THE EFFECT OF LOCATION FOR ON-SITE DETENTION (OSD) ON PEAK ATTENUATION USING STORMWATER MANAGEMENT MODEL

NURUL FATHIHA BINTI MOHD PUZI

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2017

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By

NURUL FATHIHA BINTI MOHD PUZI

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2017

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2014/2015

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: The Effect of Location for On-Site Detention on Peak Attenuation using Stormwater Management Model

Name of Student: Nurul Fathiha Binti Mohd Puzi

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

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Date :

Approved by:

____

(Signature of Supervisor)

Name of Supervisor: Assoc. Prof. Dr. Rozi Abdullah

Date :

Approved by:

____

(Signature of Examiner)

Name of Examiner :Prof. Dr. Hj. Aminuddin Ab. Ghani

Date :

ACKNOWLEDGEMENT

After all of hard work in this year, it is necessary to express my gratitude to those people who helped and contributed their precious time, leading to complete my final year project.

First and foremost I would like to express my grateful to Allah S.W.T because of His love and strength that He has given to me to finish my final year project and giving me a good health along this year. For their strong support, I would like to express my gratitude to my beloved parents and family that always being a part of my life to encourage me in all my pursuits and inspire me to follow my dreams.

I would like to express my deepest thanks to my research supervisor, Assoc. Prof. Dr. Rozi Abdullah for giving me a chance to undergo my project under his supervision. He gives me a lot of guidance in taking part of useful decision, giving necessary advices, and sharing his knowledge to complete my final year project. I also would like to acknowledge with much appreciation to all were extremely valuable for my both theoretically and practically.

Lastly, I would like to thanks to all my friends whose help me to finish up my study and always giving a new experience and support. It is very grateful to have such sincere colleagues to work together.

ABSTRAK

Objektif kajian ini adalah untuk menilai pengecilan aliran dari kawasan pembangunan bandar dengan menggunakan model SWMM. Projek ini bertujuan untuk menjalankan pemodelan air larian ribut kawasan pembangunan menggunakan model SWMM, bagi tujuan untuk menilai tempoh perbezaan tempoh masa ribut dan aliran pengecilan kawasan pembangunan. Sistem saliran di kawasan pembangunan adalah amat penting kerana ia dapat mengurangkan banjir dengan membawa air keluar terus ke sungai. Konsep "kawalan di punca" atau "Amalan Pengurusan Terbaik (BMPs)" telah diperkenalkan untuk mengelakkan berlakunya banjir kilat. Oleh itu, satu manual baru telah diperkenalkan untuk menguruskan sistem saliran dengan lebih baik iaitu "Manual Saliran Mesra Alam" (MSMA).

Model Pengurusan Air Ribut (SWMM) digunakan secara meluas untuk merancang, menganalisis dan reka bentuk yang berkaitan air larian ribut, gabungan pembentung, dan sistem saliran di kawasan pembangunan, dan juga pelbagai aplikasi untuk kawasan luar bandar. Sistem ini adalah penting dalam pemodelan terutamanya dalam penentuan saiz longkang untuk mengurangkan banjir dan ia juga boleh dimodelkan untuk menentukan kemudahan fasiliti dalam tadahan yang boleh mengurangkan banjir dan meningkatkan kualiti air larian banjir.Daripada kajian ini, jumlah keamatan hujan selama 10 tahun ARI untuk 15 minit ialah 193mm/jam dan 30 minit adalah 127mm/jam. Mengikut pengiraan daripada MSMA, jumlah bagi setiap tangki untuk kes 1 ialah 216 m^3(4 tangki), kes 2 ialah 489 m^3(2 tangki), dan kes 3 ialah 875 m^3(1 tangki). Di samping itu, daripada analisis kes 1 menunjukkan peratusan yang paling tinggi untuk pengecilan iaitu dalam lingkungan 30% berbanding dengan kes 2 dan kes 3 untuk kedua-dua tempoh ribut 15 minit dan 30 minit.

ABSTRACT

The objective of this study is to evaluate the flow attenuation of the urban development by using SWMM modelling. The project is aimed on the modelling of the drainage system in urban area using SWMM model, to evaluate storm with different duration and flow attenuation of the development area. The drainage system is an essential part of living in urban area, as it reduces the flooding by conveying water away. The concept of “control at source” or “Best Management Practices (BMPs)” were introduced to prevent flooding from happened. Therefore, a new manual was introduced to manage the drainage system to be more efficient which is “Manual Saliran Mesra Alam” (MSMA).

Stormwater Management Model (SWMM) is widely used for planning, analysis and design related to urban storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. The system is important in modelling especially in determination of drain size to reduce flooding and it is also can be modelled to determine the detention facilities that can reduce the flood and improve the quality of stormwater. Over this study, the total rainfall of 10 years ARI for 15 minutes is 193 mm/hr and for 30 minutes is 127 mm/hr. From the calculation based on MSMA the volume of each tank in case 1 is 216m^3(4 tanks), case 2 is 480m^3(2 tanks), and case 3 is 875m^3(1 tank). In addition, from the analysis of case 1 shows the higher percentage of attenuation which is approximately 30% compared to case 2 and case 3 for both storm duration of 15 minutes and 30 minutes.

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LIST OF ABBREVIATIONS

ARI	**A**verage **R**ecurrence **I**nterval
BMPs	**B**est **M**anagement **P**ractise
CMS	**C**ubic **m**eter per **S**econd
DID	**D**epartment of **I**rrigation and **D**rainage
EPA	**E**nvironment **P**rotection **A**gency
MSMA	**M**anual **S**aliran **M**esra **A**lam
OSD	**O**n **S**ite **D**etention
SWMM	**S**tormwater **M**anagement **M**odel

NOMENCLATURES

A	Drainage area
C	Runoff coefficient
d	Storm duration
I	Average Rainfall Intensity
Q	Peak flow
h, λ, θ, k	Fitting constant dependent on the rain gauge location

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Precipitation generates runoff that flow into the stream by interflow or overland flow. Water will infiltrate into the ground when there is rainfall occurrence. Interflow occurs when water infiltrates into the sub surfaces and lateral flow proceeds to downslope. As water accumulates in the subsurface, saturation may occur and interflow may exfiltrate as return flows and becoming overland flows.

Runoff is known as a portion of precipitation that is discharged from the area of the stream channels. Runoff will happens when there is flow over the ground when the land surface is saturated. There are several factors that influence the infiltration of water, such as degree of saturation, type of soil and activities that might change the properties of the soil. The direct runoff results from rainfall in urban areas that flow over urban drainage system are known as stormwater. The runoff from urban development need to be control to minimize the impact on quality and quantity of receiving waters (Van Der Sterren and Rahman, 2015). A flood can occur when there is widespread and prolonged heavy rainfall due to runoff exceeded the capacity of the rivers and streams.

In urban areas, rain that fall on the roof of a house or rain that are collected on paved areas are carried away through a system of pipes and open drains that are separated from the sewerage system. Stormwater is pure rainwater and precipitations that are accumulated in natural or constructed storage and stormwater system during storm events. The common practices to achieve goals of stormwater management are classified in four groups which is long-term flood prevention strategy, short term improvement and management measures, land use management and legislation, and a preventive approach to maintenance planned (Murrells et al, 2002).

Storage facilities have core elements to achieve one of the criteria for stormwater quantity control which peak discharge post development cannot be greater than the peak discharge of pre-development. This can be achieved with the proper location and size of the storage facilities. To reduce runoff peak flow, a simple concept of storage has resulted in widespread application of detention ponds (James et al, 1987). A detention basin and on site detention (OSD) is commonly used to reduce the peak flow and OSD is widely used in individual lot development. OSD is designed to limit the flow of stormwater to downstream drainage system and also slow down the flow to downstream area. OSD may be provided as above-ground storage such as landscape area, flat rooftop, and surface tank and as for below-ground storage such as tanks and pipe packages or may be as combination of both above-ground storages and below-ground storages within a property boundary. The effectiveness of detention ponds will depend on their size and location in reducing the peak flow of the water (James et al, 1987).

EPA Storm Water Management Model (SWMM) version 5.1 is the newest software technology to obtain the information on management and collection of stormwater. The EPA SWMM is dynamic simulations to determine the quality and quantity of the runoff primarily from urban areas. EPA SWMM is a dynamic rainfall-runoff model for quantity and quality controls that is used for single event or long-term simulation from urban areas (Gironás et al, 2010). SWMM provides an integrating Windows to input data editing, running simulations and showing results in various ways. The routing portion of SWMM transport this runoff through a system of pipes, channels, storage/treatment devices, pumps and subcatchment, and the flow rate, flow depth, and the quality of the water in each pipe and channel during simulation period comprised of multiple time steps (Rossman, 2010).

Peak flow attenuation is important in urban stormwater management because runoff from post-development increases in magnitude and volume and may cause flooding to downstream areas (Park et al, 2007). The recommended storage facilities are on-site detention (OSD) and community detention pond. It depends on the land availability, these facilities can be located on-line or off-line to the conveyance system (DID, 2012).

1.2 Problem Statement

Recently, Selangor, Kuala Lumpur, Penang and Kuching experiences flooding issues during a heavy rain where rapid urbanization is taking place and rapid development causing the water quantity and quality problems on the rise. The cause of flash floods is due to the improper drainage system. For example, in urban area such as Kuala Lumpur and Penang, improper urban stormwater drainage has been high-lighted as one of the causes of the flash floods. Several residential areas have implemented drainage systems for 10 to 20 years but no proper maintenance to reduce the problem of flash floods. It can cause property damage and loss of life (Liew et al, 2012). Three years before, there is a flash flood that happened in Kajang town due to the heavy rain. The effect from this flood is Keretapi Tanah Melayu Berhad (KTMB) was forced to stop train services into the township and vehicles are washed away by the flood (The Star Online, 2014).

From the report, the floods in Kajang occurred after about an hour of heavy rain with pictures that show the water at knee-deep levels (The Star Online, 2014). The disaster is the worst flood that happened since year 1971 that killed 32 in the Klang Valley 40 years ago. The disaster can affect on economy, people and environment. In terms of economy, the disaster had destroyed many facilities such as road, shops, restaurants and vehicles. Usually, the processes of rebuilt or doing a maintenance work of a damage facilities will take time to manage it again. When flooding occurred, chemical and hazardous material will eventually contaminate the water bodies. The most impacts of flooding is to humans. People will be traumatised and have some physical effect due to the worst flooding occurrence.

In 2000, the Department of Irrigation and Drainage officially published the Urban Stormwater Management manual for Malaysia or Manual Saliran Mesra Alam (MSMA) (DID, 2000) that aimed to promote best management practices (BMPs) for stormwater management at the source and within the catchment and to steer drainage development in the country. There are several proposals to reduce flooding problems such as structural and non-structural measures. Under structural measures, engineering methods are used to solve the problems of flooding. The river capacity can be increased to cover the excess runoff through channel improvement, construction of levees and embankments, flood by passes, river diversions, pondering and construction of flood storage dams and flood attenuation pond, either singly or in combination. In addition, non-structural measures are used if engineering method cannot resolve the issues by other measures. They include restriction of development, land use zoning, resettlement of population, flood proofing and flood forecasting, and warning system (DID, 2012).

1.3 Objectives

The objectives of this study are listed below:

1. To design and determine 3 different sizes of an OSD using MSMA.
2. To develop a model of an OSD for 3 different types of cases by using Storm Water Management Model (SWMM).
3. To evaluate the location of OSD for 3 different types of cases using Storm Water Management Model (SWMM).

1.4 Scope of work

This study focused on the collection of data such as layout of the case study, the number of the terraced house, the size of the house, the topography maps of catchment. The stormwater model for 3 different locations of OSD are applied in SWMM software. The analysis need to be carried out with the sensitivity analysis and the calibration. The peak flow attenuation percentage is evaluated by using OSD for different sizes and locations in a case study.

1.5 Dissertation Outline

Chapter 1 discusses about stormwater management in urban area and its application for reduction of peak flow of a runoff. Chapter 2 contains literature review and related research associate with this study. Chapter 3 includes the methodology and procedures used for data collection, simulation and analysis. Chapter 4 provides the presentation of data collected and analysis for this study. Chapter 5 covers the conclusions for this study and recommendation for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The continuous circulation of water in the earth-atmosphere system is known as hydrologic cycle. Hydrologic cycle of fundamental characteristic has no beginning and has no end of the processes. Over a million years. Water is always changing its states between liquid, vapour and ice (USGS, 2016). The processes involved in the hydrologic cycle are evaporation, precipitation, condensation, transpiration and runoff (NOAA, 2011).

Evaporation is the process which the water changes from a liquid state to a gas or vapour. Energy is required when evaporation process takes place. The source of energy can come from the sun, the atmosphere, the earth or objects on the earth such as humans (NOAA, 2011). The oceans, seas, lakes and rivers contribute nearly to 90 percent of moisture in the atmosphere while the other 10 percent is being provided by plant transpiration (USGS, 2016).

Precipitation is known as the water that released from the clouds in the form of rain, sleet, snow or hail. Runoff is created when the precipitation of water travels over the ground surfaces and fills the lakes and river. The water that flow through the rivers, lakes and sea that are trapped between the rock or clay layer will become groundwater. The area that usually close to the oceans or large water bodies will receive more precipitation of water that allow more water to evaporates and form the cloud. The other areas that are received less precipitation of water are usually far from water body or near the mountain. Figure 2.1 shows the hydrologic cycle processes.

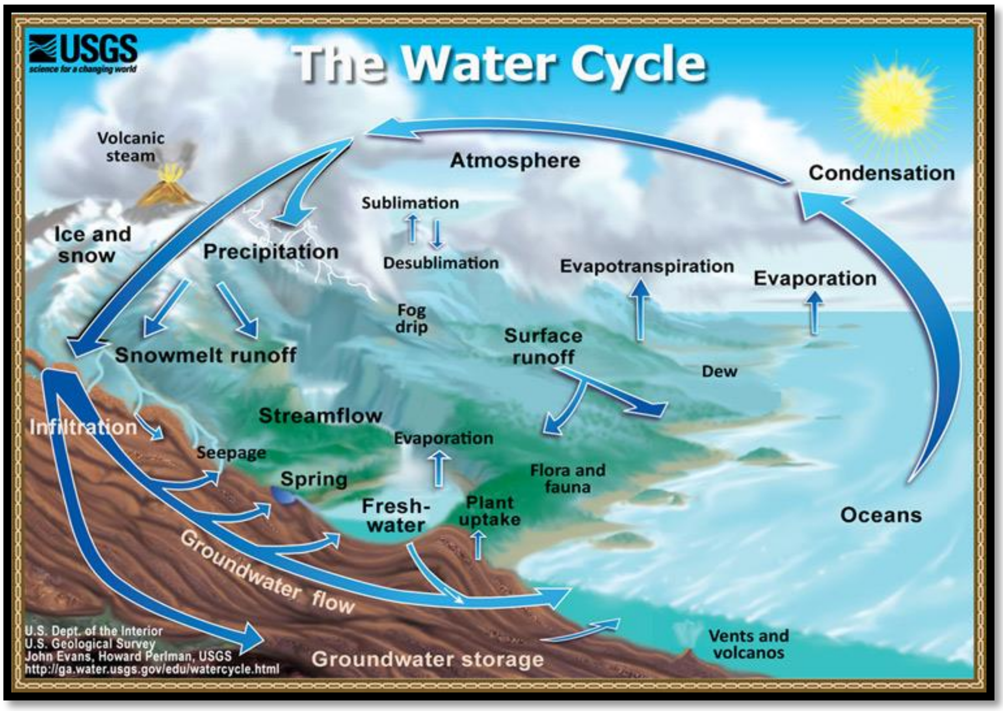

Figure 2.1: The hydrologic cycle process (USGS, 2016)

2.2 Urban Stormwater Management

Urban stormwater is defined as the runoff which mostly caused by rain in urban areas and the main flows of domestic wastewater that are handled by the urban drainage system. To minimise the problems that caused to humans and environment effect, urban drainage system should be designed to handle the wastewater and the stormwater problems (Butler and Davies, 2004).

The effect of urbanization shows that the large river basins are affected by urban development in many urban areas. As the urbanization increases, the flood frequency also increase significantly because of the urban areas are drain by small urban creeks and drainage system. So, flood frequency increases approximately by the same percentage as urbanization (Milina et al, 2012).

Stormwater discharge into water bodies can cause an impact on the emission characteristics which is quality and flow velocity and, the volume and quality of the receiving water. Urban areas will result in higher peak discharge and volume of runoff, these processes can increase the flow velocity and force of flow for a geomorphic (Tillinghast et al., 2011)

Urbanization and development can affect the quantity and the quality of the stormwater runoff. The quantity can be affected by the impervious area that are caused by the development of the urban areas. Best Management Practices (BMPs) is designed to manage the stormwater quality with different measures which is structural and non-structural (Stefan, 2006). This measure is to prevent or reduce the point source or non-point source pollution. The examples of BMPs structure that are constructed are wetlands, detention and retention ponds, swales and infiltration system.

Proper management of stormwater is important during peak flow because flooding can occur when there is not properly managed. The suitable stormwater management techniques can be obtained with the analysis of topography, geographical and hydrologic system characteristic and the factors that cause the flooding in urban area can be determined (Ronczyk et al., 2012). Source control of stormwater management is intended to reduce the excess runoff and pollution load into the drainage system. The advantages of these measures are more cost effective than the construction and maintenance of treatment systems (Barbosa et al, 2012). Stormwater management policy stresses stormwater removal from society to protect human and property, but priority conservation of ecosystems is also emphasized.

Stormwater system is divided into two: major and minor. The major system function as a transfer and control runoff collected by a minor drainage system that might overflow into downstream system and water bodies. It must protect the society from injuries, damage to property and losses of life. In addition, the minor system functions as collecting, controlling and delivering runoff from buildings, infrastructure and utilities in relatively frequent storm events that up to 10 years ARI to reduce the inconvenience flooding (DID, 2012).

There are 2 methods that are applied in runoff quantity management strategies in the past and nowadays:

I. Conveyance – oriented approach also known as rapid disposal.

II. Storage – oriented approach.

Conveyance – oriented approach allows the stormwater runoff to flow quickly into the water bodies or the stream. There are two basic system of this approach which is commonly used, separated system that separate the flow of wastewater and stormwater, and combined system which allowing the stormwater and wastewater ro flow together which is not being practically used in Malaysia (DID, 2012).

2.3 Best Management Practices (BMPs)

In 1990s, Best Management Practices (BMPs) have been used to control pollution from urban runoff and protect the waters that receive runoff flowing. Recently, some investigators have suggested that BMPs protects aquatic environment downstream (Schueler et al, 1999). Schueler (1999) believes that urban runoff the starting point hydrology in urban areas. In order to harvest water and reuse is one of the effective resolution for the purposes of the supply water in most countries. The BMPs are designed to reduce the stormwater volume, peak flow using detention and, biological and chemical treatments.

Stormwater source control has been established in several decades as one of the alternatives for stormwater management in urban areas. The principle of source control of stormwater is to manage the rainwater resources, it discharged into the sewerage system which conventional combined or separate system with control at source that is characterized by the use of best management practices (BMPs).

The main objective for the development of BMPs is to prevent the risk of flooding during rain events of unusual nature. In addition, rapid urbanization resulting in increased storm runoff, which provides greater peak flow and volume of runoff. BMPs aim to solve the problem of water pollution cleaner. The main objectives are the reduction of water pollution and flood prevention. There are some other criteria that need to be considered. The criteria are hydraulic performance and technical, sociological and environmental perspective, as well as economic, considerations operation and maintenance.

2.4 On-Site Detention (OSD)

Detention refers to the holding of runoff for short periods to reduce peak flow rates and releasing it to the natural watershed to continue the hydrological cycle (Peter et al, 1999). Mostly, OSD is applied to prevent flooding in such area of new development and housing area or factories. Many countries are currently using OSD as a structural measure for flood mitigation method. OSD is a structural element of a property drainage system that limits the site discharge of the stormwater by using an outlet restriction devices (Beecham et al., 2005).

Detention is the best way to neutralize stormwater produced by the larger urban areas. Rain gardens, infiltration trenches and bio swales is the way to collect runoff produced by areas that are smaller, and it is the most effective when used to treat water from a parcel of land of the city. However, the larger detention, appropriate to be implemented at community level because it can save water with more to prevent floods. Detention ponds to manage stormwater quantity on top of that is also functions to treat the water quality. When it rains in the catchment drainage, runoff will move to the ground or is routed to the drain or underground pipe. In some cases, water will undergo pre-treatment wetland or tank deposition. These cells are given additional treatment to remove sediment and contaminants generated by water. After it is through pre-treatment cells, it then goes into water bodies. Detention ponds also prevent floods in area of a community that are developed (Peter et al., 1999)

There are two types of OSD storage that was used which is above ground and below ground, or a combination of both. Above ground storage need an area and typically located at rooftop, tanks, landscapes area such as gardens, impervious area such as parking area or driveway area. The advantages of the above ground storage are relatively inexpensive compared to below ground storage. Safety features also are needed to prevent drowning particularly of children and senior citizen. Below ground storages is out of sight and it occupy minimum land spaces. It is quite expensive compared to above ground storage because of the material used for construct the storage (DID, 2012)

The main objective in designing the OSD facilities is to determine the required site storage (SSR) to reduce the post development discharge to that of the pre development level of permissible site discharge (PSD). In order to achieve this, the outlet structure needs to be size appropriately (DID, 2012).

2.4.1 Permissible Site Discharge (PSD)

The maximum allowable discharges that are leaving the site are given in litres/second/hectare (l/s/ha) when it is applied to a specific site. The maximum PSD is about 65l/s/ha. It need to be adjusted in accordance with the design regions as shown in Figure 2.2 and the results were summarised in Figure 2.3. The inlet size which represents the PSD capacity is shown in Figure 2.4.

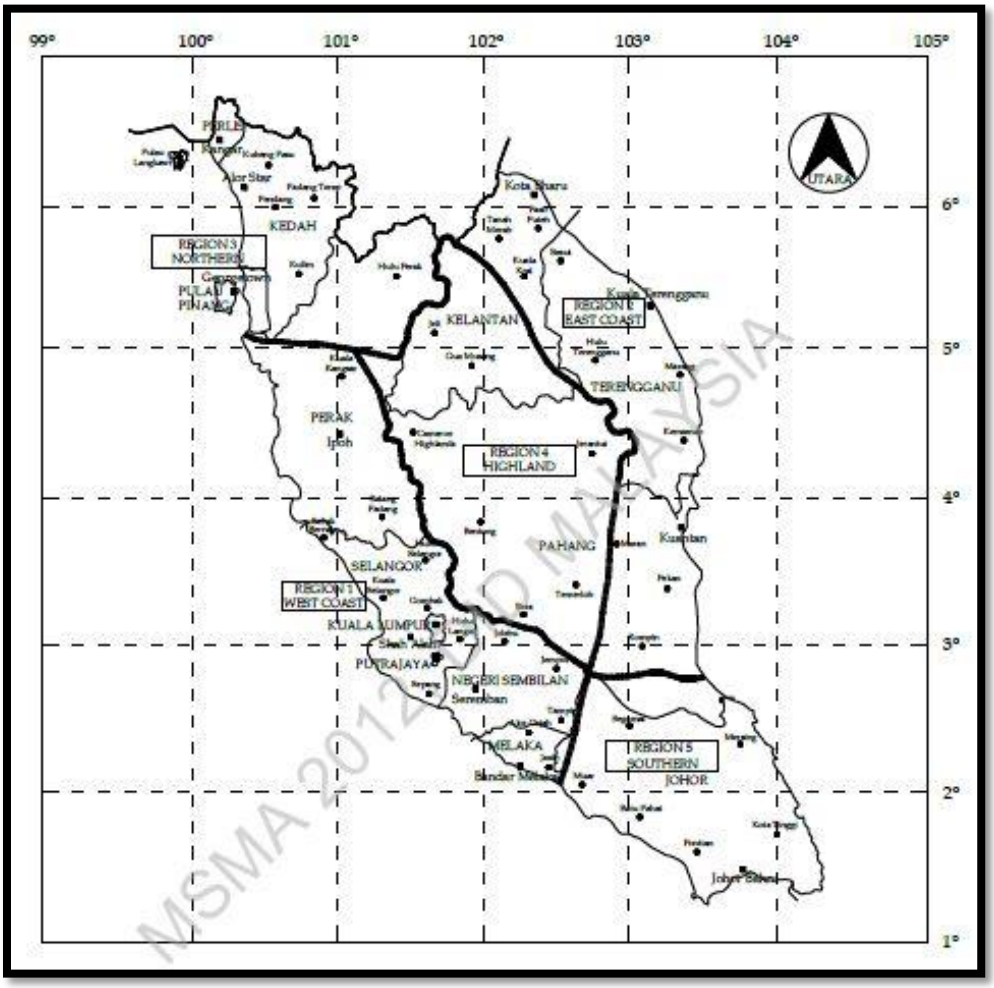

Figure 2.2: OSD in designed based on five regions (DID, 2012)

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 1 - WEST COAST										
Lowlying	63.4	64.2	64.5	65.2	65.5	322.2	363.0	394.2	478.3	540.4
Mild	76.7	77.5	77.9	78.7	79.1	306.6	340.0	367.2	448.5	504.7
Steep	87.7	88.6	89.1	90.1	90.5	294.0	327.0	350.5	426.7	478.8

Figure 2.3: Maximum Permissible Site Discharge (PSD) and Minimum Site Storage Requirement (SSR) Values in Accordance with the Five Regions in Peninsular Malaysia (DID, 2012).

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 (m^3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m^3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m^3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)	Volume (m^3)	Inlet & Overflow Dia. (mm)	Outlet Dia. (mm)
TERRAIN : MILD, SLOPE 1 : 875 TO 1 : 1999															
0.1	31	143	69	34	151	69	37	160	69	45	171	70	51	178	70
0.2	61	202	97	68	214	97	74	226	97	90	242	98	101	252	98
0.4	122	286	137	136	303	137	148	319	137	180	342	139	202	357	139
0.6	183	350	168	204	371	168	222	391	168	270	419	170	303	437	170
0.8	244	404	194	272	428	194	296	451	194	360	484	197	404	505	197
1	305	451	217	340	479	217	370	505	217	450	541	220	505	564	220
2	740	451	307	840	505	307	910	529	307	1140	597	311	1300	618	311
3	1110	553	376	1260	618	376	1365	648	376	1710	731	381	1950	757	381
4	1480	638	434	1680	714	434	1820	749	434	2280	845	440	2600	874	440
5	1850	714	485	2100	798	485	2275	837	485	2850	944	492	3250	977	492

Figure 2.4: OSD Volume, Inlet Size and Outlet Size for Region 1 (DID, 2012).

2.4.2 Site Storage Requirement (SSR)

The minimum volume (in m^3/hectare when applied to a specific site) is required to ensure that there is no spillage occurs when the outflow is restricted to the PSD. The minimum SSR for an OSD storage that has Discharge Control Pit (DCP) are shown in Figure 2.5 which shows the values in accordance with the suitable region, in m^3/ha. The information for the major towns in Peninsular Malaysia is shown in Figure 2.5. For the OSD size storage, inlet and outlet structures sizes for different types of development can refer Figure 2.4.

Terrain / Slope Condition	PSD (l/s/ha)					SSR (m³/ha)					Inlet (l/s/ha)				
	Impervious Area (as a Percentage of Project Area)														
	25%	40%	50%	75%	90%	25%	40%	50%	75%	90%	25%	40%	50%	75%	90%
KUALA LUMPUR															
Low-lying	60.4	61.0	61.4	62.0	62.3	305.2	346.7	377.9	466.1	529.7	130.0	150.0	160.0	190.0	210.0
Mild	71.2	72.0	72.4	73.1	73.4	292.6	327.9	358.0	439.6	497.8	160.0	173.0	190.0	220.0	240.0
Steep	81.7	82.6	83.0	83.9	84.3	280.6	312.6	340.5	418.0	471.6	170.0	190.0	210.0	240.0	260.0

Figure 2.5: Maximum PSD, Minimum SSR and Inlet Values in Accordance with the Major Towns in Peninsular Malaysia. (DID, 2012).

2.5 Urban Stormwater Management

EPA Storm Water Management Model (SWMM) version 5.1 is the newest version of the model, it is provides an integrated Windows environment for editing input data, running a simulation and viewing the results in the form of graph, tables and profile plots (Roesner et al, 2010). EPA SWMM can simulates all aspects of urban hydrologic cycles which includes the surface runoff, transport through the drainage network, storage and treatment and receiving water effects (Huber et al., 1984).

The EPA SWMM is a complex model and have large capabilities of simulating the flow of rainfall and pollutant from the earth's surface through the pipe and channel network, for the prediction of flow and pollutant concentration, both single event and continuous simulation may apply on the catchment that having storm sewer and natural drainage (USEPA, 2010).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presenting on the phases involved in the research study, which explained the flow of this research. This chapter also presents the simulation model for the research study. EPA Storm Water Management Model version 5.1 (SWMM) was used to determine the flow attenuation in the drainage system.

There are many application of SWMM such as design and sizing of drainage system component for flood control, sizing of detention facilities and their appurtenances for flood control and water quality protection, flood plain mapping of natural channel systems and others. The capabilities of SWMM modelling have various type of hydrologic processes that generate runoff from urban areas which include time-varying rainfall, infiltration of rainfall into unsaturated soil layer, interflow between groundwater and the drainage system and others.

EPA SWMM version 5.1 can be downloaded from the internet without any fee and the manual of SWMM are provided. The methodology of study covers the steps taken to achieve the objectives and the end result of the research study.

Figure 3.1 and Figure 3.2 show the flow chart of methodology that presents the steps to perform the research study and including data analysis.

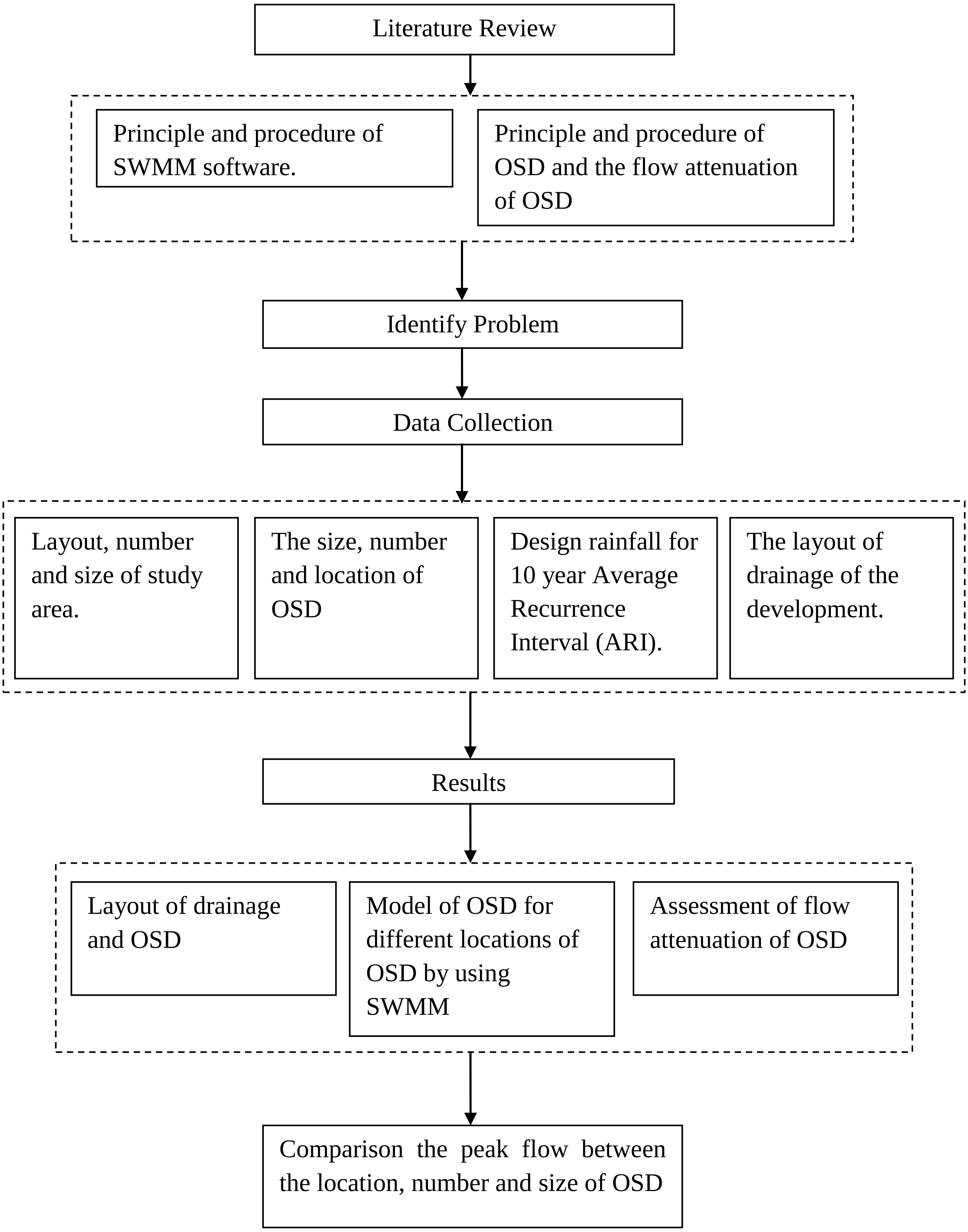

Figure 3.1: Flowchart research methodology.

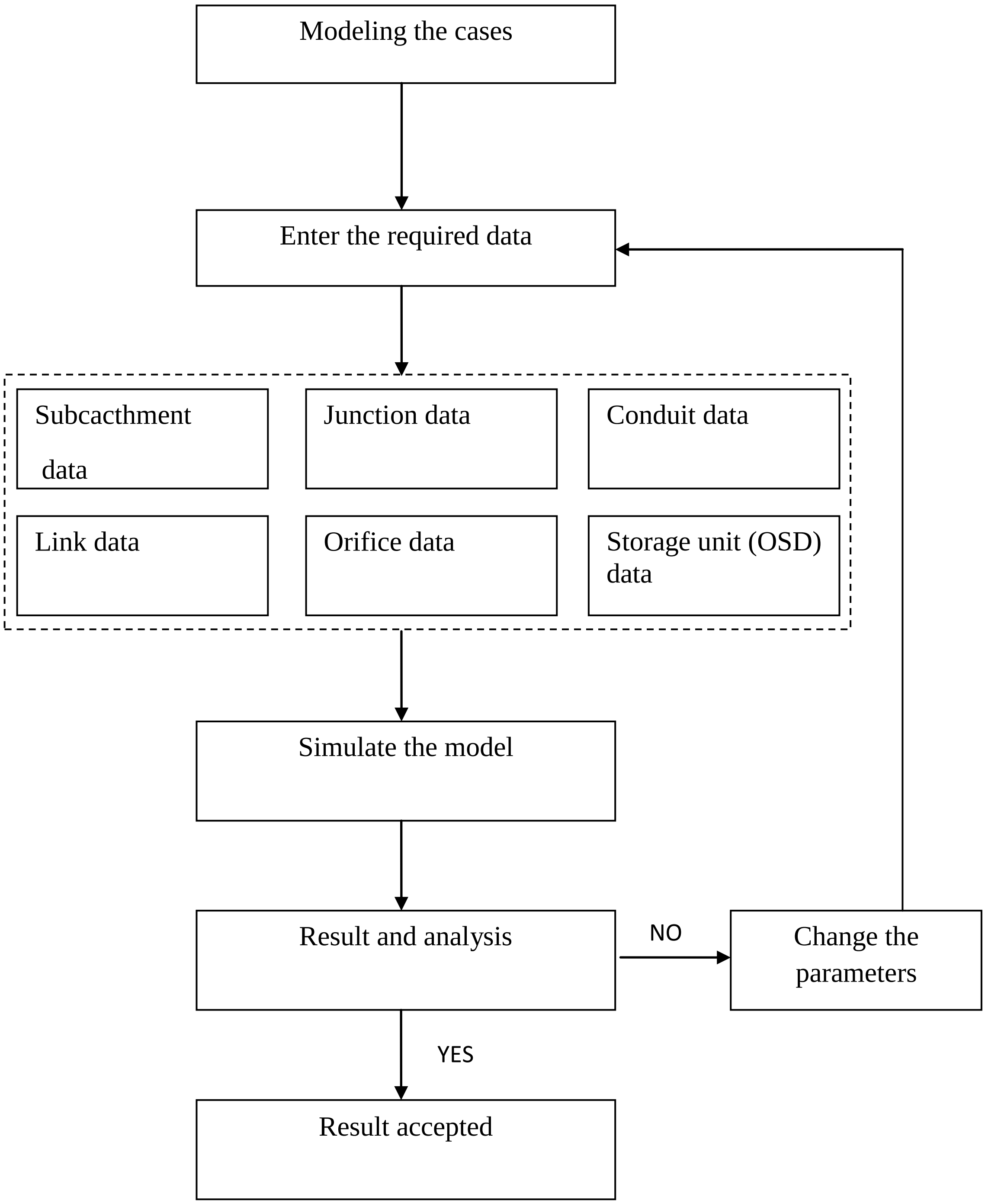

Figure 3.2: Model development using SWMM.

3.2 Data Collection

The basic data that are required to develop the SWMM model are:

1) The layout and number of terraced house.
2) The size, number and location of OSD.
3) The layout of drainage for the development.
4) Design rainfall for 10 year Average Recurrence Interval (ARI).

3.2.1 Time of Concentration

Time of concentration (tc) is the travel time of runoff flows from upstream hydraulically catchment that contribute to the point under consideration downstream. The concept of time of concentration in all peak flow estimation method assumes that the rain happens during the time concentration directly related to peak flow rate. The method is to select the design storm duration as equal to or greater than the time of concentration (tc) (DID, 2012). The equation is as follow:

$$t_c = t_o + t_d \quad (3.1)$$

Where,

t_o = the overland flow time (minutes)

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

The overland flow time can be estimated using:

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

Where,

t_o = Overland sheet flow travel time (minutes)

L = Overland sheet flow path length (m)

for steep slope ((>10%), 1 ≤ 50 m)

for moderate ((<5%), 1 ≤ 100 m)

for mild slope ((<1%), L ≤ 200 m)

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

S = Slope of overland surface (%)

Table 3.1: Values 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	0.06

The flow time in the channel can be estimated using:

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

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: Values of Manning’s Roughness Coefficient (n) for open Drains and Pipes (DID, 2012)

Drain / Pipe	**Manning's Roughness, n**
Grassed Drain	
✓ Short Grass cover (< 150 mm)	0.035
✓ Tall Grass cover (≥ 150 mm)	0.05
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 Mansory	0.035
Rock Riprap	0.03
Brickwork	0.02
Pipe Material	
Vitrified Clay	0.012
Spun Precast Concrete	0.013
Fibre Reinforced Cement	0.013
UPVC	0.011

3.2.1 Rainfall Intensity

Rainfall intensity is the ratio of total volume of rain during certain period.

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

Where,

i	=	Average rainfall intensity (mm/hr)
T	=	Average recurrence interval – ARI
d	=	Storm duration (hours)

h, λ, θ and k = Fitting constants dependent on the rain gauge location Table 3.3

Table 3.3 : Fitting Constants for the IDF Empirical Equation for the Different Locations in Malaysia for ARIs between 2 and 100 Year and Storm Durations from 5 Minutes to 72 Hours. (DID, 2012)

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Perak	1	5005003	JPS Teluk Intan	65.1854	0.3681	0.2552	0.8458
	2	4010001	JPS Setiawan	56.2695	0.3434	0.2058	0.8465
	3	4207048	Pejabat Daerah Kampar	79.2706	0.1829	0.3048	0.8532
	4	4311001	Rumah Pam Kubang Haji	47.8316	0.3527	0.1038	0.8018
	5	4409091	Politeknik Ungku Umar	62.9315	0.3439	0.1703	0.8229
	6	4511111	Bukit Larut Taiping	83.3964	0.3189	0.1767	0.8166
	7	4807016	Rancangan Belia Perlop	57.4914	0.3199	0.2027	0.8696
	8	4811075	Jln. Mtg. Buloh Bgn Serai	63.2357	0.3176	0.3330	0.8462
	9	5207001	Kolam Air JKR Selama	67.0499	0.3164	0.2255	0.8080
	10	5210069	Stesen Pem. Hutan Lawin	53.7310	0.3372	0.2237	0.8347
	11	5411066	Kuala Kenderong	68.5357	0.4196	0.1558	0.8378
	12	5710061	Dispensari Keroh	59.2197	0.3265	0.1621	0.8522
Perlis	1	6401002	Padang Katong, Kangar	52.1510	0.3573	0.1584	0.7858
Selangor	1	2815001	JPS Sungai Manggis	57.3495	0.2758	0.1693	0.8672
	2	2913001	Pusat Kwln. JPS T Gong	65.3556	0.3279	0.3451	0.8634
	3	2917001	Setor JPS Kajang	62.9564	0.3293	0.1298	0.8273
	4	3117070	JPS Ampang	69.1727	0.2488	0.1918	0.8374
	5	3118102	SK Sungai Lui	68.4588	0.3035	0.2036	0.8726
	6	3314001	Rumah Pam JPS P Setia	65.1864	0.2816	0.2176	0.8704
	7	3411017	Setor JPS Tj. Karang	70.9914	0.2999	0.2929	0.9057
	8	3416002	Kg Kalong Tengah	59.9750	0.2444	0.1642	0.8072
	9	3516022	Loji Air Kuala Kubu Baru	66.8884	0.2798	0.3489	0.8334
	10	3710006	Rmh Pam Bagan Terap	62.2644	0.3168	0.2799	0.8665

Table 3.4: Normalise Design Rainfall Temporal Pattern for Region 2: Johor, Negeri Sembilan, Melaka, Selangor and Pahang. (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	0.255	0.124	0.053	0.053	0.044	0.045	0.022	0.027	0.016
2	0.376	0.130	0.059	0.061	0.081	0.048	0.024	0.028	0.023
3	0.370	0.365	0.063	0.063	0.083	0.064	0.029	0.029	0.027
4		0.152	0.087	0.080	0.090	0.106	0.031	0.033	0.033
5		0.126	0.103	0.128	0.106	0.124	0.032	0.037	0.036
6		0.103	0.153	0.151	0.115	0.146	0.035	0.040	0.043
7			0.110	0.129	0.114	0.127	0.039	0.046	0.047
8			0.088	0.097	0.090	0.116	0.042	0.048	0.049
9			0.069	0.079	0.085	0.081	0.050	0.049	0.049
10			0.060	0.062	0.081	0.056	0.054	0.054	0.051
11			0.057	0.054	0.074	0.046	0.065	0.058	0.067
12			0.046	0.042	0.037	0.041	0.093	0.065	0.079
13							0.083	0.060	0.068
14							0.057	0.055	0.057
15							0.052	0.053	0.050
16							0.047	0.048	0.049
17							0.040	0.046	0.048
18							0.039	0.044	0.043
19							0.033	0.038	0.038
20							0.031	0.034	0.035
21							0.029	0.030	0.030
22							0.028	0.029	0.024
23							0.024	0.028	0.022
24							0.020	0.019	0.016