Hydraulic Radius
T	Average Recurrence Interval
λ, κ, θ and η	Fitting Constants Dependent on the Rain Gauge Location

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Urbanization is a process that increase the impervious surfaces by disturbance of natural landscape and replacement of vegetated surface. The alteration of landscape through development due to more demand of high human populations (Shuster et al., 2005). Impervious surfaces are defined as material or structure that prevent the infiltration of surface water into underground. It is related to the human activities and habitation through the construction of roofs, pavements, parking lots and other structures to satisfy the increasing of populations (Yao et al., 2016).

Urbanization (Figure 1.1) can directly affect the hydrology cycle. When total impervious area increase tend to generate more total runoff depth and peak flow depth while reducing of evapotranspiration and groundwater recharge (Kondoh & Nishiyama, 2000). When runoff increase while limited infiltration capacity of ground is exceeded due to less pervious surface, it will causes the flood during high rainfall precipitation and frequent rain. The changes of land use from natural surface to urban has influence on peak discharge and flood occurrence. The countermeasure can be used to minimize the flood risk in urban area.

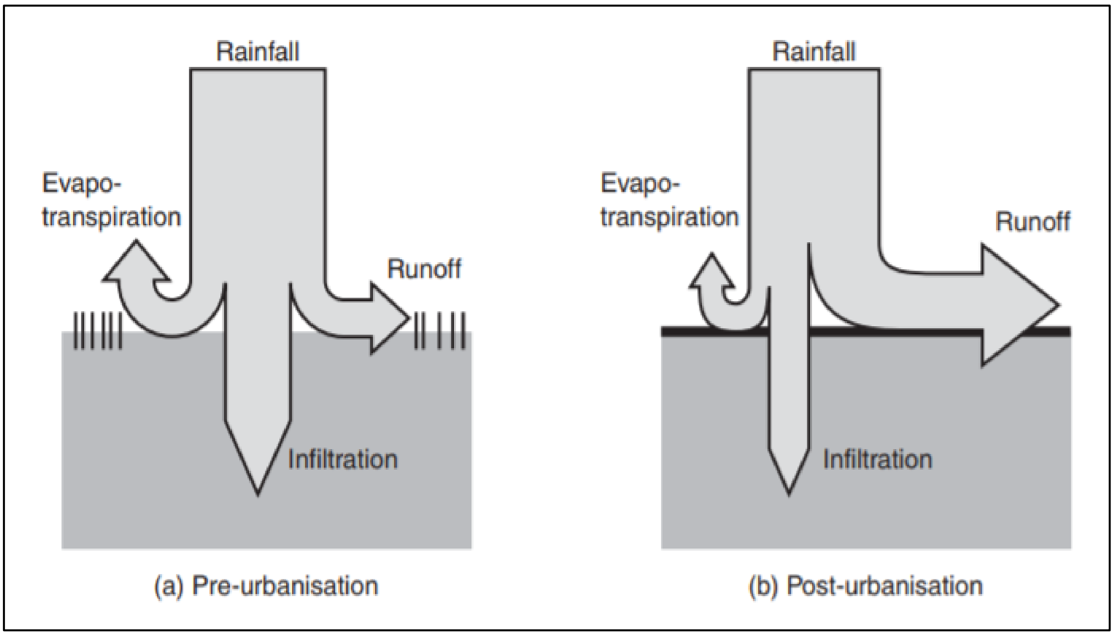

Figure 1.1: Effect of Urbanization on fate of rainfall
(Butler, 2004)

Detention facility is one of storm water quantity control facilities that employed in urban water drainage systems that limit the peak flow rate of post-development to achieve one of the criteria that equal or less than the level of pre-development. The detention facilities is a concept that reduce the peak discharge by temporary storage and gradual release the water slowly through the outlet. On-site detention (OSD) is one of detention facilities which is small storage constructed on individual or lot. OSD can be constructed as above-ground, below-ground or combination storage. The effectiveness of OSD will depend on the location, size and number within the catchment area.

EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term simulation of runoff quantity and quality from urban area. SWMM is used throughout the world for planning, analysis and design related to storm water runoff, combined and sanitary sewers and other drainage systems in urban area (Gironás et al., 2010).

1.2 Problem Statement

Generally, Malaysia is free from natural disaster such as earthquake, volcano and typhoon. However, the flood is most severe disaster that experiencing in Malaysia. Nurfarahain et al. (2016) mentioned that two major types of flood occur in this country are monsoon flood and flash flood. The monsoon flood occur mainly on east coast states of the Peninsula, northern part of Sabah and Southern part of Sarawak during months of November to March with heavy and long duration rainfall. An extreme rainfall event with long duration is common in Malaysia, especially during monsoon seasons, the phenomenon is obvious.

Flood recently occurring in northwest part of peninsula especially in state of Penang not because of monsoon flood but flash flood due to uncontrolled development and human activities. Urbanization resulted in hydrological changes such as increased the flood risk. Nibong Tebal had faced the most severe flood on September, 2017 since the previous one 38 years ago (Lee, 2017) due to long duration of rainfall and increase impervious area. Besides, Sungai Kerian is located within Nibong Tebal that is one of factor causing the flood if facing high tide and heavy rainfall. Therefore, the study is focusing on simulation and modelling of a chosen housing area which is Taman Ilmu where close to Kerian River with incorporation of on-site detention in SWMM.

1.3 Objectives

The objectives in this study are:

1. To model Taman Ilmu drainage system using SWMM.
2. To evaluate the effectiveness of OSD in Taman Ilmu drainage system.

1.4 Scope of Work

The scope of the study is to determine the effectiveness of OSD on a housing area in Taman Ilmu. The data collected include such as layout of the case study area, number of terrace house and its size. The effectiveness of OSD is evaluated through the analysis of SWMM to estimate the peak flow attenuation percentage compare to system without OSD.

1.5 Dissertation Outline

The dissertation is divided into five chapters. Chapter one discusses about storm water management in urban area and followed by problem statement, objectives and scope of works. Chapter two presents the literature review and related research associates with this study. Chapter three explains the methodology and procedures consists of data collection and input data and parameters to simulate SWMM. Chapter four presents the results of analysis and SWMM simulation in the study. Chapter five concludes the study and proposes recommendation for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Urbanization can reflect a development level of a country. However, uncontrolled development can be resulted in flooding risk problem due to urban water management is insufficient and hydrologic cycle changes. Hydrologic cycle is a process that transports water between earth's land, atmosphere and oceans through evaporation, transpiration, condensation, precipitation and runoff.

Precipitation is the water released from clouds in the form of rain, freezing rain, sleet, snow or hail and fall to the ground. It occurs when the water vapor condenses at atmosphere and precipitate after it sufficiently saturate. However, the amount, timing and location of the precipitation depend on the degree of urbanization. For the early stage of urbanization, rainfall intensity decrease. When the degree of urbanization increase, maximum rainfall increase as well (Miao et al., 2011).

Surface runoff is excess storm water from precipitation flows over the earth surface and one of main factor causing flood occurrence. The infiltration of water into ground after urbanization is decreases, therefore, the coefficient of runoff increase and at the end, the volume of surface runoff after urbanization is greater than before urbanization. The overland flow is increased after urbanization and even peak flow of low average recurrence interval (ARI) after urbanization is greater than high ARI before urbanization. This amplification effect of urbanization on flood is significant and resulting in increase of flood risk. Therefore, the storm water management is needed to study for controlling on runoff volume (Xu & Zhao, 2016).

2.2 Urban Storm Water Management

Drainage system is a system that needed to develop in urban area because of interaction between human activity and natural water cycle. Natural water cycle is provided the water to supply the human life and activities by rainfall and excess rainwater will back to nature such as river, lake or ocean through natural drainage system. However, covering of land with impermeable surfaces that divert the rainwater away from natural drainage system. Storm water is the rainwater that fall on the urban area and carry anything along with it. Therefore, the urban drainage system is designed properly to minimize the problems caused to human life and environment (Butler & Davies, 2004).

Urbanization can affect the quality and quantity of storm water runoff. Along with the increase in water quantity, non-point pollutants from various land uses and activities until end up in receiving water increases due to urbanization (Figure 2.1).

Figure 2.1: Interfaces with the public and environment (Butler, 2014)

A proper storm water management is important to implement in urban area. Storm water management is the mechanism using storm water runoff controlling purpose to minimize the peak flow rates, runoff volume, frequency of flooding and degradation of surface water quality through implementation of construction erosion and sediment control, quantity control and treatment best management practices (BMPs) to diminish the effect of land use changes. Storm water system is divided into two categories which are major and minor. The purpose of minor system is to manage runoff generated by more frequent and short duration rainfall to minimize the storm water ponding at impervious surface. While major system accommodates runoff from less frequent and long duration rainfall to eliminate the risk of loss of life and property damage by flooding. (DID, 2012)

Storm water management is required to a new development or re-development to control the runoff quantity. The urban development is significantly increase the amount of discharge with shorter lag time. The goal of storm water management is to reduce the post-development peak discharge (Figure 2.2) of any ARI to pre-development conditions of corresponding ARI or less than.

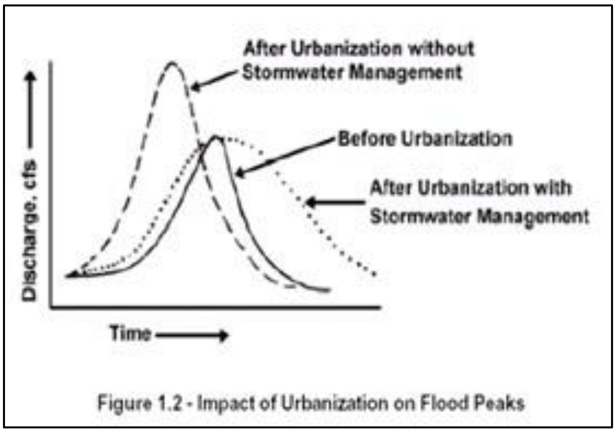

Figure 2.2: Impact of Urbanization on Flood Peaks (UNESCO, 2007)

2.3 On-Site Detention

Additional of impervious area resulted in increase of storm water runoff where previously have naturally infiltrated into ground. In order to relieve the high volume of runoff flow to downstream, the runoff is stored temporarily on site and released at a controlled rate at detention facilities. Therefore, the downstream drainage system can adequately handle. OSD as a structural flood mitigation method which limits the site discharge of storm water using outlet restriction devices (Beecham et al., 2005).

OSD is provided as above-ground storage, below-ground storage or combination of both storage within individual or lot boundary of property.

2.3.1 Above-ground storage

The storage can be classified as open storage (lawns, car parks and rooftops) or closed storage (tank). To enhance the aesthetics of a site, storage can be constructed as a pond on landscaped area is shown in Figure 2.3.

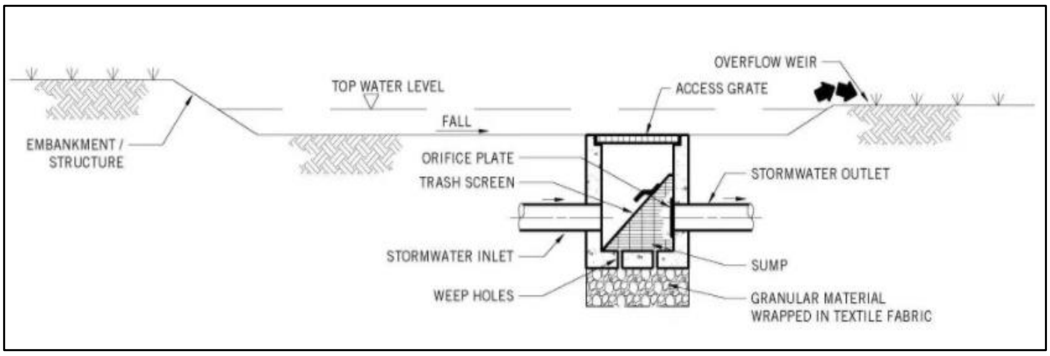

Figure 2.3: Above-Ground OSD Storage (Matthew, 2017)

2.3.2 Below-ground storage

The type of storage chosen is normally depend on the land cost and availability. The below-ground storage can be used in area which is heavily used where land availability is limited. The schematic cross-section of below ground OSD is shown in Figure 2.4.

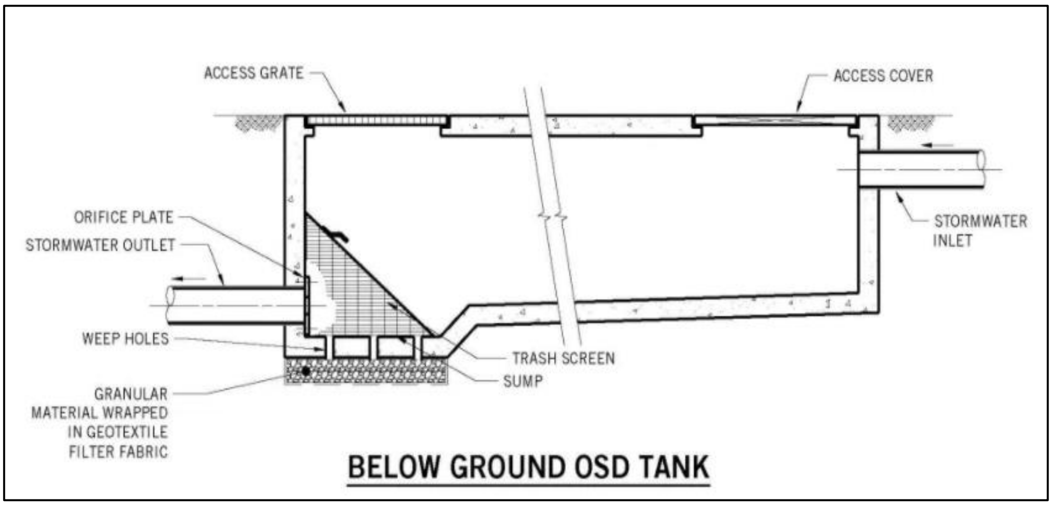

Figure 2.4: Below-Ground OSD Storage (Matthew, 2017)

2.3.3 Permissible Site Discharge (PSD)

PSD is the maximum allowable post-development discharge from a site for the selected design storm and is estimated on the basis that flows within downstream storm water drainage system will not be increased. The maximum allowable discharge is given in liters/second/hectare (l/s/ha) when applied to a specific site. Table 2.1 shows maximum PSD in accordance with five regions (Figure 2.5) in Peninsular Malaysia (DID, 2012). Figure 2.5 shows the five regions in Peninsular Malaysia for designing an OSD.

2.3.4 Site Storage Requirements (SSR)

SSR is the total amount of storage required to ensure that the required PSD is not exceeded and the OSD facility does not overflow based on the storage design storm ARI. The minimum volume (in m^3/hectare) is required for storage to ensure that spillage will not occur when the outflow is restricted to the PSD. Table 2.1 shows minimum SSR in accordance with five regions (Figure 2.5) in Peninsular Malaysia (DID, 2012).

Table 2.1: Maximum Permissible Site Discharge (PSD) and Minimum Site Storage Requirement (SSR) Values in Accordance with the Five Regions in Peninsular Malaysia (DID, 2012)

Terrain / Slope Condition	PSD (l/s/ha)					SSR (m³/ha)				
	Impervious Area (as a Percentage of Project Area)									
	25%	40%	50%	75%	90%	25%	40%	50%	75%	90%
REGION 3 - NORTHERN										
Lowlying	54.8	55.4	55.7	56.3	56.5	311.1	353.3	389.7	493.3	564.4
Mild	68.0	68.8	69.2	69.9	70.2	295.5	328.3	360.3	454.0	521.6
Steep	77.3	78.2	78.6	79.5	79.8	284.8	316.2	341.8	430.3	492.6

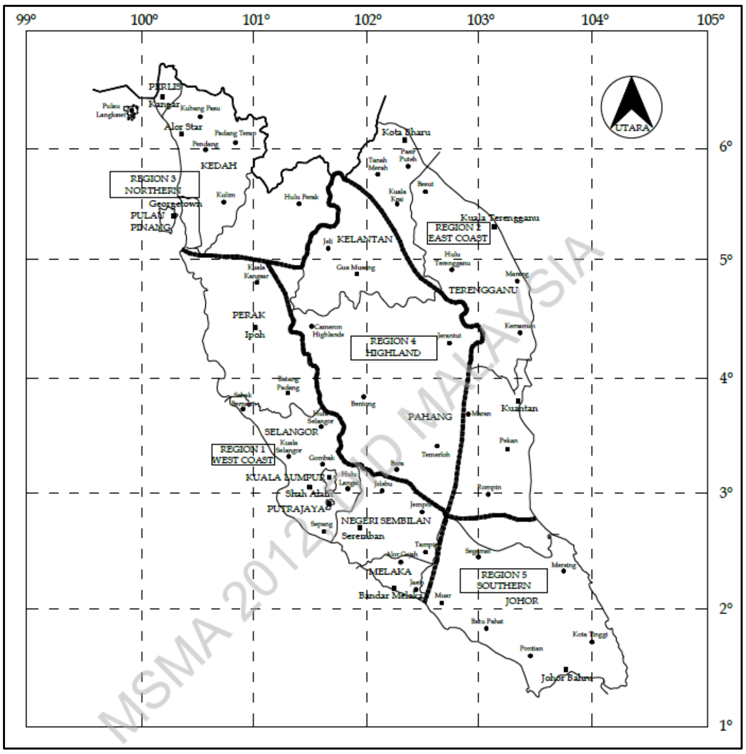

Figure 2.5: Five design regions (DID, 2012)

2.3.5 Control Types

Basically on site detention storage has two types of outlet control devices to control the rate of discharge which are standard control and high early discharge (HED) control (Boyd, 2003). Standard control storage consists of one chamber with one or more orifice outlets. HED control storage consists of first chamber and main chamber. For above ground storage, the first storage chamber is connected with a larger main chamber while below ground storage consists of first and main chambers which are separated with each other.

The advantages of HED over standard OSD storage are:

- To reduce runoff peaks to the specified PSD with lower SSR
- Runoff are filled to the design water level in the first chamber of HED, the same PSD is release for a wide range of storms.
- The outlet size is determined from the design water level in the first chamber and design PSD using standard orifice or pipe hydraulics.
- SSR is determined which being equal to the volume of the inflow hydrograph in excess of PSD.

However, HED control storages are more complicated to construct and operate than standard control and are modelled with the detailed computational method which make it more difficult.

2.3.6 Inlet and Outlet Size

Inlet is the water flow into storage tank from site and its size is larger than outlet. Outlet is located between storage system and drainage system which is used to control the flow rate. Outlet size is relatively small to reduce the discharge but it gets a minimum size. Table 2.2 shows the inlet size and outlet size in accordance with five regions (Figure 2.5) in Peninsular Malaysia (DID, 2012).

Table 2.2: OSD Volume, Inlet Size and Outlet Size for Five Different Regions in Peninsular Malaysia (DID, 2012)

Region 3

Project Area (ha)	Impervious Area (as Percentage of Project Area)														
	25%			40%			50%			75%			90%		
	Volume (m3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)
TERRAIN : MILD, SLOPE 1 : 875 TO 1 : 1999															
0.1	30	138	65	33	151	65	36	156	65	46	167	65	53	175	66
0.2	60	195	92	66	214	92	72	220	92	91	237	92	105	247	93
0.4	120	276	130	132	303	130	144	311	130	182	335	130	210	350	132
0.6	180	339	159	198	371	159	216	381	159	273	410	159	315	428	161
0.8	240	391	183	264	428	183	288	440	183	364	474	183	420	495	186
1	260	437	205	325	479	205	375	492	205	545	529	205	680	553	208
2	710	451	290	820	505	290	910	529	290	1180	597	290	1370	618	294
3	1065	553	355	1230	618	355	1365	648	355	1770	731	355	2055	757	360
4	1420	638	410	1640	714	410	1820	749	410	2360	845	410	2740	874	416
5	1775	714	458	2050	798	458	2275	837	458	2950	944	458	3425	977	465

2.4 Factors Affecting OSD

From an article (Beecham et al., 2005), the study has concluded that the implementation of OSD reduces the peak discharge at catchment compare to without OSD for all storm events. But 1 year ARI is not effective to install due to the flow is unlikely to be controlled by orifice caused little flood attenuation. Besides, decreasing PSD rate also reduces the peak discharge but the SSR increasing.

The implementation of OSD reduces the peak discharge at catchment also supported by other study(Coombes et al., 2003). The comparison of OSD not only on without OSD but also on rainwater tank. The OSD has significantly reduce peak discharge when compare to rainwater tank. This is because of rainwater tank only collect roof runoff while the stormwater runoff from roof, pervious and impervious areas is directed flow to OSD which provided more storage space than rainwater tank. However, the volume of surface runoff discharge to catchment is reduced with the installation of rainwater tank (J. et al., 2014) but not OSD. This is because rainwater tank provides retention and detention storage and OSD tank only provides detention storage.

OSD storage has its disadvantage if it is made of closed storage because of detention only delays the duration without reduces volume of runoff even reduces peak discharge (Ferguson, 1995). However, reduction of volume of runoff can be controlled by degree of infiltration. On flow duration as shown in Figure 2.6, infiltration and detention had opposite effects. Detention tended to increase the duration with increasing suppression of rate of flow while infiltration reduces the duration. Infiltration and detention reduced downstream peak rate of flow. The degree of infiltration and detention controls increase, the reduction of peak rate of flow increase. From that, if pervious area of catchment area increases, the infiltration increases as well. Besides, another method to reduce peak flow at downstream area is above ground OSD with open storage and combination of infiltration and detention.

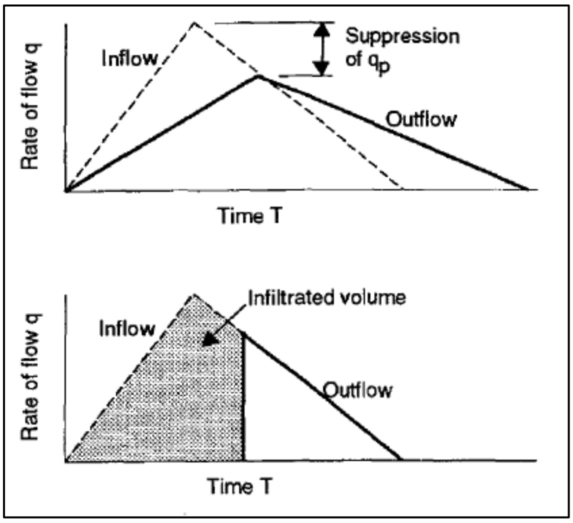

Figure 2.6: Effect of Detention (top) and Infiltration (bottom) at the Point of Discharge. (Ferguson, 1995)

The effectiveness of OSD can be affected by several factors such as location and number which are the factors go to be evaluated in this study. The greater volume of water flowing faster must be controlled to minimize the urban flood problems at lower zone. OSD in lower zones may increase flooding by combining delayed hydrographs with those coming from upstream (Mascarenhas et al., 2005).

2.5 Storm Water Management Model

SWMM is the newest version of the model that provides an integrated windows environment for editing input data, running simulation and viewing the results in the form of thematic maps, graphs, tables, profile plots and statistical reports. It is widely used for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers and other drainage systems in urban area (Gironás et al., 2010). SWMM is used for simulation of runoff quantity and quality, typically its applications are included design and sizing of drainage system components for flood control, sizing of detention facilities and their appurtenances for flood control and water quality as well as flood plain mapping of natural channel systems (USEPA, 2015).

2.6 Summary

Degree of urbanization reflects the development level of a country. However, urbanization without proper urban water management can cause flooding. A proper storm water management is important in urban area to minimize the peak flow rates, runoff volume and delay the duration. OSD, as a structural flood mitigation method is able to control the quantity of storm water runoff using the outlet restriction devices. An appropriate and comprehensive OSD design should take PSD, SSR and outlet size into consideration with reference to the urban storm water manual. The effectiveness of OSD can be affected by some various such as ARI, location and its size. In this study, SWMM is used to simulate the runoff quantity on a chosen study area.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the methodology of research study from the data collection to model simulation. The EPA SWMM version 5.1 is used to determine the flow attenuation in the drainage system. SWMM is widely used for planning, analysis and design related to drainage system in urban area. The applications of SWMM in this research study are for designing and sizing of detention facilities and their appurtenances for flood control.

Determination of appropriate sizing, number and location of OSD in chosen housing area to achieve more effective in water quantity control through using of SWMM. All the details in chosen housing area are collected to calculate the local rainfall intensity and other necessary information which will be key in for SWMM simulation.

The flow chart of methodology is shown in Figure 3.1 which includes the flow and main steps to perform the research study.

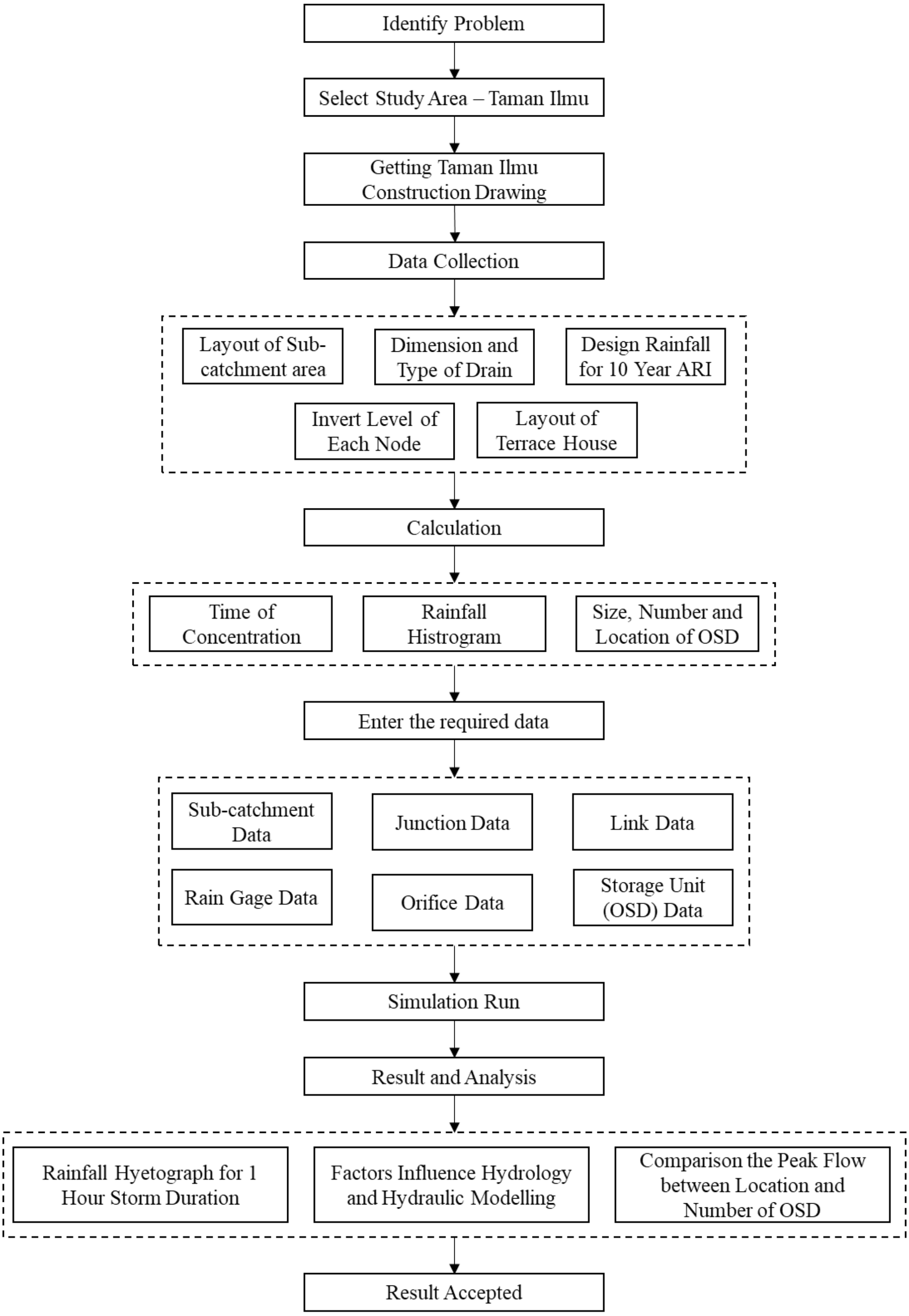

Figure 3.1: Flow chart of methodology

3.2 Data Collection

The data basically required to modelling SWMM are:

1. The layout of sub-catchment
2. Dimensions and types of drain
3. Design rainfall for 10 years ARI
4. Invert level of each node
5. The layout of terrace house in Taman Ilmu

The data above are used to calculate the time of concentration, rainfall intensity and peak flow as well as percentage of impervious area in each sub-catchment. From the sub-catchment layout, the flow path length and surface roughness of each sub-catchment can be determined. With the mentioned information together with drain dimensions and drain types, the time of concentration can be determined. Since the drain and OSD are minor system, 10 year ARI design rainfall is used. Outlet of each sub-catchment is taken as node in SWMM and its invert level is obtained from the construction drawing. The layout of terrace house is referred to determine the percentage of impervious area.

3.2.1 Time of Concentration

The time of concentration, t_c is directly related to peak flow rate. The design storm duration is selected equal or bigger than time of concentration. The equation is as follow:

$$t_c = t_o + t_d \tag{3.1}$$

where,

t_o = time of overland flow (minutes)

t_d = time of travel in roadside swales, drains, channels and small stream (minutes)

Overland flow time, t_o is the time of movement of water over the land, downslope toward a water body. The overland flow time depends on the land condition such as slope and surface with the length of sheet flow. Surface of land has varies values of Horton's roughness based on the type of surface shown in Table 3.1. The equation shown as below:

$$t_o = \frac{107.n^*.L^{1/3}}{S^{1/5}} \tag{3.2}$$

where:

L = Overland sheet flow path length (m)

for steep slope (>10%), L ≤ 50m

for moderate slope (<5%), L ≤ 100m

for mild slope (<1%), L ≤ 200m

n* = Horton's roughness value for the surface (Table 3.1)

S = Slope of overland surface (%)

Table 3.1: Value of Horton's Roughness n* (DID, 2012)

Land Surface	**Horton's Roughness n***
Paved	0.015
Bare Soil	0.0275
Poorly Grassed	0.035
Average Grassed	0.045
Densely Grassed	0.060

The drain flow time, t_d is the time of storm water flow along the drain. The drain has varying roughness shown in Table 3.2 or depth across its width and that are used to determine the drain flow time as shown in Equation 3.3 below.

$$t_d = \frac{n.L}{60.R^{2/3}.S^{1/2}} \qquad (3.3)$$

where,

n = Manning's roughness coefficient (Table 3.2)

R = Hydraulic radius (m)

S = Friction slope (m/m)

L = Length of reach (m)

Table 3.2: Value of Manning's Roughness Coefficient (n) for Open Drains and Pipes (DID, 2012)

Drain/Pipe	**Manning Roughness n**
Grassed Drain	
Short Grass Cover (<150mm)	0.035
Tall Grass Cover (≥150mm)	0050
Lined Drain	
Concrete	
Smooth Finish	0.015
Rough Finish	0.018
Stone Pitching	
Dressed Stone in Mortar	0.017
Random Stones in Mortar or Rubble	0.035
Masonry	0.030
Rock Riprap	0.020
Brickwork	
Pipe Material	
Vitrified Clay	0.012
Spun Precast Concrete	0.013
Fibre Reinforced Cement	0.013
UPVC	0.011

3.2.2 Rainfall Intensity

Rainfall intensity is defined as the ratio of the total amount of rain (rainfall depth) falling on a ground during a given period.

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}} \qquad (3.4)$$

where,

i = Average rainfall intensity (mm/hr)

T = Average recurrence interval – ARI ($0.5 \leq T \leq 12$ month and $2 \leq T \leq 100$ year)

d = Storm duration (hours), $0.0833 \leq d \leq 72$

λ, κ, θ and η = Fitting constants dependent on the rain gauge location

Table 3.3 shows fitting constants for Intensity-Duration-Frequency (IDF) for different locations in Penang. Rainfall hyetograph is derived using normalized design rainfall temporal pattern shown in Table 3.4.

Table 3.3: Fitting Constants for the IDF Empirical Equation for the Different Locations in Penang for High ARIs between 2 and 100 year and Storm Durations from 5 minute to 72 hour. (DID, 2012)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Penang	1	5204048	Sg Simpang Ampat	62.089	0.220	0.402	0.785
	2	5302001	Tangki Air Besar Sg Pinang	67.949	0.181	0.299	0.736
	3	5302003	Kolam Tkgn Air Hitam	52.459	0.191	0.106	0.729
	4	5303001	Rmh Kebajikan P Pinang	57.326	0.203	0.325	0.791
	5	5303053	Komplek Prai	52.771	0.203	0.095	0.717
	6	5402001	Klinik Bkt Bendera P Pinang	64.504	0.196	0.149	0.723
	7	5402002	Kolam Bersih P Pinang	53.785	0.181	0.125	0.706
	8	5404043	Ibu Bekalan Sg Kulim	57.832	0.188	0.245	0.751
	9	5504035	Lahar Ikan Mati Kepala Batas	48.415	0.221	0.068	0.692

Table 3.4: Normalized Design Rainfall Temporal Pattern for Region 3: Perak, Kedah, Pulau Pinang and Perlis. (DID, 2012)

No. of Block	Storm Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.215	0.158	0.068	0.060	0.045	0.040	0.027	0.015	0.021
2	0.395	0.161	0.074	0.085	0.070	0.060	0.031	0.020	0.023
3	0.390	0.210	0.077	0.086	0.078	0.066	0.033	0.026	0.024
4		0.173	0.087	0.087	0.099	0.092	0.034	0.028	0.025
5		0.158	0.099	0.100	0.113	0.114	0.035	0.038	0.028
6		0.141	0.106	0.100	0.129	0.166	0.036	0.039	0.031
7			0.104	0.100	0.121	0.119	0.039	0.045	0.044
8			0.098	0.088	0.099	0.113	0.042	0.046	0.049
9			0.078	0.087	0.081	0.081	0.044	0.052	0.058
10			0.075	0.085	0.076	0.066	0.053	0.057	0.063
11			0.072	0.063	0.047	0.046	0.056	0.069	0.074
12			0.064	0.059	0.041	0.036	0.080	0.086	0.081
13							0.076	0.073	0.078
14							0.055	0.060	0.070
15							0.048	0.056	0.058
16							0.044	0.046	0.050
17							0.041	0.045	0.044
18							0.039	0.044	0.044
19							0.036	0.039	0.030
20							0.034	0.035	0.026
21							0.033	0.028	0.025
22							0.032	0.021	0.024
23							0.031	0.017	0.022
24							0.023	0.014	0.008

3.2.3 Rational Method

The Rational method is the most frequently used technique for runoff peak estimation in Malaysia and many parts of the world. It gives satisfactory results for small discharge catchments and is expressed as:

$$Q = \frac{C.i.A}{360} \quad (3.5)$$

where,

Q = Peak flow (m^3/s)

C = Runoff coefficient

i = Average rainfall intensity (mm/hr)

A = Drainage area (ha)

3.3 Calibrated Parameters

Table 3.5 and Table 3.6 show the parameters of sub-catchment and link respectively, in which the values are constant for all sub-catchment. Taman Ilmu can be considered as low-lying with small slope and the soil beneath Taman Ilmu is clay soil. The drainage system in Taman Ilmu is using rectangular open channel.

Table 3.5: Sub-catchment Parameter data

Parameter	
Slope	0.05 %
Manning's N-Impervious N-Pervious - Short Grass - Dense Grass	 0.012 0.15 0.24
Depression storage Dstore-Impervious Dstore-Pervious	 0.05 mm 0.20 mm
Infiltration: Horton Max. Infil. Rate - Clay Soil with Dense Vegetation Min. Infil. Rate Decay Constant Drying Time Max. Volume	 50.8 mm/hr 0.508 mm/hr 1.4 (1/hr) 7 days 0

Table 3.6: Link Parameters data

Parameter	
Conduit Geometry - Barrels - Shape	 1 Rectangular
Conduit Roughness	0.015
Flow Units	CMS
Link Offsets	Depth
Routing Model	Kinematic Wave
Force Main Equation	Hazen-Williams
Entry Loss Coeff.	0.5
Exit Loss Coeff.	1

3.4 Storm Water Management Model

The modelling consists of few steps to model the runoff of study area are shown below:

1. Collect the data of study area.
2. Create a new project.
3. Draw the required objects on the map.
4. Set up object properties to be used.
5. Run and simulate the model.
6. Present the results in graph, table and statistics.

3.4.1 Study Area

The study area has been chosen is Taman Ilmu, Nibong Tebal. Pulau Pinang. This is because Sungai Kerian is located just beside Taman Ilmu (Figure 3.2) that is one of factor causing the flood if facing high tide and heavy rainfall. The area of Taman Ilmu about 26 hectar. The study is performed to model the flow attenuation of study area through SWMM. All the information about the study area must be collected prior to the modelling. After all the data required have been obtained, enter the data as input into modelling system to simulate the model. The results of simulation is shown in graph, table and statistics once the simulation is successfully completed. There are three variables that can be adjusted to determine the effectiveness of OSD in different cases which are size, number and location.

Figure 3.2: Location of Taman Ilmu