MODELLING SUSTAINABLE URBAN STORMWATER SYSTEM IN DIAMOND CITY USING SWMM

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SCHOOL OF CIVIL ENGINEERING
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By

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ABSTRAK

Urbanisasi ialah perubahan penggunaan tanah seperti penukaran kawasan luar bandar kepada bandar. Peningkatan proses pembandaran menyebabkan kemungkinan banjir yang lebih tinggi. Urbanisasi menyebabkan penggunaan tanah telah berubah dari permukaan yang tembus kepada permukaan yang tidak tembus. Hal ini memyumbangkan penyusupan semula jadi air ribut ke dalam tanah menjadi lebih rendah. Hal ini turut menyebabkan limpasan permukaan lebih banyak apabila hujan lebat berlaku. Apabila kapasiti saliran tidak dapat memenuhi jumlah limpasan, akhirnya banjir akan berlaku. Dalam kajian ini, kolam penahan digunakan sebagai alat untuk mengurangkan banjir di kawasan kajian. Sistem saliran di kawasan kajian yang terletak di Diamond City yang terletak di Mukim, Semenyih, Daerah Hulu Langat, Selangor Darul Ehsan dimodelkan dan disimulasikan dengan menggunakan EPA Storm Water Management Model (SWMM). Objektif kajian ini adalah untuk melakukan pemodelan SWMM pada sistem saliran di Diamond City, menilai kecekapan sistem saliran untuk ARI tahun yang berbeza dan juga menilai kecekapan kolam penahan dalam kajian adalah untuk ARI tahun yang berlainan. SWMM banyak digunakan dalam merancang, menganalisis dan merancang sistem saliran bandar. Faktor memilih kawasan kajian tersebut adalah kerana ia lebih mudah dilanda banjir. Berdasarkan pengiraan, masa kepekatan adalah 21.93 minit di mana masa aliran darat adalah 5.92 minit dan masa aliran longkang adalah 16.01 minit. Oleh itu, tempoh ribut selama 30 minit digunakan. Berdasarkan hasilnya, aliran puncak pada aliran keluar sistem saliran adalah 4.46 m^3/s pada 100 tahun ARI sementara aliran puncak pada 10 tahun ARI adalah 3.85 m^3/s. Kajian ini juga menunjukkan kolam penahan mencapai peratusan pengurangan aliran dalam linkungan 90%.

MODELLING SUSTAINABLE URBAN STORMWATER SYSTEM IN DIAMOND CITY USING SWMM

ABSTRACT

The urbanization process leads to a higher possibility of flooding. As the land use has changed from pervious to impervious surface, the natural infiltration of stormwater into the ground becomes lesser. The change of land use causes more surface runoff when there is heavy rainfall. When the drainage capacity is incapable of catering to the volume of runoff, the flood will occur eventually. In this study, the retention pond is used as a device to mitigate flooding from happening in the study area. The drainage system in the study area located in Diamond City in Mukim, Semenyih, Daerah Hulu Langat, Selangor Darul Ehsan is modeled and simulated using EPA Storm Water Management Model (SWMM). The objectives of the study are to conduct SWMM modelling on the drainage system in Diamond City, evaluate the efficiency of the drainage system for different years ARI, and evaluate the efficiency of retention ponds in the study area for different years ARI. SWMM is widely used in planning, analysis, and designing urban drainage systems. The main reason for the chosen study area is largely due that it is very susceptible to flooding. Based on the calculation, the time of concentration is 21.93minutes where the overland flow time is 5.92 minutes and the drain flow time is 16.01 minutes. Hence, a 30-minutes storm duration is used. Based on the result, the peak flow at the outfall of the drainage system is 4.46 m^3/s for 100 years ARI while the peak flow for 10 years ARI is 3.85 m^3/s. The higher the ARI, the drainage system is more susceptible to overflow or flooding. The result also shows the percentage of flow attenuation of the retention pond is around 90%.

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LIST OF ABBREVIATIONS

ARI	Average Recurrence Interval
BMPs	Best Management Practices
CMS	Cubic Meter Per Second
EPA	Environmental Protection Agency
DID	Department of Irrigation and Drainage
IDF	Intensity-Duration-Frequency
MSMA	Manual Saliran Mesra Alam
PSD	Permissible Site Discharge
SSR	Site Storage Requirements
SWMM	Storm Water Management Model

LIST OF SYMBOLS

i	Average Rainfall Intensity
n^*	Horton's Roughness Value for Surface
d	Storm Duration
n	Manning's Roughness Coefficient
T	Average Recurrence Interval
t_c	Time of Concentration
t_o	Overland Flow Time
t_d	Channelized Flow Time
L	Overland Sheet Flow Path Length
S	The slope of overland surfaces
R	Hydraulic Radius
A_o	Area of Orifice
Cd	Orifice Drainage Coefficient
H_o	Effective Head on the Orifice from the Centroid of the Opening
g	Acceleration due to Gravity
B	Width of the Broad-Crested Weir
H	Height of Broad-Crested Weir
Q_d	Peak Discharge
C_{BCW}	Coefficient of Discharge from Broad-Crested Weir

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In Malaysia society, there is an exponential population growth over time. Based on the Department of Statistics Malaysia, Malaysia's population in 2020 is estimated to have 32.7 million and it has an annual growth rate of 0.4%. Malaysia is an upper-middle-income country that is developed and most of its population chooses to live in cities to achieve high-income status. Hence, urbanization which is a prerequisite in developing our country has been increasing tremendously along with the increase in human proportion. Urbanization is the change of land use such as the change from rural uses to urban development. The removal of vegetation and soil due to urbanization will alter the land's natural hydrology and infiltration characteristics (Engineering *et al.*, 2002).

Urban development causes an increment in impervious areas. This will then result in lower infiltration characteristics. Manning's coefficient of land use is increased. The increase in Manning's coefficient triggers an increase in rainfall-runoff volume and discharge rate. Consequently, the peak discharge increases. Flood commonly happens when the volume of runoff has exceeded the drainage capacity and infiltration rate. The factors that influence the peak discharge of flood are the intensity and duration of storms, vegetation, and the geology and topography of stream basins (Konrad, 2003).

Drainage systems play a vital role in channeling surface runoff away from developed areas to rivers or agricultural irrigation canals. Meanwhile, sustainable urban drainage is a system that considers the social and environmental factors while designing the drainage systems (Zakaria, Engineering and Drainage, 2004). The sustainable urban drainage system can reduce the impact of urbanization on flooding by managing the runoff flow rates.

Stormwater facilities are fundamental in preventing streams from erosion and pollution which are due to development activities. A retention pond is a facility that controls the stormwater quantity which is due to larger urbanizing catchments (DID,2012). Retention ponds can store surface runoff temporarily and discharge it through a control structure to avoid the urban area from flooding. The size of the retention pond mainly depends on the pre-and post-development rate. The factors to be considered in designing the dry retention pond are land area, contributing area, and slope of the site. By introducing a retention pond into the development site, the water flows slowly and stores in it temporarily for a short time. Usually, urban areas depend on the use of retention ponds to decrease the peak runoff rates. The function of the control device found in the pond is to maintain the discharge of stormwater equal to the pre-development rate.

EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff model which can simulate the quantity and quality of surface runoff from urban areas (Ermalizar and Junaidi, 2018). SWMM modelling tools can provide a valid outcome in modelling hydrologic processes for urban water management (Tang *et al.*, 2021). This model is also broadly used for planning analysis and designing urban drainage systems (Gironás *et al.*, 2010)

1.2 Problem Statement

Malaysia is a country that lies in a geographically stable region since the location of Malaysia is not within the “Pacific Ring of Fire” zone. Hence, Malaysia is safe from natural catastrophes such as volcanoes and earthquakes. However, floods often overwhelm our country. Most floods occur when the drainage system cannot properly channel the water in the cyclical monsoons (Bhuiyan *et al.*, 2018). On 19 July 2020, Selangor Disaster Management Unit chief Ahmad Fairuz Mohd Yusof said Hulu Langat is the district that experiences the worst flooding. In Hulu Langat, the Semenyih River is the main contributing factor that triggers floods during heavy rain.

Besides, the flooding in urban areas may also be due to the limited or temporarily decreased efficiency of surface drainage although the storm sewer is designed appropriately (Palla *et al.*, 2018). Unpredictable clogging can also lead to flooding although the internal capacity of drainage is exceeded. The occurrence of flood brings tremendous adverse effect to public safety, residents’ property and health, drinking water, and aquatic life.

The government spent a huge amount of money to mitigate floods in urban and rural areas. Engineers should understand the relationship between rapid development and drain stability in designing the drainage system using models and guidelines to mitigate downstream flooding by addressing the control at the source. Hence, it is vital to utilize SWMM software to study the simulation and modelling of the drainage system chosen development area located in Diamond City near to Semenyih River. Apart from that, the effectiveness of retention pond is evaluated by using the SWMM software to mitigate flooding.

1.3 Objective

The research aims to determine the effectiveness of retention ponds on the housing area in Diamond City. The specific objectives are:

- To evaluate the effectiveness of drainage system of Diamond City for 10, 50, and 100 years ARI using SWMM model
- To determine runoff quantity control of retention pond for 10, 50, and 100 years ARI

1.4 Scope of Work

This study aims to determine the effectiveness of the drainage system with the implementation of retention ponds for the selected parcels, which are Parcel 1, 2, 3, 4, and 5 in the Diamond City housing area. The data obtained are the drainage layout of the study area, length, and size of the drain as well as the invert level of each node for the drainage system. After obtaining the data, the time of concentration is calculated to determine the intensity of rainfall in the study area. SWMM software is then used to model and simulate the data and study the runoff hydrograph with the implementation of the retention ponds.

1.5 Dissertation Outline

The dissertation comprises five chapters. Chapter one is to introduce the sustainable urban stormwater system, problem statement, objective, and scope of works. Chapter two describes the literature review and relevant research that have been studied. Meanwhile, Chapter three explains the research methodology and procedure to simulate SWMM by using the data collected. Chapter four highlights the result and discussion of the analysis done from the SWMM simulation. Lastly, Chapter five covers the study conducted and states some suggestions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Rapid urbanization has brought water quantity issues. Urban development often changes the natural underlying surface condition. The changes cause interruption of the original vegetation cover, reduce the amount of infiltration and increase the amount of runoff. These will then trigger flooding and inundation. Precipitation processes play an important role in constructing the drainage system, especially in urban areas. The hydrological cycle has three main parts which are precipitation, evaporation, and condensation. Precipitation happens when there is a condensation of water vapor which becomes larger droplets of water. As the water droplets accumulate and become large enough to drop from cloud, rain, hail, sleet or snow takes place. The amount of precipitation varies throughout the world, in a country and even in a city. The hydrological cycle along with global warming can increase the amount of extreme precipitation (Tabari, 2020). The risk of flooding becomes even higher when the drainage system is built improperly.

Urban runoff is surface runoff which is due to excess rainfall and an increase in the size of impervious areas. Raining water infiltrates into the ground soil until the rate of rainfall goes beyond the limit of the soil's infiltration capacity. This will generate urban runoff once the flow of water can no longer be released. The source of flooding and water pollution largely comes from urban runoff. As the surface imperviousness increases in urban area, a higher runoff volume will be generated from the evapotranspiration and infiltration (Lee *et al.*, 2018). As urban development increases the direct runoff, so does the average recurrence interval (ARI).

2.2 Urban Stormwater Management

Since urban development becomes rapid, impervious surfaces increase. Water quality issues which are caused by the pollutants washed from residential areas to rivers become a great concern. Hence, it is important to design drainage systems well. A stormwater drainage system consists of gutters, open drains, pipes, and overland flow paths. The drainage system will drain and remove surface water flow from the development area. The design of the drainage system allows the maintenance activities to be done without any damage to the other assets. To make sure that the drainage system can perform satisfactorily, the design of the drainage system must be according to appropriate ARIs and storm durations. Proper construction of an urban drainage system in cities can mitigate the nuisance from flooding by removing the runoff from urban areas fast (Yazdanfar and Sharma, 2015). A flood can bring health issues, property losses, and even casualty.

The stormwater can infiltrate into the soil, stay stagnant on the surface and evaporate or run off to a nearby stream. Before any development is done, the stormwater will soak into the soil or evaporate. During torrential rain, runoff that is flowing on the ground becomes slowed since it is filtered by plants. On the contrary, as more development occurs, the runoff is channeled to stream via the storm drainage system very fast. However, this scenario will decrease the natural processes of infiltration, evaporation, and filtering. Eventually, the quantity and speed of stormwater runoff will increase tremendously. As a result, the development area becomes vulnerable to flood.

Stormwater management is the mechanism that minimizes the flow rates in catchments, surface water volumes, recurrence of flooding, and decline in surface water quality by controlling stormwater runoff to reduce the effect of land-use changes

(DID,2012). The stormwater system is divided into major and minor systems. Minor system facilities are swales, gutters, on-site detention, bio-retention, and the best management practices that accumulate, store and channel runoff to the stream. The size of the minor quantity system is according to the surface water produced by the incessant short-duration rainfall. The major system consists of natural streams, channels, community and regional ponds, wetlands, lakes as well as culverts. The volume of stormwater generated by the occasional long-duration rainfall determines the criteria for designing the major quantity system.

Stormwater management aims to control the runoff quantity for new development or redevelopment projects. Urban development is the change of rural areas into manufacturing infrastructure and utility development. Meanwhile, the definition of redevelopment is the re-establishment and reconstruction of residential, economic, industrial, or infrastructure area which is already built. The type of development or redevelopment project determines the performance of runoff quantity control requirements. For any ARI circumstances, the post-development peak should be lower than or equivalent to the pre-development peak flow. The amount of discharge at the outlet increases in a short duration as the urban development area increases. The objective of stormwater management is to mitigate flooding by decreasing the post-development peak discharge until it is equal to or less than the pre-development condition with the use of detention or retention facilities.

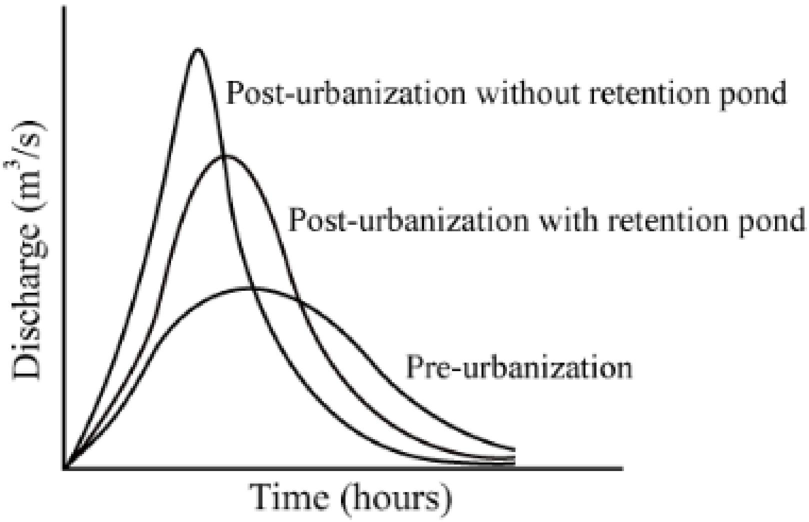


Figure 2.1: Hydrograph Schematic (Ensley and Hancock, 2019)

2.3 Rainfall Estimation

Rainfall estimation studies and designs require rainfall data and characteristics. To prepare proper drainage and stormwater management in a residential area, an appropriate and significant rainfall design is needed (DID,2012). The frequency, duration, and intensity analyses of rainfall data are the important element for rainfall estimation

2.3.1 Average Recurrence Interval

The average recurrence interval (ARI) is the average duration of time between exceedances of a specific rainfall depth for a specific period and location (DID,2012). An ARI can be presented in terms of probability. As the ARI is an average rainfall amount, it can approximate the probability or percent chance of the rainfall occurring in any given year. Sometimes, an ARI is also known as the return period. The main economy and level of conservation determine the selection of the design ARI of a drainage runoff facility. The ARI of rainfall is a good measure of flooding potential.

2.3.2 Time of Concentration

Time of concentration, tc is the sum of an initial time or overland flow time and the channelized flow travel time through the storm drain, ditch, channel, or paved gutter (Specialist, Area, and January 2006). Apart from that, the time of concentration is also known as the duration required for the surface water to move from the furthest hydraulic distant point to the outlet. The furthest hydraulic distant point is the point in which its travel time of runoff to the outlet is the longest. The slope, watershed character, and flow path are the factors that alter the time of concentration. We also can determine the time of concentration by taking the time from the end node of the excess rainfall to the node on the decreasing curve of the unit hydrograph. The hydraulic properties of the conveyance element can help the estimation of the time of concentration. The equation of tc is shown below:

$$t_c = t_o + t_d \tag{2.1}$$

where,

t_o = Overland flow time (minutes)

t_d = channelized flow time (minutes)

Overland flow time, t_o is the duration of the movement of runoff over the land downslope to the surface water body. It can be categorized into sheet flow travel time and shallow travel time (Vara and Ganti, 2018). The maximum flow distance, surface roughness, surface slope, rainfall intensity, and infiltration rate can affect the time of concentration for overland flow. The values of Horton’s Roughness, n* which is dependent on the land surface are shown in Table 2.1. The equation of t_o is given below:

$$t_o = \frac{107.n\, L^{\frac{1}{3}}}{S^{\frac{1}{5}}} \tag{2.2}$$

where,

L = Overland sheet flow path length (m)

n* = Horton’s roughness value for the surface

for Steep Slope (>10%), L ≤50m

for Moderate Slope (<5%), L ≤100m

for Mild Slope (<1%), L ≤200m

S = Slope of overland surfaces (%)

Table 2.1: 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	0.060

Channelized flow time, t_d is determined by the hydraulic properties of the conveyance system. The channelized flow time can be calculated by dividing the length of conveyance by velocity. Each type of drain or pipe has its value of Manning's roughness coefficient respectively. It has been shown in Table 2.2. The equation is given below:

$$t_d = \frac{n.L}{60.R^{\frac{2}{3}}.S^{\frac{1}{2}}} \tag{2.3}$$

where,

n = Manning's roughness coefficient (Table 2.2)

R= Hydraulic radius (m)

S= Friction slope (m/m)

L= Length of reach (m)

Table 2.2: Values 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)	0.050
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 Masonry	0.035
Rock Riprap	0.030
Brickwork	0.020
Pipe Material	
Vitrified Clay	0.012
Spun Precast Concrete	0.013
Fibre Reinforced Cement	0.013
UPVC	0.011

2.3.3 Rainfall Intensity

Rainfall intensity is the average rainfall rate for the period of maximum rainfall with a length of time equals to the time of concentration (Specialist, Area and January 2006). Rainfall intensity can also be described as the ratio of the total amount of rainfall to the length of the period. Rainfall intensity is usually expressed in terms of depth units per unit time which is mm per hour (mm/hr). The estimation of rainfall intensity can be calculated as shown below:

$$i = \frac{\lambda T^{k}}{(d+\theta)^{\eta}} \tag{2.4}$$

where,

i = Average rainfall intensity (mm/hr)

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

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

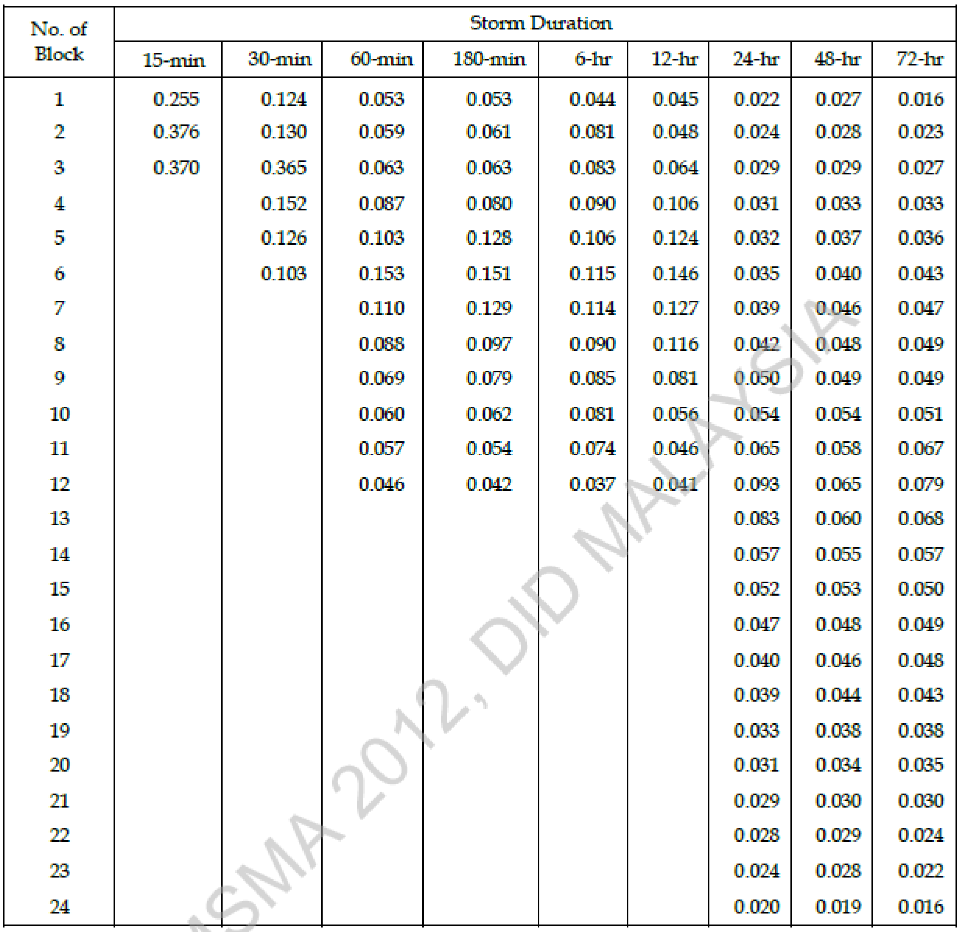
λ, k, θ, and η = Fitting constant dependent on the rain gauge location

The rainfall intensity-duration-frequency curves are often used for the planning, design, and operation of hydraulic infrastructures. The IDF curves can be affected by the increase in rainfall intensity and frequency. IDF curves show the probability of known average rainfall intensity for a duration of time. Long-term historical rainfall observations are required to derive the IDF curves. The Intensity-Duration-Frequency (IDF) fitting constant for the locations in Selangor is shown in Table 2.3 while the rainfall hyetograph derivation using uniform temporal pattern design is shown in Table 2.4.

Table 2.3: Fitting Constant for the IDF Empirical Equation for the Different Locations in Malaysia for High 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
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 2.4: Normalised 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

2.3.4 Runoff Coefficient

The runoff coefficient, C is a parameter that shows the capability of the drainage area to change rainfall to surface water (Thomas A. Seybert, 2006). It is presented in a number between 0 and 1. The coefficient was originally taken as a factor of ground surface only and it is not dependent on rainfall intensity and other watershed factors. There are different types of factors that affect the runoff coefficient. Those factors are infiltration losses, catchment storage, the precursor of wetness, and the physical characteristics of the catchment.

In hydrological runoff modelling, land use can be defined in many ways. Assigning a runoff coefficient to the use of land is a common method in defining land use. The runoff coefficient can be divided into two methods which are the rational method and the NRCS runoff curve number method (Thomas A. Seybert, 2006). For the Rational Method, the runoff coefficient, coefficient with 0 represents there is no runoff on the ground surface while 1 is the situation where all rainfall is generated to surface water. In the NRCS curve number method, a curve number (CN) is given to a certain soil cover complex. The range of CN values is from 40 to 98, where 98 is the situation that has a very high possibility of runoff and 40 is the situation that has a very low possibility of a runoff.

A few methods have been developed to present the values of the runoff coefficient. The runoff coefficient can be presented in tabular selection tables and simple recommended values. All these methods are based on engineering judgments, experiences as well as observed flood data. Table 2.5 shows the average runoff coefficient for different land use of both major and minor systems using rational methods.

Table 2.5: Recommended Runoff Coefficient for Various Land use (DID,2012)

Land use	Runoff Coefficient (C)	
	For Minor System (< 10- year ARI)	For Major System (>10-year ARI)
Residential		
Bungalow	0.65	0.70
Semi-detached Bungalow	0.70	0.75
Link and Terrace House	0.80	0.90
Flat and Apartment	0.80	0.85
Condominium	0.75	0.80
Commercial and Business Centres	0.90	0.95
Industrial	0.90	0.95
Sports Fields, Park, and Agriculture	0.3	0.4
Open Spaces		
Bare Soil (No Cover)	0.50	0.60
Grass Cover	0.40	0.50
Brush Cover	0.35	0.45
Forest Cover	0.30	0.40
Roads and Highways	0.95	0.95
Water Body (Pond)		
Retention pond (with outlet)	0.95	0.95
Retention Pond (no outlet)	0.00	0.00

2.4 Retention pond

The land area functions as a rainforest catchment to absorb most of the rainwater into the groundwater table before any development is done. Deforestation for the construction of roads, buildings, and shopping complexes results in low permeability of the surface terrain. This causes the surface runoff to increase. Problems like flash floods and erosion may happen. To tackle the problems, a retention pond is recommended to be constructed.

Retention ponds are one of the best management practices (BMPs). It can decrease the peak flow or increase the period of the discharge flows to remunerate for the high volume of runoff (Ensley and Hancock, 2019). Besides, retention ponds can fit in a limited land space of urban areas. A well-designed retention pond will provide aesthetic, amenity, and ecological benefits to the urban landscape too (NWRM, 2013). However, the purpose of retention ponds is mostly to prevent the adverse condition of the rising volume of surface water which is caused by urban development (Ensley and Hancock, 2019).

Retention ponds mitigate flooding by controlling stormwater quantity impacts from the large urbanizing catchment. Apart from that, retention ponds are considered a sound way to improve the stormwater quantity and quality and promote increased infiltration. The design of ponds can control runoff from all storms by retaining surface drainage and discharge it at a proper rate when there is no more risk of flooding (NWRM, 2013). The characteristics of the pond’s contributing drainage area, design factors and maintenance factors can govern the water quality treatment effects of retention ponds (Nayeb Yazdi *et al.*, 2021).

A retention pond can provide stormwater attenuation by storing runoff and discharge it at a controlled rate (NWRM, 2013). The implementation of retention ponds results in the outflow hydrograph that its peak discharge is lower than the inflow hydrograph. In other words, the implementation of a retention system can decrease the hypothetical site’s runoff hydrograph to a peak discharge which is equal to the predetermined maximum allowable release rate. Hence, the risk of flash floods decreases. The reason why retention ponds are widely used to mitigate flooding is mainly that the design of the pond is simple and the price of construction is relatively cheap (McPhillips and Matsler, 2018).

The regulations for retention pond construction can be divided into two types which are peak standards and duration standards (Ensley and Hancock, 2019). The objective of the peak standard is to evaluate the ability of retention ponds to decrease the maximum post-urbanization outflow to the value of the pre-urbanization peak flow. Meanwhile, the period standards are to decrease the period of sediment-transporting flows in post-urbanization flows to that of pre-urbanization sediment-transporting discharges. Hancock et al. (2010) state that the construction of retention ponds must follow both standards.

2.4.1 Above-ground storage

The above-ground storage consists of a depressed or excavated area on the land surface. These types of ponds do not require an earthen dam or berm. The above-ground storages can be placed on the rooftop, lawns, gardens, car park, and driveway. The main benefits of this type of storages are that they can be fixed into any development area easily and relatively cheaper than below-ground storages. To avoid drowning, safety tools such as signboards and fencing should be installed for above-ground storage.

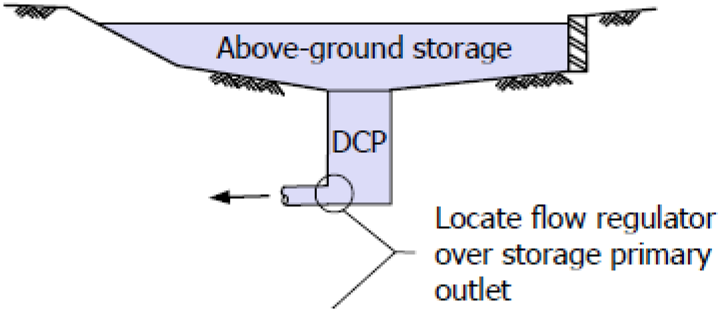


Figure 2.2: Illustration of Above-ground Storage Tank (DID, 2012.)

Table 2.6: Recommended Maximum Storage Depth for Various Land use (DID,2012)

Site Classes	Maximum Storage Depth
Pedestrian Areas	50mm
Parking Areas and Driveways	150mm
Landscaped Areas	600mm
Rooftops	300mm

2.4.2 Below-ground storage

Development can be strengthened by preparing a small quantity of the required storage volume underground. This small size of storage can limit the frequency of ponding water in an above-ground storage area. Although in difficult topography, it is also suitable to install below-ground storage. However, the cost of building below-ground storage is higher than above-ground storage systems. This kind of storage is difficult to inspect for silt accumulation, difficult to maintain, and can be dangerous in maintaining the pond. The regulation requirements for working in restricted spaces should be paid attention to by designers. The requirement for workers to walk in the storage space for examination and maintenance tasks should be minimized by the design.

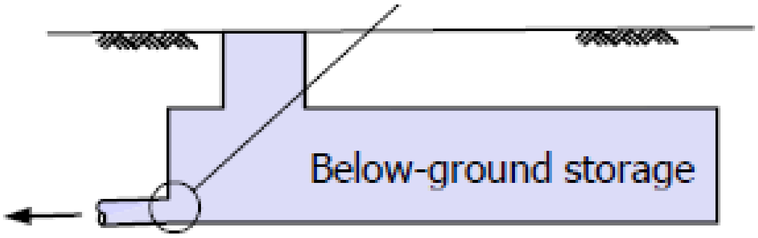


Figure 2.3: Typical Below-ground Storage Tank (DID, 2012.)

2.4.3 Permissible Site Discharge (PSD)

The PSD is the maximum admissible post-development outflow from a development area for a chosen design storm and is approximated on the basis that no increase in the flows within the downstream stormwater drainage system (DID,2012). The unit of the admissible peak discharge for the site used is in litres/second/hectare (l/s/ha) or in litres/second (l/s). Table 2.6 depicts the inlet dimension which represents the PSD capacity. Besides the Figure 2.4 shows the parameter which the Peninsula Malaysia can be categorized into five design regions with different uniform design storms.

2.4.4 Site Storage Requirement (SSR)

The SSR is the capacity of storage needed to maintain the required PSD is not beyond the limit and the retention pond does not undergo surcharge according to the storage design storm ARI (DID,2012). The unit used for SSR is in meter cube/ hectare (m³/ha). Table 2.6 shows the various sizes of retention ponds as well as their inlet and outlet structures. To find the dimension of the storage, requires project area, the slope of the terrain, and percentage of impervious area.

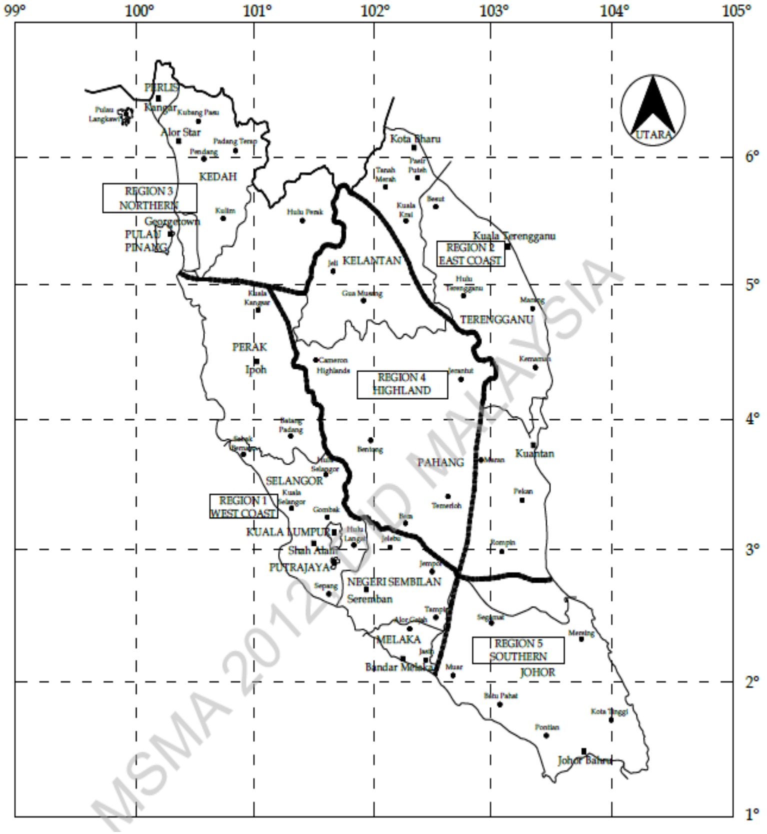


Figure 2.4: Five Design Region (DID,2012)

Table 2.7: Example of Maximum Permissible Site Discharge (PSD) and Minimum Site Storage Requirement (SSR) Values for Region 1-West Coast following the Five Regions in Peninsular Malaysia (DID,2012)

Terrain/ Slope Condition	**PSD (l/s/ha)**					**SSR (m^3/ha)**				
	Impervious Area (As a Percentage of Project Area)									
	25%	**40%**	**50%**	**75%**	**90%**	**25%**	**40%**	**50%**	**75%**	**90%**
Region 1- West Coast										
Low lying	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

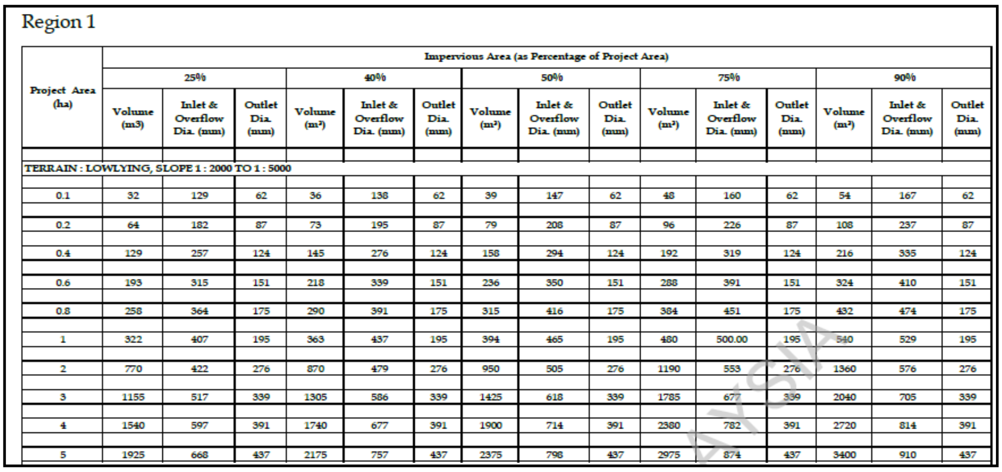
2.4.5 Inlet and Outlet Size

The inlet and outlet structures of stormwater retention ponds play a vital part in maintaining the level of pond water and preventing flooding in development areas. The inlet structure of the retention pond is the open drain that receives surface water from impervious covers such as roads and roofs into the retention pond. Meanwhile, the outlet structure is where the water is released gradually to the downstream monsoon drain. The determination of proper inlet and outlet size of retention ponds is imperative in developing an urban area (DID,2012). The size of the outlet structure commonly is smaller than the size of the inlet structure. The smaller outlet size is to decreases the discharge. Table 2.7 shows the minimum inlet and outlet structure size which depends on the five regions in Peninsular Malaysia. Since the reduced level of the study area is flat, mild terrain is chosen.

A retention pond can be prone to flooding when the inlet and outlet structures filled with trash, vegetation, and sediment cause blockage of water flow. Hence, it is important to keep the inlet and outlet structure clear so that the retention ponds can manage stormwater efficiently.

Table 2.8: Retention pond Volume, Inlet Size and Outlet Size for Five Different Regions in Peninsular Malaysia (DID,2012)

Region 1



Region 1

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 : LOWLYING, SLOPE 1 : 2000 TO 1 : 5000															
0.1	32	129	62	36	138	62	39	147	62	48	160	62	54	167	62
0.2	64	182	87	73	195	87	79	208	87	96	226	87	108	237	87
0.4	129	257	124	145	276	124	158	294	124	192	319	124	216	335	124
0.6	193	315	151	218	339	151	236	350	151	288	391	151	324	410	151
0.8	258	364	175	290	391	175	315	416	175	384	451	175	432	474	175
1	322	407	195	363	437	195	394	465	195	480	500.00	195	540	529	195
2	770	422	276	870	479	276	950	505	276	1190	553	276	1360	576	276
3	1155	517	339	1305	586	339	1425	618	339	1785	677	339	2040	705	339
4	1540	597	391	1740	677	391	1900	714	391	2380	782	391	2720	814	391
5	1925	668	437	2175	757	437	2375	798	437	2975	874	437	3400	910	437