MONASH University

HYDROLOGICAL IMPACTS OF LAND USE CHANGE ON STREAMFLOW QUANTITY IN A SUB-CATCHMENT OF KLANG BASIN

ONG HON LIM

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signature: …[redacted]

Print Name: ONG HON LIM

Date: 19 OCTOBER 2017

Abstract

Asian countries such as eastern coastal China have experienced rapid industrialization and urbanization and this situation has also occurred in Malaysia. In the mid-1980s, Malaysia has experienced rapid urbanization and increase in its urban population. The impact on the process of urbanization and urban growth in the developing countries such as Malaysia has taken place with the expansion of the industrial sector. The transformation of forested catchment to urbanized cone which practically is to change the pervious surfaces to impervious surfaces is known to be one of the sources of drastic change in hydrological characteristics of the catchments. The high proportion of densely developed area greatly reduces the amount of water infiltrating into the soil and, consequently, most rainfall is converted to run-off. The present study aims to characterize the impact of urbanization on hydrological characteristics in an urbanized tropical catchments. A catchment from Klang Valley, Malaysia, Sungai Dua Besar river basin is chosen as the study catchment to assess the land use change and its impact in a time frame from year 1966 to 2020. The land use maps on four specific snap shots namely 1966, 1984, 2002, and 2010 are used to capture the trend in land use change. The land use for year 2020 is predicted using re-adjusted land use prediction model by government. Then a hydrological/hydraulic model was developed to implement the land use change effect in terms of hydrological characteristic of catchment specifically flood-related parameters such as flood peak and flood extent areas. Finally, using the calibrated/validated hydraulic model water level was estimated for different rainfall duration and frequency. Digital Elevation Model (DEM) data was used to identify the inundated areas for different Average Recurrence Interval (ARI) for years 2010 and 2020. Comparison showed that catchment inundation area in 2020 is 6.6, 4.7 and 3.0 percent higher than 2010 for 20, 50, 100- years ARI. It was concluded that the results of this study can be utilized for catchment land use management plans.

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Table of Contents

CHAPTER 6 – HYDRAULIC MODEL DEVELOPMENT

CHAPTER 7 – RIVER FLOOD MODELLING

CHAPTER 8 – SUMMARY AND CONCLUSION

Appendices

List of Figures

List of Tables

List of Symbols

Symbol	Description
n	Manning's n value
Fo	Maximum infiltration rate
Fp	Infiltration rate into soil
Fc	Minimum or asymtopic value of Fp
t	Time from beginning of storm
k	Decay coefficient
Dp	Depression storage
S	Catchment slope, percent
ZD	Zero detention
R^2	Coefficient of determination
y	Simulated flow
x	Observed flow
CE	Nash-Sutcliffe Coefficient of efficiency
X_{obs}	Observed flow rate
X_{est}	Simulated flow rate
$X_{avg.obs}$	Average value (mean value) of the observed flow rate
RPE	Relative peak error
Q_p	Peak flow
RMSE	Root mean square error
MAE	Mean absolute error
fi	Prediction value
yi	True value
Y	Urbanized area 2020

Symbol	Description
X	Number of years in land use
HAT	Highest astronomical tide
MHWS	Mean high water spring
MHWN	Mean high water neaps
MSL	Mean sea level
MLWS	Mean low water spring
MLWN	Mean low water neaps
LAT	Lowest astronomical tide
Tc	Time of concentration

CHAPTER 1
INTRODUCTION

1.1 Background

Urban development increases flood risk in cities due to local changes in hydrological and hydro meteorological conditions. The relationship between the increasing urban runoff and flooding due to increased imperviousness is better perceived than that between the cyclic impact of urban growth and the urban rainfall via microclimatic changes (Huong and Pathirana, 2013).

Urbanization invariably increases the flood risk as a result of heightened vulnerability stemming from population concentration, wealth growth, and increasing infrastructures (Taisuke et al., 2009). Flood hazard also increases by hydrological and hydroclimatological changes brought about by the land use and microclimatic changes driven by urbanization (WMO/GWP, 2008). The hydrological changes that result in urban flooding are long understood and quantified. The climate variability and change have direct consequences on global flood hazard (Milly et al., 2008). The increased frequency of occurrence of flood events in the world is partially attributed to climate change-driven increase of extreme precipitation (IPCC, 2002, 2007).

Malaysia is different in terms of climate compared to other regions such as Australia and European countries as Malaysia is a tropical climate country and has high intensity rainfall events. This can lead to flooding especially in urban areas where land surface is covered with impervious materials. With the increasing rate of urbanization, Malaysia as one of the developing countries in tropical region (with high rainfall intensity) has higher chance of being flooded.

The Malaysian society is rapidly transforming into an urban society (Norhaslina Hassan, 2009). Urbanization is a continuous process of population concentration in cities and metropolitan areas which plays an important role in the development and modernization of society (United Nations, 1987).

Although rapid industrialization has been relatively well-planned and regulated, it has generated an increase in pressure on urban areas especially in the Klang River Basin which is the most densely populated area of the country. With an estimated population of over 4.4 million (about 16 percent of the national population), and growing at almost 5 percent per year, the Klang River Basin has experienced the highest economic growth in the country (ADB, 2007). The increased numbers of commercial lots, industrial estates and housing areas have overtaken the ability of current drainage system to convey and store water especially during heavy storms. For Klang district, the problem of runoff, drainage and flooding has emerged in new dimensions with adverse impacts on landscape, vegetative cover, receiving waters and catchment values. As a result the Klang district is facing serious impacts such as flooding generated from continuous land use changes.

Therefore, it is important to study the potential flooding impact of such continuous change in land use. This case study aims to understand land use changes in an urbanized topical catchment in Klang Valley and evaluate the potential impacts of land use change of flood-prone areas. In this study a hydrologic-hydraulic model is developed to predict the flood prone areas in the study catchment for different scenarios of land use change and design rainfall.

1.2 Problem Statement

In Malaysia, rivers have been known to be one of the important water resources in our life including animals, plants and aquatic organisms. It has provided water supplies for the population and industry, a means of navigation route for materials and commences (Neal et al., 2006). Nowadays, the functions of the river have been disturbed due to urbanization which gives rise to increase in population and urban life activities. Most of the river pollution issues in Malaysia arise from inadequately controlled development and activities in the river basin. This can dramatically bring negative impact in the runoff quality within catchments. The runoff in urbanized areas washes down contaminants accumulated on land surfaces into the drainage system before they are transported to the receiving waters.

Rapid industrialization, although relatively well-planned and regulated, has generated an increase in the pressure on urban areas especially in the Klang River

Basin, the most densely populated area of the country. With an estimated population of over 4.4 million (about 16 percent of the national population), and growing at almost 5 percent per year, the Klang River Basin has experienced the highest economic growth in the country (ADB, 2007). The increased numbers of commercial lots, industrial estates and housing areas have overtaken the ability of current drainage system to convey and store water especially during heavy storms. For Klang district, the problem of runoff, drainage and flooding has emerged in new dimensions with adverse impacts on landscape, vegetative cover, receiving waters and catchment values. As a result, the Klang district is facing serious impacts generated from continuous land use changes to flooding.

1.3 Research Objectives

The objectives of the research are as follows:

(i) To develop an accurate physically-based rainfall-runoff model calibrated on historical data of the Sungai Dua Besar Catchment (Case Study).

(ii) To characterize the land use change and come out with a projected land use pattern for different future time windows based on national development plans and historical areal maps of the region.

(iii) To employ the calibrated rainfall-runoff model of Phase 1 and the projected future land use to estimate the corresponding discharge and evaluate the impact of such land use change on flood peak and flood extent.

1.4 Scope of study

The scope of study for this research is drawn to describe the structured mechanism of the performance of this research, as well as providing details on the issues and the associated areas to be addressed. The scope of study covers various components consisting of:

1. Data and information collection for the understanding of the present and future conditions within the study area.

2. Analysis on the effect of land use changes towards stormwater flooding problems.

3. Conduct hydrological and hydraulic modelling to investigate the impact of urbanisation to Study area.

1.5 Thesis Content

The thesis consists of eight chapters and brief descriptions of each chapter are as described as below:

Chapter One presents the general information regarding urbanisation issues, problem statement, objectives of the research, scope of study, and the layout of the thesis.

Chapter Two consists of literature review related to the research. It covers the effect of urbanization and how the stormwater research has evolved throughout the years. The information gathered on stormwater management practices, stormwater management facilities and water quantity structural measures performance are also elaborated. This chapter also includes the use of computer models in urban stormwater management and its performance.

Chapter Three outlines the methodology of data collection that has been developed in this study in order to conduct and support the development of hydrological and hydraulic modeling. The different approaches used for hydrological and hydraulic modeling in this research are also signified here.

Chapter Four scrutinizes the results and analysis on urbanization impact based on the changes of landuse.

Chapter Five elaborates on the rainfall runoff model development including the sensitivity analysis, calibration and validation of the model based on certain events.

Chapter Six explains the hydraulic model development with reference to the rainfall runoff model explained earlier in the previous chapter. The calibration and validation results are based on the same events is shown in this chapter.

Chapter Seven outlines the river flood modelling once all the calibration and validation process has been confirmed. The flood extents in 2D map is shown in this chapter.

Chapter Eight highlights the conclusions obtained from the analysis of the results as well as suggesting recommendations for further researches.

1.6 Knowledge Gap

The increasing concern about the hydrological impact of urbanisation which resulted in flooding and damage to public properties has resulted in the implementation of structural and non-structural measures by the local authorities. However, the Research and Development (R&D) on this case in Malaysia is still lacking compared to overseas such as the characteristics of the land use data tabulated for each year provided by the town council. Therefore, this study has been conducted because it is important to compile information on land use change for effective management in the future to be used by the engineers in consulting firm and local authorities.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter reviews the studies that assessed the factors and causes of land use change due to urbanization and the impact of it on the hydrological characteristics of catchments. This literature review will help to reveal the gaps in knowledge about land use change associated with urbanization and the imposed changes in the stream flow regime which in turn can lead to higher flood peaks, volumes, and bigger flood plains. In this chapter, various models related to stormwater runoff quantity analysis (such as DRAINS, DR_3M-QUAL, HSPF, MIKE-SHE, HEC-HMS, STORM and XP-SWMM) are also reviewed to identify the suitable modelling tool for current study.

2.2 Definitions and Concepts of Land Use

Land use refers to the intended use or management of the land cover type by human being. Thus, land use involves both the manner in which the biophysical attributes of land are manipulated and intent underlining that manipulation (the purpose for which the land is used e.g., agriculture, grazing, etc). The land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change, or maintain it. Therefore land use in this way establishes a direct link between land cover and the actions of people in their environment (Di Gregorio and Jansen, 2005). Thus the term land use can be understood as functional dimension (i.e. use) and corresponds to the description of areas in terms of their socio-economic purposes (the way area is used for urban activities, agriculture, forestry etc.) (Mattila et al., 2011).

2.3 Factors/ Causes of Land Use Change

Land use is constrained by environmental factors such as soil characteristics, climate, topography, and vegetation. It is also reflects the importance of land as a key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and catchment water storage. Land is a fundamental factor of production and through much of the course of human history it has been tightly coupled to economic growth. As a result, control over land and its use is often an object of intense human interactions. Human activities that make use of or maintain attributes of land cover are considered as the primary cause to the changes in the surface of land. Studying about these changes requires a multi-disciplinary approach that is conducted in the field social and natural sciences (Keken et al., 2015). Land use changes are very important and they are probably the main cause of global changes in environment. To date, human activities have been the major contributor or cause of land use changes in the world (Geri et al., 2010).

(Ouyang et al., 2009) claimed that human-induced land use changes can entail drastic impacts on structure and composition of regional landscape which in turn may have serious impact on biodiversity and quality of the local environment. By dominant economic development and ongoing population growth, human activities are growing exponentially and quickly altering the landscape. The most dominant changes that occur to the landscape include urbanization, deforestation, irrigation, road building, animal husbandry, and agriculture augmentation. Humans have a uniquely dominant influence over land worldwide. Changes in surface of land and landscape undoubtedly can change the function and structure of ecosystems and influence regional and global climate, hydrology, vegetation, biogeochemical cycles, and biodiversity (Wan et al., 2015). Changes in land use have potentially large impacts on water resources, yet quantifying these impacts remain among the most challenging problems in hydrology (Costa et al., 2003; Stonestrom et al., 2009).

Nowadays, continual rapid change of land use is common in developing tropical countries. It is controlled by the potential value of the land for agricultural, forest, urban, or nature protection uses and is governed by multilevel economic and socio- cultural interactions (Niehoff et al., 2002). These countries such as Malaysia, Indonesia, Thailand, and Philippines utilize land either for economic development such as agriculture expansion or urbanisation or for daily subsistence through such practices of shifting agriculture (Abdullah and Nakagoshi, 2006). Improper land use development may interfere with ecological processes that determine the functioning of land cover and this can have drastic effects on different components of the hydrological cycle and soil erosion (Arnell, 1989; Veldkamp and Fresco, 1996). (Natkhin et al., 2015) concluded that land use and climate changes have had an impact on the run-off characteristic of the Ngerengere River in Tanzania during recent years. Moreover, (Hamilton and King, 1983) and (Hamilton and Pearce, 1987) showed that the removal of forest cover from a watershed can result in significant hydrological changes including a decrease in evapotranspiration and interception of rainfall by the tree canopy (increased net precipitation) and also an increase in surface litter and runoff volume. The latter is one of the major causes of local flash floods.

Malaysia has been experiencing extensive land use change associated with government development policies. In the 1960s and 1980s, Malaysian economic development was mainly based on the agricultural sector. During this time, approximately 28,000 km^2 (13%) of the forested areas were converted into agricultural land, especially for oil palm and rubber plantations. In the 1980's, there was a major economic transformation to focus on the manufacturing sector. By 1987, this sector became the fastest growing sector and its growth rate exceeded that of the agricultural sector to account for 22.6% of the country’s gross domestic product, GDP (Economic Planning Unit Malaysia, 2004). As a result, there has been an increased demand for land, which has involved further removal of permanent forest reserves. All of these changes have been identified as major causes of environmental degradation in Malaysia (Jamaluddin, 2000).

2.4 Assessment of Land Use Changes

Land use changes have potentially large impacts on water resources (Stonestrom et al., 2009). Rapid socio-economic development drives land use changes, which include changes of land use classes, e.g., conversion of cropland to urban area due to urbanization, as well as changes within classes such as a change of crops or crop rotations (Wagner et al., 2013).

In a longer period globally, nearly 1.2 million km^2 of forest and woodland and 5.6 million km^2 of grassland and pasture have been converted to other uses while cropland has increased by 12 million km^2 during the last 3 centuries. Humans have transformed significant portions of the Earth's land surface: 10 to 15 percent currently is dominated by agricultural row crop or urban-industrial areas, and 6 to 8 percent is pasture (Vitousek et al., 1997).

Investigations of the effects of past land use changes on water availability have been carried out in many regional studies worldwide (Ghaffari et al., 2010). Furthermore, impacts of land use scenarios on the water resources have been analysed in many other regional studies e.g., in Germany (Barthel et al., 2012), Canada (Wijesekara et al., 2012) and Kenya (Mango et al., 2011).

The study of land use changes can be done using modeling and trend analysis. The cellular automata–Markov approach was used to model the 2020 land use map in Hulu Langat River Basin, Malaysia. The year 2020 is the target time so that by this year, Malaysia is targeted to be a fully developed country. CA–Markov modelling allows simulation of land changes among the multiple categories, and combines the CA and Markov chain procedure for land cover prediction (Eastman, 2003).

In order to analyze the trend of land use changes caused by urbanization, historical land use maps were assessed using simple regression-based models. The detected trends in land use change were used in predicting future land use such as for 2020. (Memarian et al., 2012b)

2.5 Urbanization

Asian countries have experienced rapid industrialization and urbanization in the past decades (Liu et al., 2008; Long et al., 2007) and this situation also occurred in Malaysia. Malaysia as one of the Asian countries has not been an exception as it has gone through a rapid development and increase in its urban population started from mid-1980s. The impact of urbanization and urban growth in Malaysia is evident as its economy has changed from an agricultural base to a manufacturing base since 1987 (Malaysia, 1991). This change has brought pressure on the local and state governments to provide land for the required infrastructures for the growing urban populations (Yuen et al., 2006). (Jamaliah, 2004) stated that urban populations in Malaysia has increased from 35.8% in 1980 to 61.8% in 2000 as a result of urbanization.

It is clear that urbanization processes within a watershed create a new hydrological environment by replacing the natural surfaces (change of land cover) such as forest and soil with artificial surfaces such as concrete and asphalt. These changes tend to increase the area of impervious surfaces (Paul and Meyer, 2001), decreases infiltration of precipitation and increases runoff in proportion to the cover (type, extent and porosity) of the impervious surface (Dunne and Leopold, 1978; Douglas, 1983; Hall, 1984; Gordon et al., 1992; Leopold, 1994; Arnold and Gibbons, 1996).

2.6 Hydrologic Impact of Urbanization

When natural land is altered by human activities due to urbanization, the rainfall that used to be absorbed into ground now must be collected by storm sewers that convey the runoff into local streams. These streams may not have the capacity to handle the artificially inflated amounts of runoff causing flash flood and flooding in the catchment. Many hydrological studies have shown that land use changes have affected the hydrology of various watersheds of the world. Land use changes such as conversion of forests to agricultural land and urbanization of these lands are become a common scene in Malaysia. Rapid urbanization and other land use changes related to population growth alter the hydrological regime by increasing the peak flow and volume of surface runoff, while decreasing infiltration (Sahin and Hall, 1996). (Zhang et al., 2015) stated that the increase in annual surface run-off is related to urbanization, and the centre area of the city has experienced the largest increase in annual surface run-off.

This statement was supported by (White and Greer, 2006) who investigated the effects of watershed urbanization on the streamflow characteristics of Los Penasquitos Creek, in coastal Southern California. They found that the runoff increases between 200 to 500% when impervious surface cover exceeds 10% of the watershed (Arnold and Gibbons, 1996; Paul and Meyer, 2001). The total runoff increased by an average of 4% per year as urbanization increased from 9% to 37%, representing an increase of over 200% from 1973 to 2000. In northern

Ohio, urbanization at a study area was found to cause a 195% increase in the annual volume of runoff, while the expected increase in the peak flow for the local 100-year event was only 26% for the same site. Although any increase in severe flooding is problematic and cause for concern, the much larger increase in annual runoff volume, and associated decrease in groundwater recharge, likely has a much greater effect on the in-stream biological conditions (Pitt, 2005). (Pakorn et al., 2010) also found that the increase in the impervious surface area from urbanisation in Yom River, Thailand cause an increase in peak discharge flows as well as an increase in the stream levels.

(Bruijnzeel, 1990); (Calder, 1992); (Chang and Lau, 1993) and (Munoz and McDonnell, 2013) stated that changes of land use is usually accompanied by an increase in surface runoff and/or streamflow, decreased infiltration due to soil compaction (which would lowered the water table), higher peak flows and earlier peaks in stream floods which may lead to greater flood drainage downstream. Once forested catchment is replaced by urban development, several physical characteristics of the catchment may change which in turn can have a drastic change in hydrologic properties of the catchment. (Souza et al., 2015) found that activities associated with land use/cover changes and urbanization induces several local impacts including a change in atmospheric composition, water and energy balances, and ecosystem.

The major finding from land use change studies on water relations were summarized as tabulated in Table 2.1.

Table 2.1: Studies on the Impact Land Use Change on Water-Related Topics.

Land Conversion Activity	**Impact on Water-Related Topics**
Urban development (Huong and Pathirana, 2013)	Increases the frequency and rate of peak flow Increases duration and amount of interflow Increases total annual discharge or runoff Increases flooding from source area contribution
Changes in surface land (Wan et al., 2015)	Influence regional climate Local impacts (flood, etc.)

Land use and land cover changes (Souza et al., 2015)	Changes in water and energy balances Changes to flow pattern
Forest to urban development (Bhaduri et al., 1997) and (Munoz and McDonnell, 2013)	Changes to water quality Changes in streamflow Changes in runoff Decreases in groundwater recharge

2.7 Urban Flooding

The problems arising from urban flooding range from minor ones, such as water entering the basements of a few houses, to major incidents, where large parts of cities are inundated for several days. Most modern cities in the industrialized part world usually experience small scale local problems mainly due to insufficient capacity in their sewer systems during heavy rainstorms. Cities in other regions, including those in South/South-East Asia, often have more severe problems because of much heavier local rainfall and lower drainage standards. This situation continues to get worse because many cities in the developing countries are growing rapidly, but without the funds to extend and rehabilitate their existing drainage systems. The extent and frequency of urban flooding in large cities in developing countries make them good case studies for urban drainage modelling, as flood data are available and the impact of alleviation schemes can be evaluated straight away (Mark Ole et al., 2004).

Increased runoff in the urban environment may cause urban flooding which affects day-to-day activities, properties and even human lives. The recent flooding in Malaysia caused the loss of properties worth millions of dollars. Klang, Selangor, where the study was based, is being subjected to intensive short duration rainfalls in recent history which can cause localised urban flooding and even worse riverine flooding. Nevertheless, flooding is a serious issue for urban cities all around the world which is gradually intensifying in frequency with changes in urbanization and climatic conditions. Modern urban environments providing accelerated runoff mainly by land use change and manmade drainage systems. The worst case is when no effective measures (structural and non-structural) have been taken into account for flood mitigation in the design stage and during the maintenance of urban stormwater management systems.

2.8 Numerical Modelling

One way of analysing catchment hydrological behaviour is by creating a numerical model which represents the hydrological features and processes of the actual catchment numerically. Numerical modelling is essential to analyse the rainfall runoff process in a gauged or un-gauged catchment because of the limitations in measurement techniques and measured data. Modelling is also important for hydrologic prediction purposes when it comes to decision making aspects of planning (Beven, 2001). Catchment hydrology depends on catchment characteristics such as rainfall pattern, soil properties, flow paths, the watershed's width and gradient, land use, humidity, and evapotranspiration. All or some of those catchment characteristics can be considered according to their sensitivity to the catchment hydrology when building a non-linear function in the hydrological system. Before applying a model to a catchment it is necessary to calibrate it by using gauged data to ensure the model represents the actual catchment hydrology (Beven, 2001; Wagener et al., 2004). When deciding parameters to be considered in model development, the sensitivity of modelling processes on catchment characteristics plays a major role. Therefore sensitivity analysis and estimation of predictive uncertainty have become central research topics in the hydrological modelling community (Abebe et al., 2010). There are a number of models that have been implemented for stormwater runoff quantity analysis. Some of the well-practiced ones including DRAINS, DR_3M-QUAL, HSPF, MIKE-SHE, HEC-HMS, STORM and XP-SWMM are reviewed in the next section.

2.8.1 DRAINS

DRAINS is a multi-purpose Windows-based program for designing and analysing urban stormwater drainage systems and catchments which was first released in 1998. DRAINS is used to analyse peak flows, runoff volumes, and system deficiencies. The DRAINS can also model drainage systems of all sizes from small to very large (up to 10 km^2) using storage routing model. Working through a number of time steps that occur during the course of a storm event, it simulates the conversion of rainfall to stormwater runoff hydrographs and routes it through networks of pipes, channels and streams.

2.8.2 DR$_3$M-QUAL

The Distributed Routing, Rainfall, Runoff Model (DR$_3$M) is a continuous or event scale quantity model which was developed by the U.S. Geological Survey (USGS) to simulate urban runoff at various points in the watershed. The hydrographs generated by DR$_3$M are used by a companion model, DR$_3$M-QUAL (Alley and Smith, 1982b). This model is represented by several elements including overland flow, channels, pipes, and reservoirs. Each element computes runoff differently. Runoff from overland elements and routing in the channel elements are computed using the kinematic wave approximation. In this model, two types of overland elements are considered which are the pervious and impervious. The user needs to specify the time steps and distance used in the kinematic wave approximation. For routing in the channel element, the shape and size of the channel are supposed to be set by the user. Reservoir routing can be simulated by linear storage or modified pulse routing.

2.8.3 HSPF

The Hydrological Simulation Program-Fortran (HSPF) was developed by the US Environmental Protection Agency in the mid 1970’s. The HSPF is a comprehensive package for simulation of watershed hydrological processes on pervious and impervious land surface, in the soil profile, streams, and well-mixed impoundments. It is a continuous watershed hydrology model using hourly time steps. For hydrological modelling, HSPF simulates the variable time steps from one hour to one day and can be used for continuous or event-based modelling. The HSPF also divides watersheds into sub-watersheds that are homogeneous. Model can predict the flow in the most downstream reach of the delineated sub-watersheds; all intermediate reaches are used only in routing calculations (Chow and Yusop, 2012).

2.8.4 MIKE-SHE

The spatially distributed, physically based hydrological model was developed by DHI that delivers a truly integrated modelling of groundwater, surface water, recharge and evapotranspiration (Christiaens et al., 2001). MIKE-SHE includes all important aspects of hydrology when such a project or study requires a fully integrated model. The MIKE-SHE model is based on the SHE (Systeme Hydrologique Europeen, Abbot et al., 1986). It is a complex mechanistic model, which covers the entire hydrological system on a catchment scale, combining components for overland flow (two-dimensional Venant equation), river flow (one-dimensional Saint-Venant equation), transport through the soil profile (one-dimensional Richards' equation), and ground water flow (three-dimensional Boussinesq equation).

2.8.5 HEC-HMS

The Hydrologic Modelling System (HEC-HMS) model is designed to simulate the precipitation – runoff processes of dendritic watershed systems and with soil moisture accounting (SMA) algorithm, it accounts for watershed's soil moisture balance over a long-term period and is suitable for simulating daily, monthly, and seasonal stream flow and indirect runoff (interflow and groundwater flow). The model requires inputs of daily rainfall, soil condition and other hydro meteorological data (Roy D. et al., 2013).

2.8.6 STORM

The Storage, Treatment, Overflow, Runoff Model (STORM) is a simplified hydrologic model developed by the Corps of Engineers Hydrologic Engineering Center (HEC) at 1974s in Davis, California. (Chow and Yusop, 2012) claimed that the rainfall inputs (hourly) are used to generate runoff depth (hourly) in STORM by the use of simple runoff coefficient, soil-complex-cover and unit hydrograph methods. Flow routing cannot be simulated in STORM but runoff may be routed through a constant rate treatment device with excess flow diverted to a storage device. Since STORM is usually run only in a screening or planning mode, comparative evaluations can usually be made without calibration.

2.8.7 XP-SWMM

The Stormwater Management Model (SWMM) is the first computer-based runoff model developed by the Environmental Protection Agency (EPA) and released in 1971. Several major improvements have been made since then. In 1980's, the model became self-sustaining by external interest such as the XP Software. Modifications have been made to the SWMM software which came out with the XP-SWMM. The XP-SWMM is an enhanced version of the SWMM coupled with the XP interface. The graphical EXPERT environment (XP) is a user-friendly, graphic-based environment that encompasses data entry, run-time graphics, and post-processing of results in graphical form. The XP-SWMM can perform continuous and event-based simulations in urban area and in the basins with artificial drainage system. User can set the rainfall intervals and computation time. The model can be adopted for small and large basins, and the drainage area can be divided into hundreds or thousands of sub-catchment (Hong et al., 2005). The XP-SWMM also included non-linear reservoir equation, Horton or Green-Ampt equation, Kinematic and Dynamic wave routing.

The previous studies in the United States have simulated flow from a surface stream into cave using SWMM where promising results were obtained. SWMM is also well-practiced in Korea with several applications. The XP-SWMM has been applied to several urban hydrologic modeling applications in many of United States (US) cities as well as Canada, Europe, and Australia. The model has been used for very complex hydraulic analysis for combined sewer overflow mitigation, as well as for many stormwater management planning studies and pollution abatement projects.

2.9 Comparison of Stormwater Models

Various models for stormwater have been reviewed in this subchapter as presented in Table 2.2 such as the DRAINS, DR_3M-QUAL, HSPF, MIKE-SHE, HEC-HMS, STORM and XP-SWMM. These models represent a wide range of capabilities and have been categorised in terms of their functionality, accessibility and quantity components in the model. The components of these models have been discussed with regards to urban stormwater behaviour.

Table 2.2: Previous Research and Development on Stormwater Models.

Model	Primary author/ organisation & Country	Versions	Routing level	Simulation Type	Strength/Output	Limitations
DRAINS	Watercom and Dr. Geoffrey O'Loughlin, Australia	First: 1998 Latest: Version 2017	Simple Storage, Hydrologic	Single event	DRAINS will perform hydraulic grade line analyses, design stormwater drainage systems and produce summary graphs and tables.	Main applications not included in DRAINS (a) continuous modelling over long periods.
DR_3M-QUAL	U.S. Geological Survey (USGS), United States	First: 1978 Latest: Version II, 1991	Simple Storage, Hydrologic	Continuous, Single event	Analyses impacts on receiving waters and control strategies; frequency duration analyses of specified outputs.	Weak sediment transport simulation, except in storage basins; quality predictions must be calibrated
HSPF	U.S.EPA (US Environmetal Protection Agency)	First:1966 Latest: Version 11, 1997	Simple Storage, Hydrologic	Continuous, Single event	It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions.	Unidirectional treatment of flow hydraulics, limited treatment of urban drainage system, lack of comprehensive parameter guidance and extensive data requirements

Model	Primary author/ organisation & Country	Versions	Routing level	Simulation Type	Strength/Output	Limitations
MIKE-SHE	DHI	First: 1977 Latest: Version 2017	Simple Storage, Hydrologic	Continuous, Single event	Produce accurate integrated models for partition rainfall into runoff, evapotranspiration and groundwater recharge.	Huge amount of input variables and parameters necessary to run the model.
HEC-HMS	US Army Corps of Engineers	First: Version 2.1.1 Latest: Version 4.2.1	Simple Storage, Hydrologic	Continuous, Single event	HEC-HMS comes with an Arc-View extension which automates the construction of the model input and especially the averaging of soil type and land cover properties, topography and local drainage delineation.	The calibration procedure of HEC HMS adopted in the continuous modelling involved only manual calibration.

Model	Primary author/ organisation & Country	Versions	Routing level	Simulation Type	Strength/Output	Limitations
STORM	Corps of Engineers Hydrologic Engineering Center (HEC), California, United States	First: 1974 Latest:Version 6.5, 2007	Simple Storage	Continuous	STORM utilizes simple runoff coefficient, SCS and unit hydrograph methods.	Only hourly precipitation inputs are possible.
XP-SWMM	Various US EPA & XP Software, Australia	First: V5.01 1997 Latest: XPSWMM v2017	Simple Storage, Hydrologic	Continuous, Single event	Interactive analysis engine; Predict detailed quantity & quality results; Evaluation of BMPs for different scenarios; Can perform with artificial drainage system; User can get the rainfall interval & computation time; Can be adopted for small & large basins & drainage area.	Not a public domain product; lack of subsurface quality routing; limited kinetics (A first order decay rate can be specified for each pollutant in the Transport Block).

XP-SWMM was chosen for this research due to its spatial capabilities of having GIS engine that can handle the latest GIS data formats and support of the SWMM engine from EPA. The inherited capabilities from the XP-SWMM model that are useful for this study are its dynamic hydraulic and hydrological modeling capabilities of simulating runoff quantity and quality in urban areas. It can be used to model large complicated drainage networks with different conduit shapes and sizes.

2.10 Conclusion on Literature Review

Economic development has also been closely linked with environmental problems in river basins in Malaysia. These problems are associated with multiple factors such as urbanization, diminishing forests and rapid changes in catchment land use and floods. Urban land use change will have impacts on surface runoff and also streamflow. As the land surface is developed for urban use, artificial structures add impervious areas to the watershed, which considerably diminishes the water storage capability. As the area covered by structures becomes greater, the amount of vegetation, natural surface and infiltration will inevitably reduce and causes flood.

To date, a few profound studies have been carried out on the impact of urbanization on hydrological characteristics in Malaysian catchments. (Memarian et al., 2012; Amini et al., 2011). For this thesis study, the catchment area is lacking on the historical land use map for the year 2015. The validated SWMM model was used to estimate the imperviousness in the catchment for year 2015. After re-adjustment of the land use prediction model, only then the imperviousness percentage was estimated for the year 2020. A hydraulic model was later developed using same historical data to estimate water level in the waterway. Finally, by using Digital Elevation Model (DEM) data combined with the results of the hydraulic model, the potential flood prone areas were identified for different Average Recurrence Interval (ARI) for year 2020.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter describes the methodology of the present study including land use analysis and development of hydrologic and hydraulic models in the study catchment Sungai Dua Besar, located in Selangor, Malaysia. This chapter also consists of data collection, model calibration and testing procedures, and data analysis and interpretation. To address the three objectives highlighted in chapter 1, three phases are defined for this study:

Phase I: Landuse Change Study/Analysis

The target in this phase is to study the changes of land use based on the available historical land use data. In this study, the changes in land use were captured for several time frames to identify the trend up to the present time. Then the future land use was then predicted by the projection of the identified trend and also incorporating the future national development plans.

Phase II: Rainfall-runoff model Development

In this phase, firstly a hydrological model was developed to transfer the rainfall to runoff. Then a hydraulic model was developed to model the stream flow in the catchment and estimate the flood plain.

Phase III: Predict the Impact of Estimated Land Use Change

In this phase, the projected land use for the future was implemented into the developed hydraulic model to estimate the future flood plain after such land use change. The resulted flood plain was compared by the one produced for the current land use status. This comparison was made to show the impact of land use on hydrological characteristics of the catchment and also to estimate the potential risks in future development.

The general framework of this study can be summarized using a flow chart schematically shown in Figure 3.1.

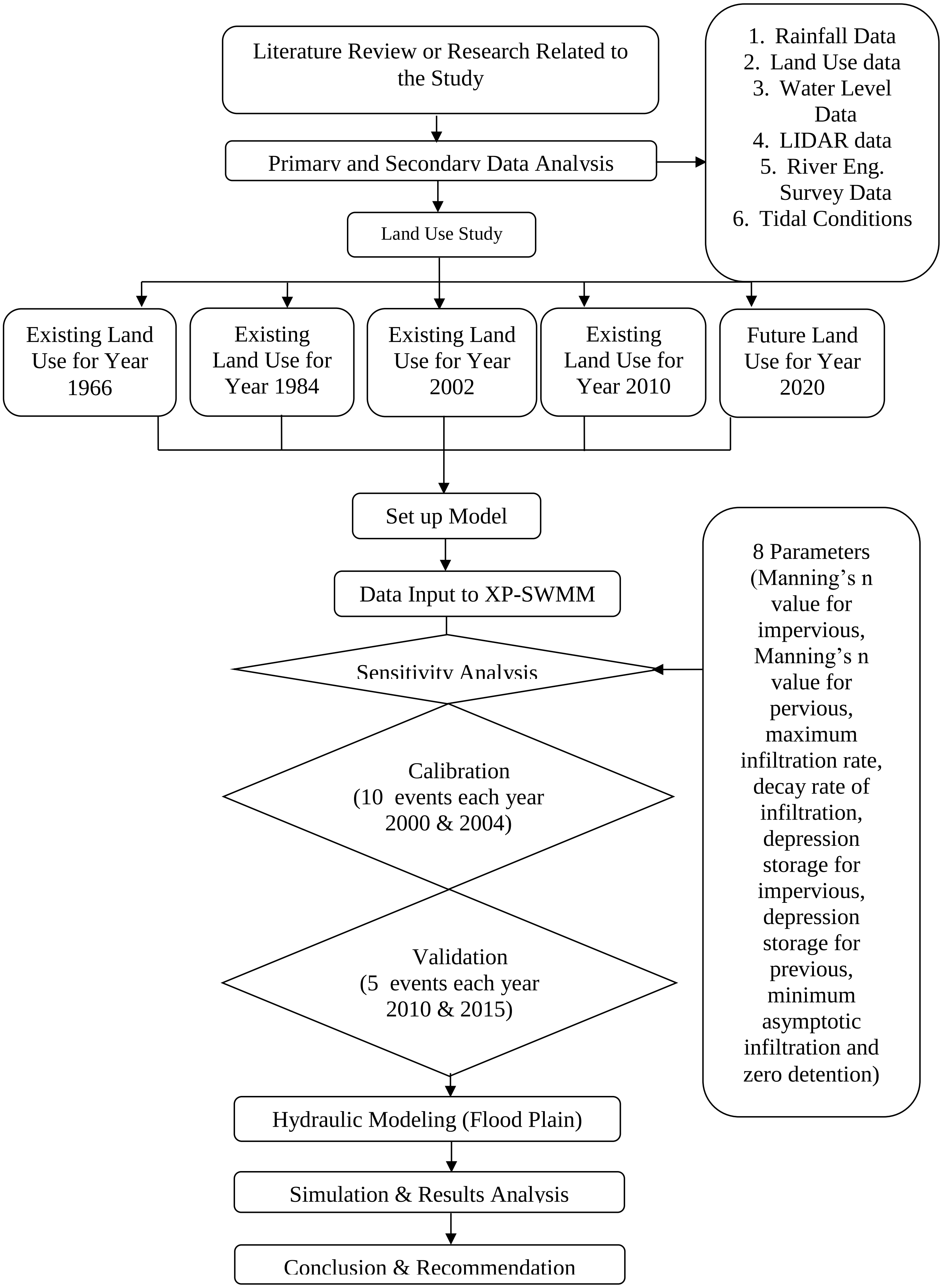


Figure 3.1: Overall Schematic View of the Project Methodology.

This chapter consists of two main parts: (1) study site and data used; and (2) models used. It is worth mentioning that the detailed methodology of each phase of this study is provided in their corresponding chapters (i.e. chapters 4, 5, and 6).

3.2 Study Catchment and Data Used

The purpose of this study is to determine the hydrological impacts of land use/land cover (LULC) change in a tropical climate catchment in Klang Valley, Malaysia using an integration of hydrological modelling, hydraulic modelling, Geographic Information System and statistical methods.

3.2.1 Study Site

The study catchment is Sungai Dua Besar which is located in Klang Valley one of the most urbanized catchments in Malaysia. The Klang District is situated on the south-west of the Selangor State and located about 32 km to the west of Kuala Lumpur and 6 km east of Port Klang. The district of Klang is divided into two parts by the Klang River, in which both are referred to as Klang North (Mukim Kapar) and Klang South (Mukim Klang). The Klang Town is a highly urbanized district which covers a total land area of 573.8 km^2 with a population well above 800,000.

The study area, Sungai Dua Besar Catchment, is at the west side of the North Port with the area of approximately 1765 ha. The river flows through Sungai Dua Besar before it goes into Sungai Che Awang as shown in Figure 3.2. The catchment is highly developed in comparison to the other catchments nearby and is relatively flat with the terrain range of +3.5m to -1.5m AMSL.

In this study, Sungai Dua Besar Catchment was divided into 9 sub catchments as shown in Figure 3.2. These sub catchments will be used later in the hydrological and hydraulic model development stage.

Figure 3.2: Location of Sungai Dua Besar Catchment.

3.2.2 Data Collection

In order to conduct and support the development of rainfall-runoff model, the data collection was conducted. The data collection can be classified into two types which are the Primary Data and Secondary Data. The primary data such as rainfall data, water level data, land use data, river engineering surveys, and LIDAR data are essential to identify the preliminary or existing condition of the study area. The primary data involved providing land use data from local council (Klang Municipal Council), hydrological data from Department of Drainage and Irrigation (DID), and engineering survey data from the Consultant, ZHL Engineers Sdn Bhd. The secondary data consists of existing data and information of stormwater facilities for the study area which are normally available in urban drainage design approval reports and were provided from DID. The required sources of the data and reports were obtained from the local/district government agencies and private agencies such as DID and Klang Municipal Council (known as MPK). The land use map can be obtained in several formats such as shape files (.shp) and image files (.jpg). The shape file format is generally better than image format as it already has the projection and information required (e.g. area, type of land use and percentage of the area based on different types of land use). If image format is obtained, the image file does not contain the projection and the required information; therefore, the method is to rectify the image map using the shape file as the basic projection so that the map image can be overlay correctly. The digitizing process can be done using Geographical Information System (GIS) and Global Mapper 15 software. All the land use maps were in shape file format for this study and no rectification was needed.

The LiDAR data of Sungai Dua Besar sub-catchment was also provided to be used in hydraulic model. The LiDAR data used in this study is with contour resolution of 0.2 m in the vertical axis and covers 573.8 km^2 of Klang District. In ArcGIS, all the LIDAR asc files are converted to raster files. Once the files are in raster, DEM is created. Land use data was used to determine the soil permittivity (pervious and impervious) of the Study area. DEM was built from a combination of data collection from Light Detection and Ranging (LiDAR survey) as well as geographical or ground survey data. The function of LIDAR data is to delineate the sub catchments and extract the elevation data in order to get the catchment slope parameters.

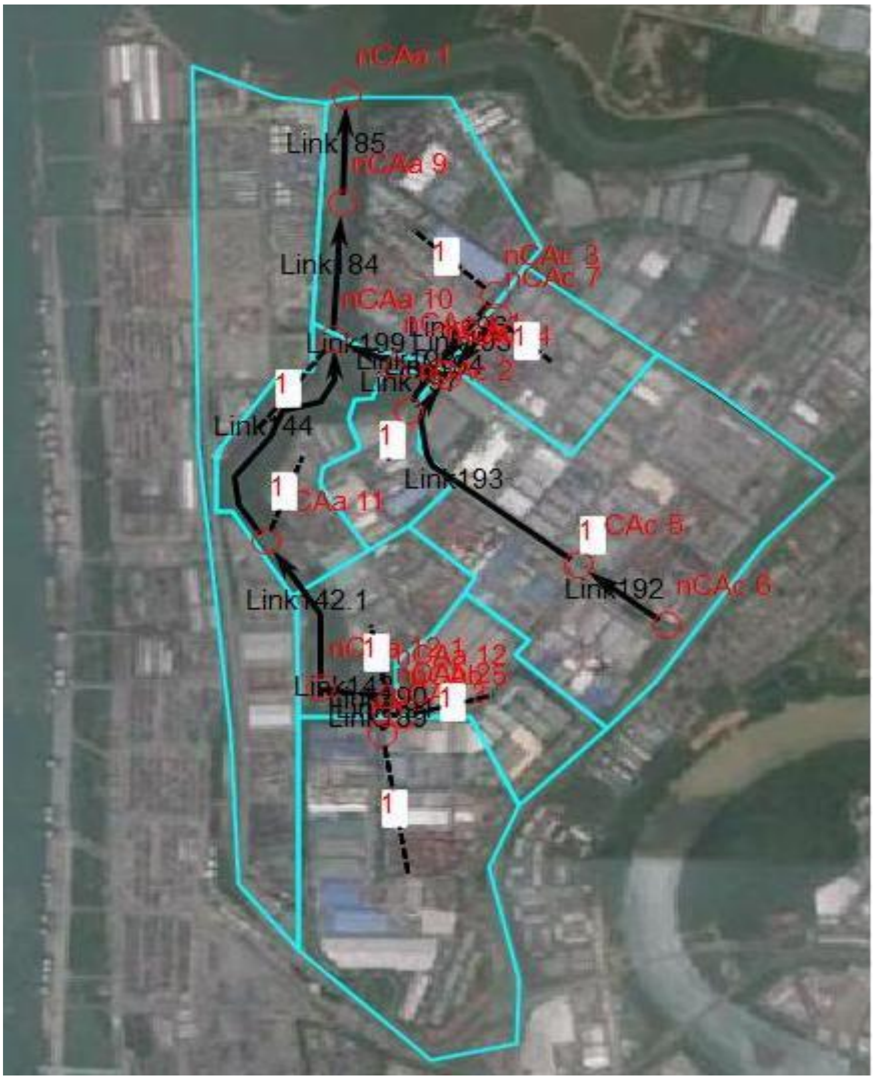


Figure 3.3: Map of Sungai Dua Besar Catchment.

3.3 Model Used

3.3.1 XP-SWMM: Background

The XP-SWMM is a dynamic rainfall-runoff-subsurface runoff simulation model used for single event to long term simulation of the surface/subsurface hydrology quantity and quality from primary urban areas. The hydrology component of XP-SWMM operates on a collection of sub catchment areas divided into impervious and pervious areas with and without depression storage to predict runoff, pollutant loads, evaporation and infiltration losses from each of the sub catchment.

The routing or hydraulic section of XP-SWMM transports the water through a system of closed pipes, open channels, storage and other regulators.

To develop a XP-SWMM model for a catchment several physical and hydrologic parameters are required. The physical parameters include the catchment area and slope and also the dimension of drain system. On the other hand, the hydrologic parameters such as catchment width, Manning’s coefficients, depression storages, and infiltration coefficients are also required. The hydrologic parameters are more difficult to estimate compared to the physical parameters. The rainfall intensity and duration, catchment size, slope, storage and morphology, land use and percentage imperviousness are factors that affect the hydrograph.

As a portion of precipitation may be lost through the interception, depression storage, infiltration, evaporation and transpiration (Chow et al., 1988), hydrologic model such as XP-SWMM needs to consider such processes in its model. The XP-SWMM provides five major types of Hydrograph Generation techniques including:

i. Non Linear Reservoir Method
ii. Kinematic Wave Method
iii. Laurenson Method
iv. SCS Unit Hydrograph method
v. Other Unit Hydrograph Methods, Nash, Snyder (Alameda), Snyder Rational Formula, Time area, Clark’s Hydrograph and Santa Barbara Urban Hydrograph

In this study the Clark’s Hydrograph was adopted. This is due to the accuracy and simplicity of the method and input data required for every method.

3.3.2 Model Parameters

In the XP-SWMM Model, there are 8 main parameters are applicable for sensitivity analysis. These parameters are Manning's n value for impervious, Manning's n value for pervious, maximum infiltration rate, decay rate of infiltration, depression storage for impervious, depression storage for previous, minimum asymptotic infiltration and zero detention (ZD).

3.3.2.1 Manning's Roughness n (Impervious and Pervious)

The Manning's Roughness n value for the sub catchment is not as well known for overland flow as for channel flow because of the considerable variability in ground cover, transitions between laminar and turbulent flow, very small depths, etc. Some estimates of Manning's roughness are given in the Table 3.1. The following table was compiled by Crawford and Linsley by calibration using the Stanford Watershed Model.

Table 3.1: Manning’s n Value.

Ground Cover	**Manning’s n**
Smooth Asphalt	0.010
Asphalt or concrete paving	0.014
Packed clay	0.030
Light turf	0.200
Dense turf	0.350
Dense shrubbery and forest litter	0.400

3.3.2.2 Maximum (Initial) Infiltration Rate, Fo

The maximum or initial infiltration capacity (mm/hr) depends primarily on soil type, initial moisture content and surface vegetation conditions. For single event simulation the initial moisture content is important. The values listed in Table 3.2 can be used as a rough guide.

Table 3.2: Maximum Infiltration Rate.

No.	**Type of Soils**	**Infiltration Rate (mm/hr)**
1.	Dry sandy soils with little or no vegetation	127.0
2.	Dry loam soils with little or no vegetation	76.2
3.	Dry clay soils with little or no vegetation	25.4
4.	Dry sandy soils with dense vegetation	254.0
5.	Dry loam soils with dense vegetation	152.0
6.	Dry clay soils with dense vegetation	51.0

7.	Moist sandy soils with little or no vegetation	43.0
8.	Moist loam soils with little or no vegetation	25.0
9.	Moist clay soils with little or no vegetation	7.6
10.	Moist sand soils with dense vegetation	84.0
11.	Moist loam soils with dense vegetation	5.1
12.	Moist clay soils with dense or no vegetation	18.0

3.3.2.3 Decay Rate of Infiltration

The decay rate of infiltration was adopted from Horton's equation:

$$Fp = Fc + (Fo - Fc)^{e-kt} \qquad \text{(Equation 3.1)}$$

Where

Fp = infiltration rate into soil, mm/hr

Fc = minimum or asymtopic value of Fp, mm/hr

Fo = maximum or initial value of Fp, mm/hr

t = time from beginning of storm, sec

k = decay coefficient

This equation describes the familiar exponential decay of infiltration capacity evident during heavy storms. However, the XP-SWMM program uses the integrated form to avoid an unwanted reduction in infiltration capacity during periods of light rainfall.

3.3.2.4 Depression Storage (Impervious and Pervious)

Depression storage is the volume that must be fill prior to the occurrence of runoff. It represents the loss or "initial abstraction" caused by such phenomena as surface ponding, surface wetting, interception and evaporation. Separate depression stores are required for pervious and impervious areas. Impervious area depression storage is depleted by evaporation. A relationship for depression storage versus catchment slope has been developed:

Dp = 0.0303 * S ^ -0.49 (Correlation coefficient 0.85) (Equation 3.2)

Where

Dp = depression storage, inch

S = catchment slope, percent

Pervious area depression storage is subject to both infiltration and evaporation. This parameter is best represented as an interception loss, based on the type of surface vegetation. For grassed urban surfaces, a value of 0.10 inches (2.5 mm) is typical.

3.3.2.5 Minimum (Asymptotic) Infiltration Rate, Fc

The minimum or ultimate value of infiltration capacity is essentially to the saturated hydraulic conductivity, or "permeability" of the soils. The Table 3.3 lists ranges of this parameter for various soil groups.

Table 3.3: Minimum (Asymptotic) Infiltration.

No.	**Hydrologic Soil Group**	**Minimum (Asymptotic) Infiltration (mm/hr)**
1.	A	7.6 – 11.4
2.	B	3.8 – 7.6
3.	C	1.3 – 3.8
4.	D	0.0 – 1.3

3.3.2.6 Zero Detention (ZD)

Zero Detention (ZD) is where the part of the sub catchment with impervious area that cannot detent water at all (immediate runoff). This parameter assigns a percentage of impervious area to the sub catchment in order to indicate immediate runoff in the model.

3.3.3 Model Calibration and Validation

To better estimate the parameters of the model, a sensitivity analysis can be used to identify the impact of changing one single parameter on the model while others are fixed.

The hydrological models are usually parameterized by deriving estimates of topography and physical properties of the soils, aquifers and land use of the basin. The reliability of model predictions depends on how well the model is defined and parameterized. However, the estimation of model parameters is difficult due to the large uncertainties involved in determining the parameter values, which cannot be directly measured in the field. Therefore, model calibration is necessary and important to improve the model performance. Hence, the calibrations of these models necessitate calibrating the quantity model as input to the quality model.

Model calibration is a process in which a generalized model is adjusted so that the model predictions better represent site-specific processes and conditions. During calibration, model parameters are optimized in an effort to increase accuracy and reduce model prediction uncertainty. Calibration is performed by carefully selecting model parameter values, adjusting them within their recommended ranges, and comparing predicted output variables with observed data for a given set of conditions (Arnold et al., 2012). Since the crucial goal of model calibration is to optimize unknown parameter values in the model, this process is also called parameter optimization.

To calibrate the model the control parameters (input data) for each of the conceptual components need to be determined so that the resultant system can mimic the real response of the catchment. Since surface runoff varies with the catchment characteristics, calibration of a model usually requires adjustment of the model control parameters to minimize prediction errors. There are two components to categorize the control parameters of a model including the measured parameters and the inferred parameters. Measured parameters are the ones that are physically measured such as catchment area, rainfall depth, or rainfall intensity. On the other hand, inferred parameter refers to the parameters that are not measured and are determined from the application of the model. Examples of inferred parameters are Manning's roughness for catchment surfaces or channels, depression storage, catchment or sub-catchment imperviousness. Generally, the values of inferred parameters are assumed error free during the calibration process.

In this study, the control parameter values for a catchment modeling system are typically determined by an alternative method that has been chosen which is the modification of control parameter values to achieve minimum error between simulated and observed hydrographs. This alternative method can be described as a “trial and error” method whereby the values of the control parameters are modified in a systematic manner to achieve maximum goodness-of-fitness between the observed parameters and predicted parameters. The simulation results are then compared with the observed hydrograph both graphically and statistically.

Validation is about testing the established parameters using an independent data set usually in the form of measured flows. Validation of hydrological model is the process of evaluating performance of a simulation or prediction model and can be distinguished between scientific validation and performance validation (Daniela et al., 2012). During validation, there must be agreed methodologies to access model peculiarities and limitations.

3.3.4 Model Evaluation

In this study, the model performance is assessed by using several evaluation criteria. Model evaluation can be done using error statistics and goodness of fit measures (Amin et al., 2012). Using different criteria in model assessment always helps to have a better overall view of different aspects of model performance. The following criteria are used in this study:

(i) Coefficient of Determination (R^2)

In statistics, the coefficient of determination, denoted R^2 or r^2 and pronounced "R squared", is a number that indicates the proportion of the variance in the dependent variable that is predictable from the independent variable(s). It provides a measure of how well observed outcomes are replicated by the model, based on the proportion of total variation of outcomes explained by the model.

A data set has n values with y as simulated value and x as observed value.

$$R^2 = \left(\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \right)^2 \qquad \text{(Equation 3.3)}$$

The Nash-Sutcliffe Coefficient of Efficiency (CE) was used to compare the goodness-of-fit between the measured flow and the simulated flow. CE indicates how well the plot of observed versus simulated and is defined as:

$$CE = \frac{\sum (X_{est} - X_{avg.obs})^2}{\sum (X_{obs} - X_{avg.obs})^2} \qquad \text{(Equation 3.4)}$$

Where

X_{obs} = the observed flow rate

X_{est} = the simulated flow rate

$X_{avg.obs}$ = the average value (mean value) of the observed flow rate

(iii) Relative Peak Error (RPE)

Relative Peak Error (RPE) has been included in this study to evaluate the ability of the proposed models to accurately predict peak flows. RPE is defined as:

$$RPE = \frac{|\text{Observed } Q_p - \text{Simulated } Q_p|}{\text{Observed } Q_p} \qquad \text{(Equation 3.5)}$$

Where

Q_p = the peak flow

Values of RPE closer to zero indicate better estimation of peak flows.

(iv) Root Mean Square Error (RMSE)

Root mean square error (RMSE) is a frequently used measure of the differences between values (simulated and observed values) predicted by a model or an estimator and the values actually observed. The RMSE represents the sample standard deviation of the differences between predicted values and observed values. These individual differences are called residuals when the calculations are performed over the data sample that was used for estimation, and are called prediction errors.

$$RMSE = \sqrt{\frac{1}{n} \sum (X_{obs} - X_{est})^2} \qquad \text{(Equation 3.6)}$$

Where

X_{obs} = the observed flow rate

X_{est} = the simulated flow rate

(v) Mean Absolute Error (MAE)

Mean Absolute Error (MAE) is the average vertical distance between each point and the Y=X line, which is also known as the One-to-One line. MAE is also the average horizontal distance between each point and the Y=X line. *fi* is the prediction and *yi* is the true value for n sets of data.

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n} |fi - yi| \qquad \text{(Equation 3.7)}$$

CHAPTER 4
LAND USE STUDY

4.1 Study of the Land Use Change

The land use change is assessed by four (4) land use maps of the study site obtained from various government agencies including Ministry of Agriculture and Lands Malaysia, Federal Department of Town and Country Planning Peninsular Malaysia and Klang Municipal Council for years 1966, 1984, 2002, and 2010. Moreover, a map for 2020 was also available which is provided based on the national development plans for the study region. Twelve (12) different land use types were taken into interpretations for study site including Water Body, Forest, Industrial, Infrastructure and Utility, Institutional, Residential, Commercial, Vacant Land, Open Space and Recreational, Agricultural, Transportation, and Others. The area of each land use type was calculated using the available maps. Figure 4.1 shows the land use for year 1966. As can be seen roughly 85% of the area is covered by forest.

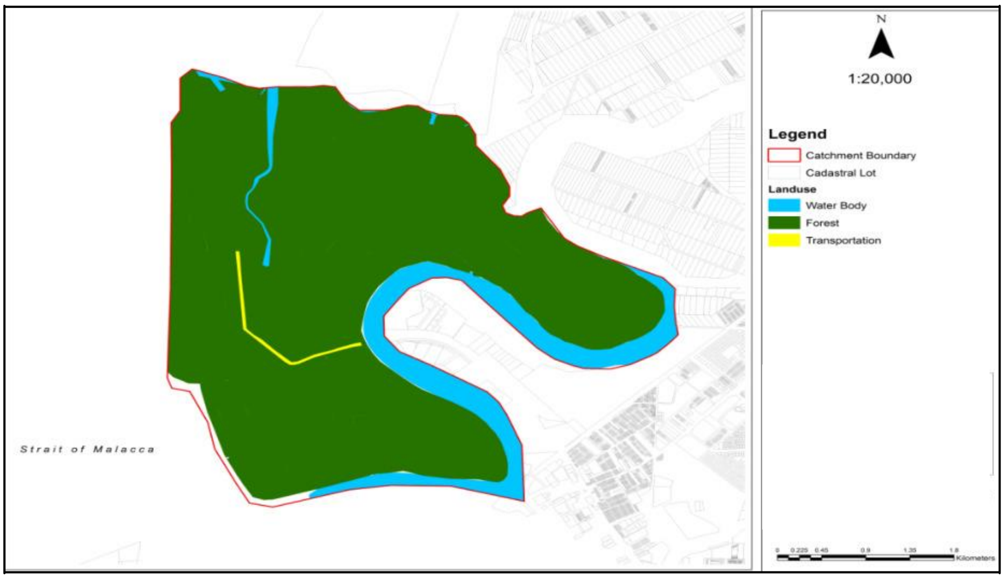


Figure 4.1: Land Use Distribution Map of Sungai Dua Besar Catchment in 1966.
(Source: Ministry of Agriculture and Land Malaysia)

The land use distribution for Sungai Dua Besar catchment in year 1984 is presented in Figure 4.2. As can be seen, after 18 years the catchment has gone through a significant transformation where 22% of area has been changed to industrial area. Forestry encompasses about 55% of the catchment area.

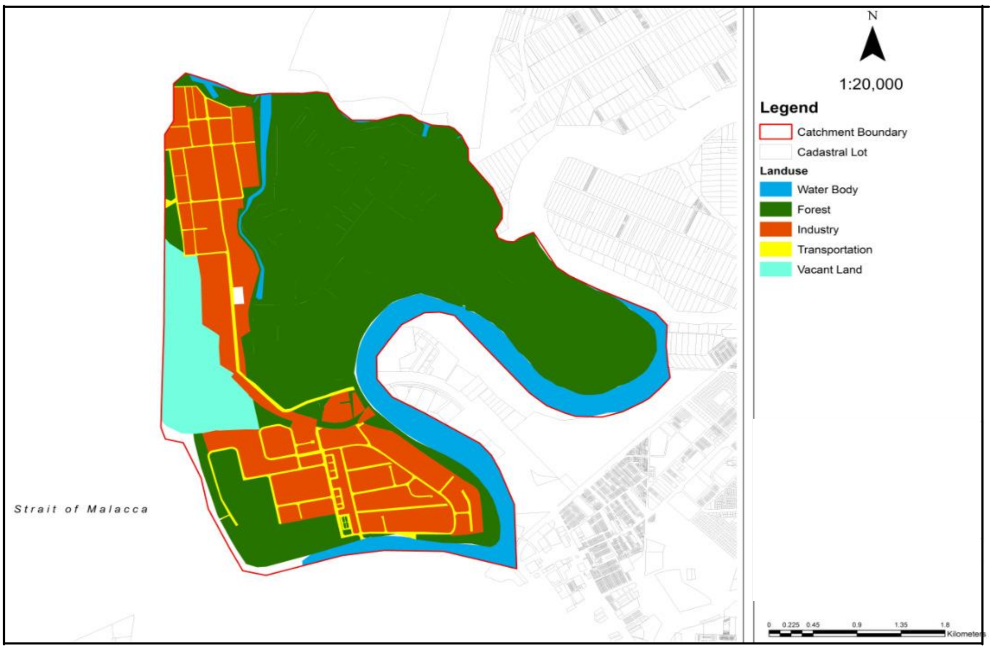


Figure 4.2: Land Use Distribution Map of Sungai Dua Besar Catchment in 1984. (Source: Ministry of Agriculture and Land Malaysia)

Figure 4.3 shows the land use distribution for the year of 2002. As can be seen, about 42% of the total area has been developed as industrial zone and 11% has been utilized for transportation infrastructures. The forest area has experienced a significant reduction to only 18% of the total area. Reviewing the land use map for year 2010 (See Figure 4.4) showed that a fast trend of urbanization has happened and a significant change in development of residential area has occurred. Figure 4.4 shows that residential area stands for 11% of the total land use while industrial area has not gone through a serious change as its percentage is changed from 42% in 2002 to 48% in 2010. Transportation has been sustained at 11% and forestry facing a major decline up to 7% of the total area of the catchment. The detailed area of each type of land uses and their percentages are presented in Table 4.1. In order to come up with a model to capture the land use change within the study time frame, two different scenarios were adopted as following:

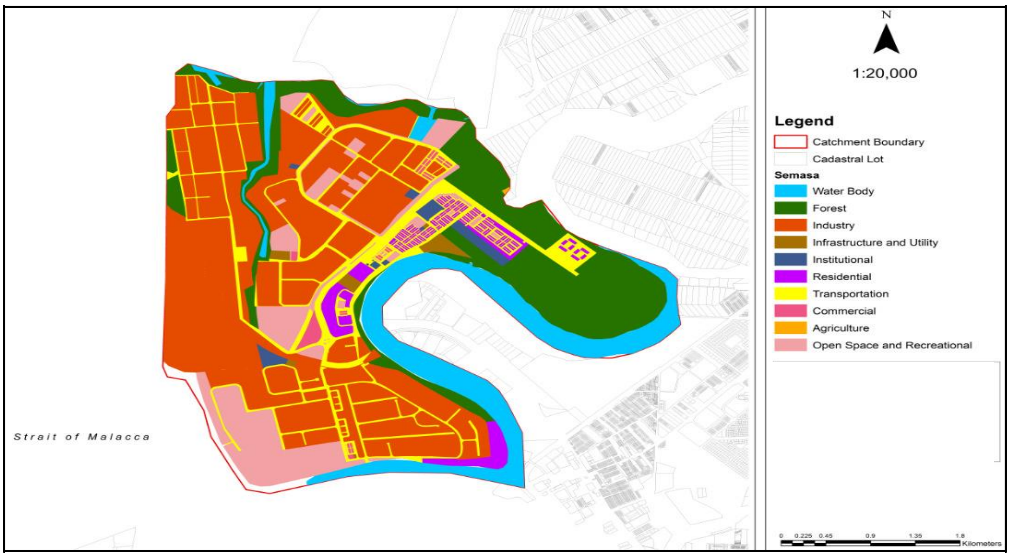


Figure 4.3: Land Use Distribution Map of Sungai Dua Besar Catchment in 2002. (Source: Federal Department of Town and Country Planning Peninsular Malaysia)

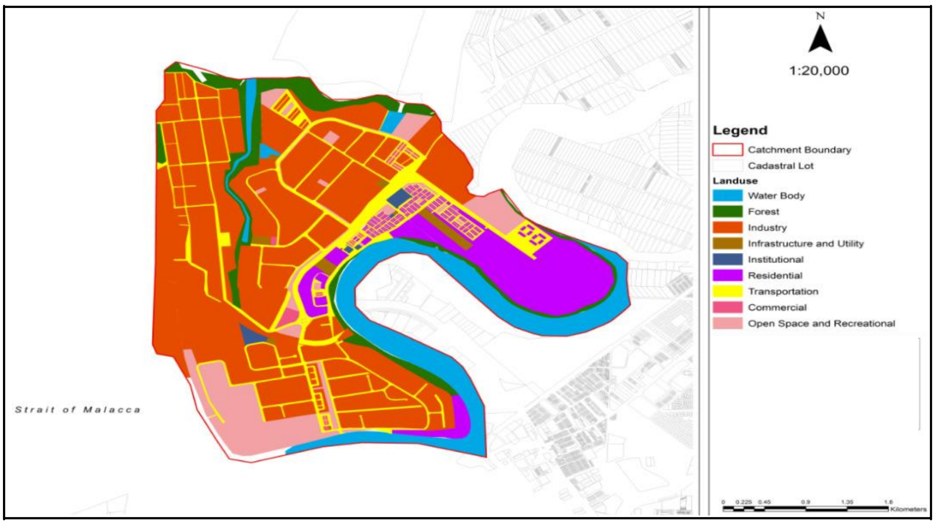


Figure 4.4: Land Use Distribution Map of Sungai Dua Besar Catchment in 2010. (Source: Federal Department of Town and Country Planning Peninsular Malaysia)

Table 4.1: Summary of Land Use Distribution for Sungai Dua Besar Catchment for Four Different Timeframes.

Land use	**1966**		**1984**		**2002**		**2010**	
	Area (Ha)	**Area (%)**	**Area (Ha)**	**Area (%)**	**Area (Ha)**	**Area (%)**	**Area (Ha)**	**Area (%)**
Water Body	213	12	213	12	218	12	216	12
Forest	1529	87	967	55	322	18	120	7
Industrial	0	0	389	22	746	42	838	48
Infrastructure and Utility	0	0	0	0	13	1	17	1
Institutional	0	0	0	0	20	1	10	0
Residential	0	0	0	0	57	3	192	11
Commercial	0	0	0	0	12	1	10	1
Vacant Land	0	0	118	6	0	0	0	0
Open Space and Recreational	0	0	0	0	172	10	154	9
Agricultural	0	0	0	0	0	0	0	0
Transportation	8	0	63	4	190	11	198	11
Others	15	1	15	1	15	1	10	0
Total	**1765**	**100**	**1765**	**100**	**1765**	**100**	**1765**	**100**

Scenario (1):

In this scenario, the 12 available land use types were grouped into two major types namely non-urbanized and urbanized. Water bodies, forest, vacant lands, open spaces and recreational areas, and agricultural lands were considered as non-urbanized while the remaining ones were considered as urbanized. Table 4.2 shows the summary of area (ha) for years 1966, 1984, 2002, and 2010 based on the two grouped land uses. Area versus time scatter plots was provided for non-urbanized and urbanized areas to capture the trends of change. Proper curve-fitting process was also carried out for future prediction. Figure 4.5 and 4.6 show the fitted linear functions for urbanized and non-urbanized areas (in the studied time frame), respectively. It is worth mentioning that these figures just show the trend line and the linear functions are mathematically valid up to 61 years from the first historical data point (i.e. from 1966 to maximum 2027). This is due to the fact that total catchment area is fixed and the non-urbanized area can ultimately decrease to zero in the worst case scenario. In scenario (1) of this study, it was assumed that the observed trend is going to continue up to 2020 (54 years after 1966). This projection is mathematically valid since it still falls within the valid domain (i.e. 54 < 61).

Table 4.2: Summary of Land Use Distribution based on Scenario (1) Classification of Urbanized and Non-Urbanized Surfaces.

	1966	**1984**	**2002**	**2010**
Land Use	**Area (Ha)**	**Area (Ha)**	**Area (Ha)**	**Area (Ha)**
Urbanized	23	468	1053	1275
Non-Urbanized	1742	1297	712	490

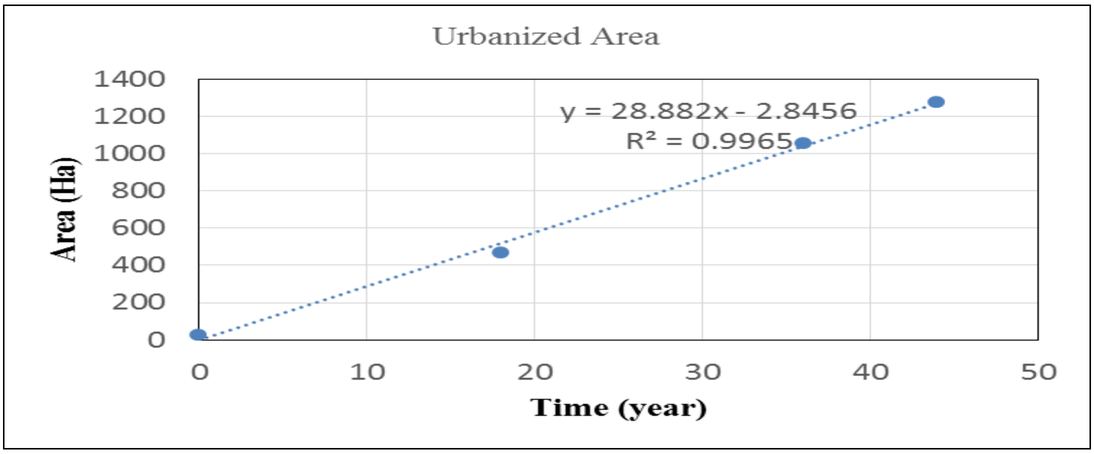


Figure 4.5: Change in Urbanized Land Area within 44 years Timeframe of 1966 to 2010.

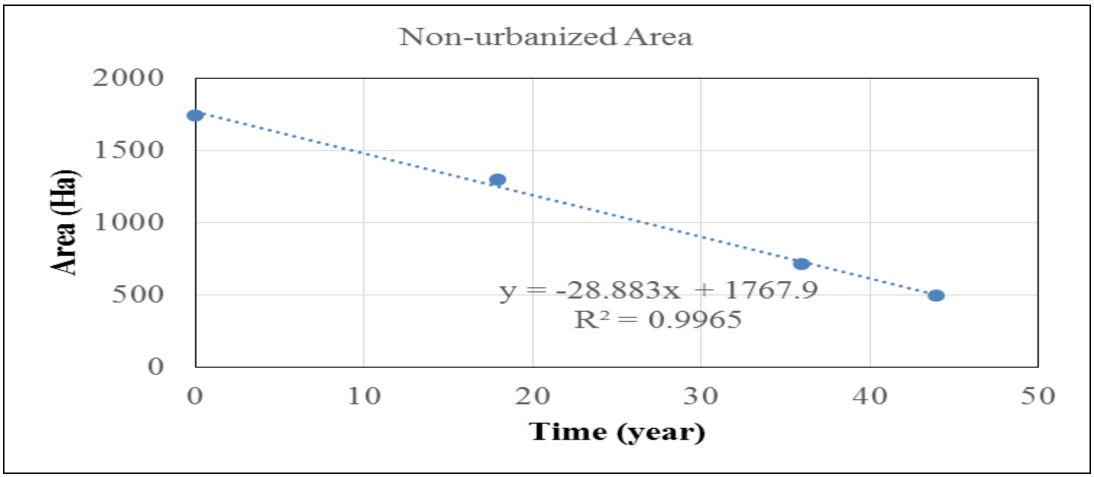


Figure 4.6: Change in Non-Urbanized Land Area within 44 Years Timeframe of 1966 to 2010.

Scenario (2):

In this scenario, only the main key players of urbanization including industrial, residential, and transportation were considered and individual change trend for them was assessed. The result of this assessment is provided in Figures 4.7-4.9 for industrial, residential, and transportation land uses, respectively. As can be seen, except for residential area, the other two has a linear trend of increase. In this scenario, it is assumed that the future urbanized area is the summation of projected areas for these three land uses and the remaining area is non-urbanized. It is worth mentioning that practically the total area of the catchment is fixed; therefore, the summation of these three land use areas can ultimately reaches to the total area even for the worst case that non-urbanized area decreases to zero. Mathematically such case happens 57 years after the first data point (i.e. from 1966 to 2023) if the trend remains unchanged throughout time. Therefore, the resulted trend of land use change in Scenario (2) can predict land use distribution for year 2020 (considering x = 54 years in the formula).

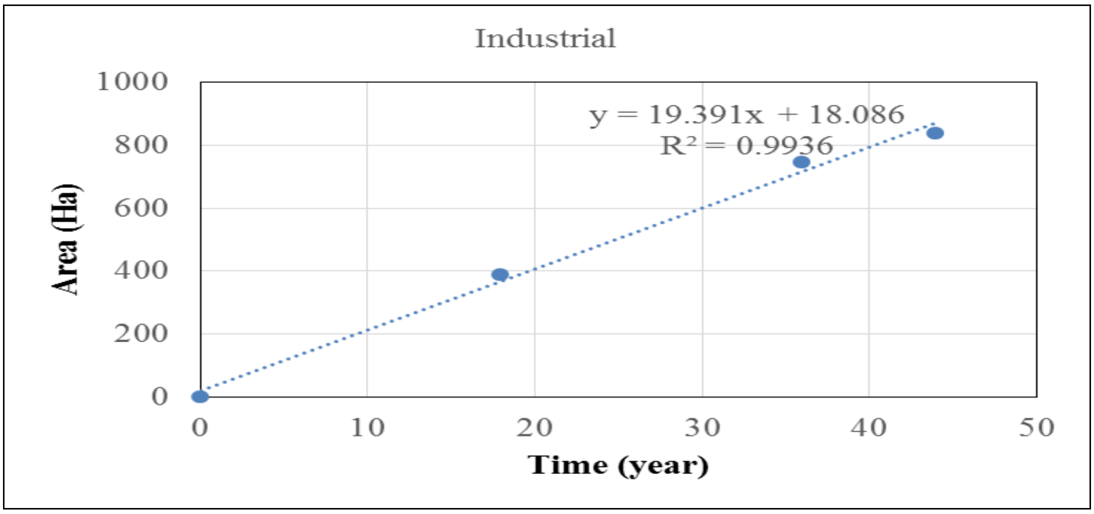


Figure 4.7: Change in Industrial Area within 44 years Timeframe of 1966 to 2010.

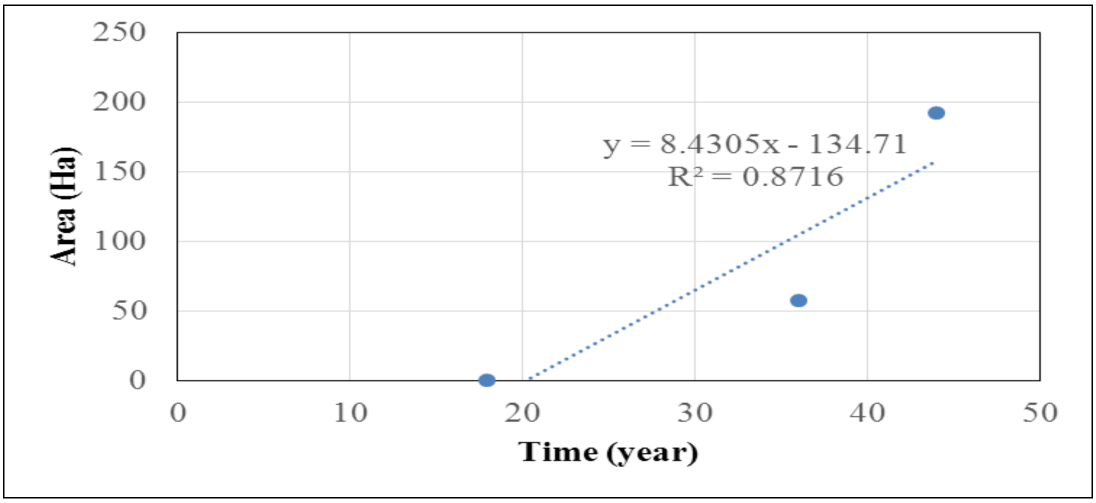


Figure 4.8: Change in Residential Area within 44 years Timeframe of 1966 to 2010.

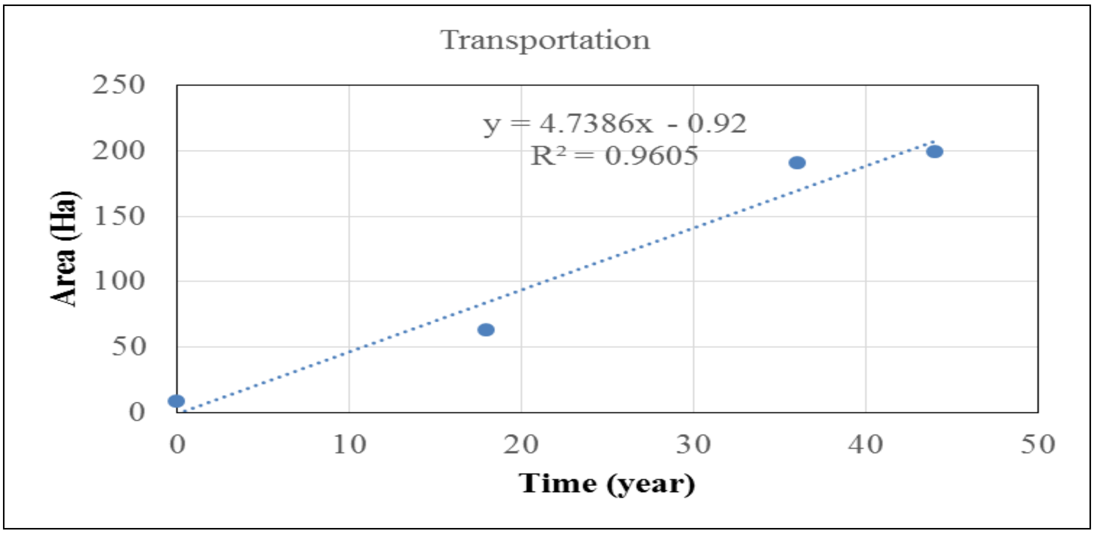


Figure 4.9: Change in Transportation Area within 44 years Timeframe of 1966 to 2010.

The projection of land use for Sungai Dua Besar catchment for the year of 2020 is provided by Klang Municipal Council (MPK) based on the future development plans. Figure 4.10 shows the projected land use for 2020. MPK has predicted that the commercial area will increase up to 1% by the year 2020 while the residential area covers about 3% of the total area. In this projected land use map the industrial area is reduced to 32%. Another major change is the predicted transportation infrastructure where an increase up to 28% is estimated.

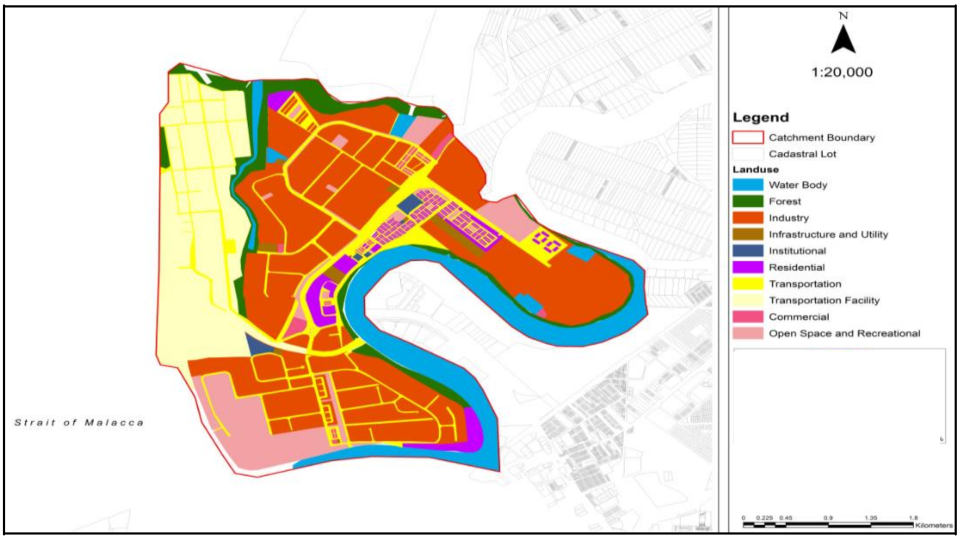


Figure 4.10: Future Land Use Distribution of Sungai Dua Besar Catchment for Year 2020. (Source: Klang Municipal Council)

The predicted urbanized area calculated based on the projected map by MPK (Figure 4.10) was then compared with estimated values given by Scenarios (1) and (2).

The same categorization of non-urbanized and urbanized surfaces were adopted for MPK map and then compared with the estimated values of linear trend presented in Figures 4.5 and 4.6. The results are presented in Table 4.3 for comparison. As can be seen, linear trend shows more sever urbanization of 88% compared to the one obtained from MPK map with 72%. Therefore, it is concluded that using the linear trend of scenario (1) can be a more conservative approach for development of any flood prediction as well as flood risk analysis and management.

Table 4.3: Comparison of Estimated Urbanized and Non-Urbanized Areas Obtained by Linear Trend of Scenario (1) and MPK Projected Map for the Year 2020.

	MPK Projection		**Scenario (1) Projection**	
Land Use	**Area (Ha)**	**Area (%)**	**Area (Ha)**	**Area (%)**
Urbanized	1277	72	1557	88
Non-Urbanized	488	28	208	12
Total	1765	100	1765	100

The estimated urbanized area obtained based on the 3 key-players of urbanization (residential, industrial, and transportation) by scenario (2) was then compared with the estimated ones by MPK projection map and is presented in Table 4.4. As can be seen, Scenario (2) predicts even more sever urbanization trend compared to scenario (1). In this scenario, the estimated urbanized area is projected to be 93% of the total area while MPK and scenario (1) gave 72% and 88%, respectively. It is concluded that for even a more conservative flood risk assessment, Scenario (2) could be chosen as the land use predictor. However, MPK map is based on the future planning and if the national policies are really going to be implemented, it can be expected to have a more moderate urbanization trend.

Table 4.4: Comparison of Estimated Urbanized and Non-Urbanized Areas Obtained by Linear Trend of Scenario (2) and MPK Projected Map for the Year 2020.

	MPK Projection		**Scenario (2) Projection**	
Land Use	**Area (Ha)**	**Area (%)**	**Area (Ha)**	**Area (%)**
Urbanized	1277	72	1641	93
Non-Urbanized	488	28	124	7
Total	1765	100	1765	100

4.2 Conclusion on Land Use Study

Two different approaches were considered to project the land use change in year 2020 including: Scenario (1) which is based on summation of non-urbanized and urbanized areas; Scenario (2) which is based on three key-player parameters of urbanization. The results of the two land use analyses were then compared with the projected MPK map which is provided based on the national development plans. The comparison between the results showed that scenario (2) predicts the highest urbanization area for year 2020 followed by Scenario 1 and MPK future land use plan. MPK projection for urbanized area in year 2020 is 72% whereas scenario 1 predicted an urbanized area of 88% and scenario 2 gave the highest prediction of urbanized area of 93%. However with the local council development control plan in mind, it is wise to use scenario 1 as an input of land use in the flood modelling analysis since scenario 1 gave a higher value of urbanized areas than the MPK projection in year 2020. Scenario 2 gave a value of urbanization on the high side. This value might not be achievable due to economic, social and political constraints on this catchment. It was concluded that for a conservative flood risk analysis, the two proposed analyses could be better choices. This is due to the fact that the complete implementation of MPK land use plans may be affected by some unseen factors in the future. Therefore, it would be better to have a more conservative flood risk analysis to minimize the potential tolls of such natural disasters.

CHAPTER 5
RAINFALL RUNOFF MODEL DEVELOPMENT

5.1 Introduction

Understanding the sources of uncertainty in stormwater management models and their consequences for the model outputs is essential so that subsequent decisions are based on reliable information (Wagener et al., 2004). In rainfall-runoff modeling, several catchment parameters such as surface roughness coefficients and infiltration rate have an impact on resulted runoff. Such parameters can be changed through time due to the imposed land use alteration. The sensitivity of the model to the change of each of these parameters is different; therefore, running sensitivity analyses for selected parameters of the model (those which are not actually measured) are necessary. Sensitivity analysis is part of calibration process of a rainfall-runoff model to avoid unnecessary trial and error procedure in fine-tuning of the model parameters. (Schlesinger et al., 1979) defined rainfall-runoff model calibration as the procedure of adjusting model parameters to reproduce the response of a river basin to a rainfall event within the range of accuracy specified in the performance criteria. On the other hand, model validation involves conducting tests in which the capability of the given site-specific model would be assessed for an unseen rainfall-runoff event. Model validation is designed to confirm that the calibrated model can be used for different data sets considering the limited range of conditions inherited in the calibration and validation data sets.

5.2 Sensitivity Analysis for XP-SWMM Model

Every model has a level of uncertainty associated with it because no model can perfectly represent reality for all the variances of nature itself. Hence the results of modelling processes and outputs have to be interpreted carefully to provide a close estimation of the real behavior of a system. Therefore a need arises in modelling to control and reduce the uncertainties of the results along with providing a degree of confidence level of the model and its output (Deletic et al., 2012). Sensitivity analysis is one of the most important tools for modelers, as it is used to determine ‘uncertain’ model parameters that have the biggest effect on the model outputs (Dotto et al., 2010; Saltelli et al., 1997). A sensitivity analysis can identify the parameters for which model reacts most sensitively to. Thus such analysis can simplify and accelerate the calibration process or enable a more focused planning for future research and field measurement. Sensitivity analysis can prove the suitability of a model concept and strengthen trust in a model and its predictions (Saltelli, 2000). In XP-SWMM, the results of the sensitivity analysis can be used for estimating the default calibration parameters as well as evaluating the comparative performance of parameters using the default values. By doing so, this procedure was expected to reduce the amount of effort and time required to calibrate a model (Abustan, 1997). Sensitivity analysis can provide estimated parameter values of calibration processes as well as to observe the sensitivity of the peak flow and time to peak.

In this study, imperviousness, catchments area, width, and slope are the fixed parameters (measured). Therefore, they are not included in the sensitivity analysis on model parameters. In XP-SWMM, there are another 8 main parameters that need to be considered for sensitivity analysis. These parameters are: Manning's coefficient (*n*) value for impervious, Manning's coefficient (*n*) value for pervious, maximum infiltration rate, decay rate of infiltration, depression storage for impervious, depression storage for previous, minimum asymptotic infiltration and zero detention (ZD). For running the sensitivity analysis on model parameters, each individual parameter was changed for ±5%, ±10%, ±20%, ±30%, ±50% and ±75%. For each change, simulation was made while all other parameters remained fixed so the effect of each individual parameter on the outputs (runoff volume and peak discharge) can be captured.

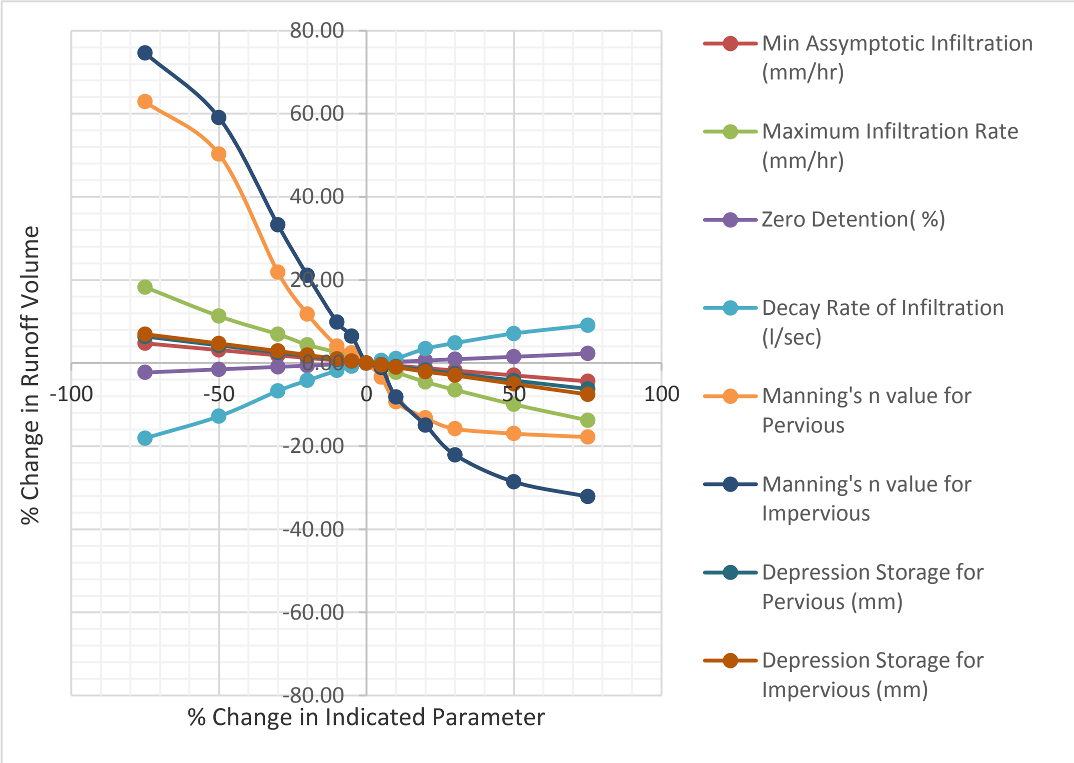


Figure 5.1: Sensitivity Analysis Results for Predicting Runoff Volume.

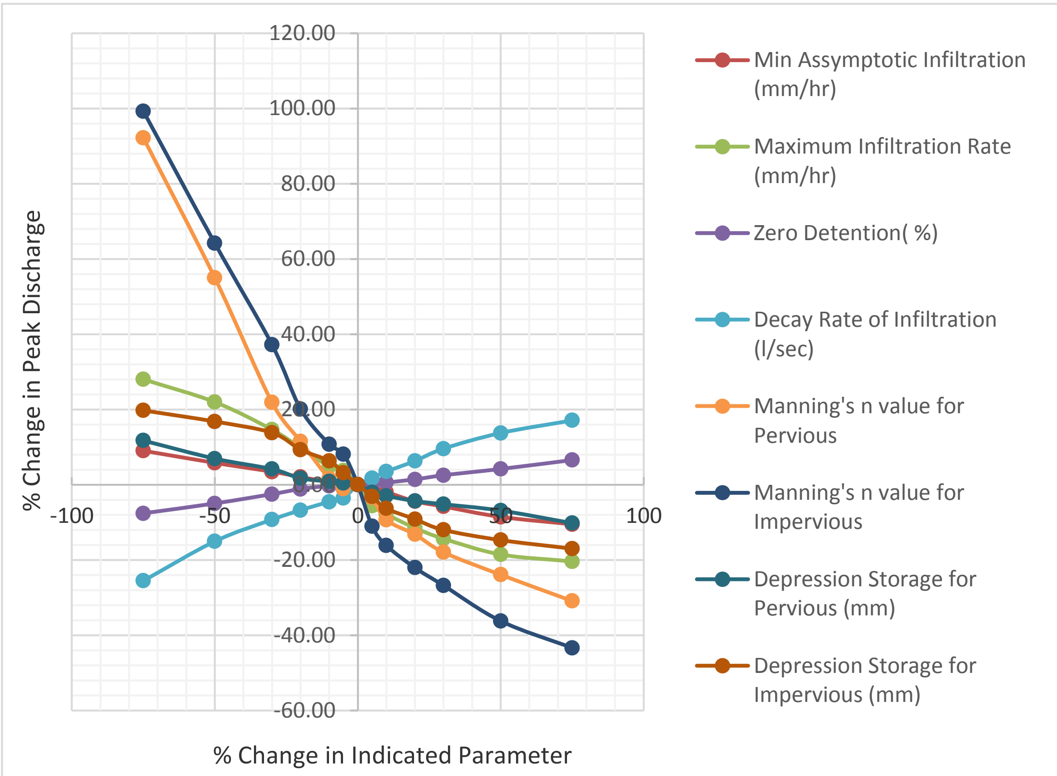


Figure 5.2: Sensitivity Analysis Results for Predicting Peak Discharge.

The most sensitive parameter is Manning's coefficient (*n*) value for impervious surface as analysis showed that runoff volume and peak discharge are significantly sensitive to Manning's coefficient (*n*) value for impervious surface. This was evident as 75% increase of the Manning's coefficient (*n*) value for impervious surface caused 32.13% reduction in runoff volume and 43.38% reduction in peak discharge. On the other hand, 75% decrease in the Manning's coefficient (*n*) value for impervious surface leads to 74.62% increase in runoff volume and 99.27% increase in peak discharge. The sensitivity analysis on Manning's coefficient (*n*) value for pervious surface also showed that it directly affects the two outputs of the model. For example, 75% increase of this Manning's coefficient (*n*) value for pervious surface can cause a 17.82% decrease in runoff volume and 30.91% decrease in peak discharge. Furthermore, 75% reduction of Manning's coefficient (*n*) value for pervious surface leads to 62.89% increase in the value of runoff volume and 92.18% increase in peak discharge.

Sensitivity analysis also showed that runoff volume and peak discharge have meaningful sensitivity to maximum infiltration rate parameter. This parameter depends primarily on soil type, initial soil moisture and surface vegetation conditions. As can be seen in Figures 5.1 and 5.2, 75% increase in maximum infiltration rate causes 13.77% reduction in runoff volume and 20.40% reduction in peak discharge. Infiltration in XP-SWMM model is implemented by using Horton Infiltration equation. This equation is used to represent the exponential decay of infiltration capacity of the soil that occurs during heavy storm events. Decay rate of infiltration parameter have direct relation with runoff volume and peak discharge. It was found that, 75% increase in this parameter causes runoff volume to increase 9.11% and 17.08% in peak discharge. The sensitivity analysis on depression storage component for both impervious and pervious did not show any significant change in runoff volume and peak discharge. Therefore, it was concluded that these two parameters are not influential in calibration process.

The minimum asymptotic infiltration parameter is essentially the saturated hydraulic conductivity or "permeability" of soils. In this study, the value of minimum asymptotic infiltration was estimated according to recommended values in XP-SWMM 2016 user manual. The results showed that there is an overall reverse relationship between minimum asymptotic infiltration parameter and the two outputs (runoff volume and peak discharge). However, this parameter does not have an impact on the calibration process. For instance, 75% increase of this parameter only shows 4.39% and 10.52% decrease in runoff volume and peak discharge.

Based on the XP-SWMM 2016 user manual, ZD parameter is the percentage of the sub-catchment (impervious area) with immediate runoff. This means ZD is equivalent to immediate runoff and the default value in XP-SWMM for ZD is 25%. From the result of sensitivity analysis, it was concluded that runoff volume and peak discharge are not significantly sensitive to ZD parameter. It is worth mentioning that ZD is directly related with runoff volume and peak discharge as 75% increase in ZD caused 2.28% and 6.54% increase in runoff volume and peak discharge. This parameter also does not influence the calibration process.

In order to prioritize the significance of parameters impact on model output, the summary of sensitivity analysis is presented in Table 5.1 by ranking parameters based on level of their impact on model output. It was then concluded that parameters ranking 1 to 3 are the main key players in calibration process of the model. These three parameters are: Manning's coefficient (*n*) value for impervious surface, Manning's coefficient (*n*) value for pervious surface and maximum infiltration rate. The parameters ranking from 4 to 8 have no significant impact on the sensitivity analysis.

Table 5.1: Ranking of the Effectiveness for Model Parameters on Runoff Volume and Peak Discharge.

Rank	**Effective Parameters**	**Runoff Volume (%)**	**Peak Discharge (%)**
1	Manning's n value for impervious	74.62	99.27
2	Manning's n value for pervious	62.89	92.18
3	Maximum infiltration rate	18.28	28.00
4	Decay rate of infiltration	9.11	17.08
5	Depression storage for impervious	6.95	16.74
6	Depression storage for pervious	6.39	11.72
7	Minimum asymptotic infiltration	4.76	9.02
8	ZD	2.28	6.54

5.3 Model Calibration

To calibrate the XP-SWMM model, the study catchment has been divided into 9 sub catchments according to existing main drain or canal (See Figure 5.3). Each sub catchment has its own set of input parameters. A total of 20 rainfall-runoff events were selected for model calibration from which 10 events were selected from year 2000 and another 10 events from year 2004 with imperviousness 60% (land use map 2002). The three most suitable automated rainfall stations to be used for analysis are Bandar Klang Station (3014080), Selat Muara Station (3013003) and Pusat Kawalan JPS, Telok Gong Station (2913001) with reference to the JPS Hydrology Section Malaysia. One gauging station situated near the river mouth under North Port was used to validate the simulated results. The available discharge and water level data period is from year 2000 to year 2015.

Figure 5.3: Schematic Map of the 9 Sub Catchments of Sungai Dua Besar.

Table 5.2: Input Values for 9 Sub Catchments (Fixed Parameters and Non Fixed Parameters).

Name	Slope (m/m) Fixed	Width (m) Fixed	Area (ha) Fixed	Impervious Percentage (%) Fixed	Manning's n value for impervious Non-Fixed	Manning's n value for pervious Non-Fixed	Maximum infiltration rate (mm/hr) Non-Fixed
SDB1	0.002	675	136.829	75	0.017	0.045	76.2
SDB2	0.003	918	176.844	50	0.017	0.045	152
SDB3	0.003	1254	209.782	50	0.0275	0.05	25
SDB4	0.001	1252	247.079	70	0.015	0.035	25
SDB5	0.005	650	205.488	65	0.017	0.045	25
SDB6	0.002	540	195.365	65	0.017	0.045	152
SDB7	0.005	3857	213.391	65	0.015	0.035	76.2
SDB8	0.01	978	202.508	50	0.015	0.035	76.2
SDB9	0.004	780	177.714	50	0.015	0.035	25

5.3.1 Calibration Process

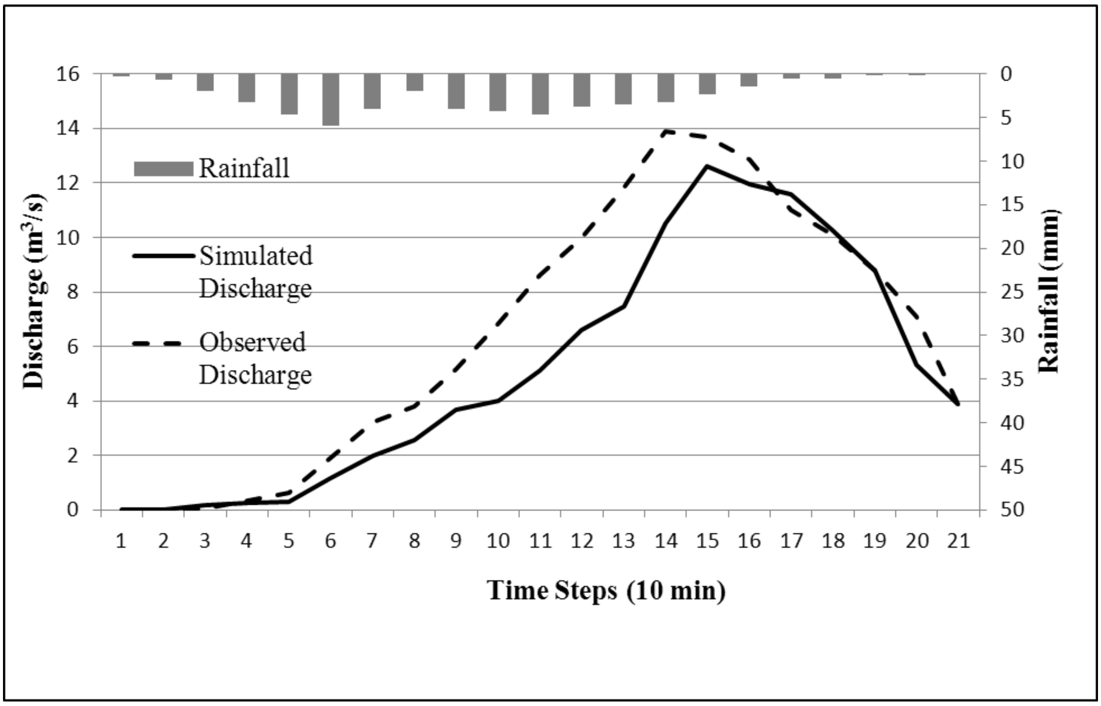
For this study, parameters such as imperviousness, catchment area, width and slope are fixed parameters and the values are measured accordingly to their sub catchments. For those 8 parameters that are not measured, sensitivity analyses need to be done. To develop a well calibrated hydrological (rainfall-runoff) model by XP-SWMM, the results of the sensitivity analyses were incorporated to identify the most influential parameters.

The fixed parameters (9 sub catchments) are referred to existing land use map 2002 and Table 5.2. Parameters which do not exceed 20% change in runoff volume and peak discharge will be assigned a constant value. The constant parameters values used in the calibration process are, minimum asymptotic infiltration = 1 mm/hr, decay rate of infiltration = 0.001l/s, depression storage for impervious = 1 mm, depression storage for previous = 2.5 mm and zero detention = 25%. Parameters that affect the runoff volume and peak discharge the most are Manning's n value for impervious, Manning's n value for pervious and maximum infiltration rate. These parameters are selected by their percentage change in runoff volume and peak discharge, which exceed 20% for each parameter.

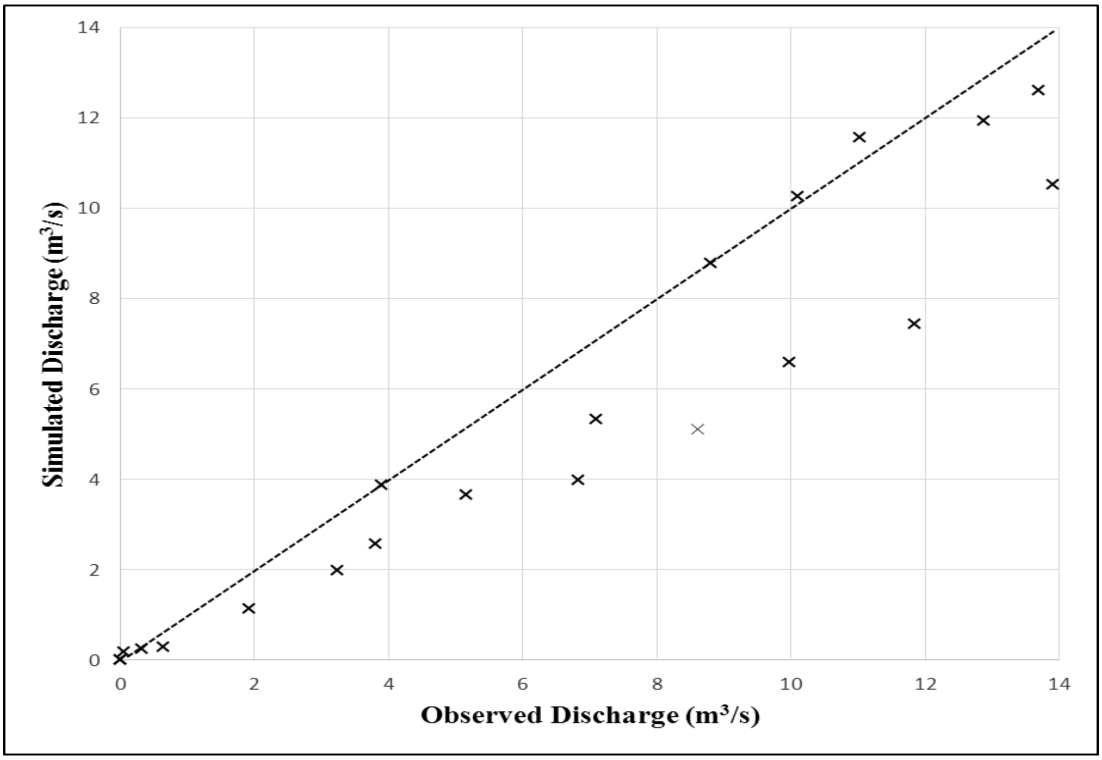
The average values after calibration for the effective parameters are presented in Table 5.3 and 2 sets of observed and simulated hydrograph with scatter plot for 2000 and 2004 were produced as illustrated from Figure 5.4 to Figure 5.5.

Table 5.3: Average Values of Important Model Parameters for Sub Catchments of the Study Site Considering 20 Calibration Events.

Name	**Manning's n value for impervious**	**Manning's n value for pervious**	**Maximum infiltration rate (mm/hr)**
SDB1	0.0245	0.0525	76.0857
SDB2	0.0245	0.0525	151.772
SDB3	0.035	0.0575	24.9625
SDB4	0.0225	0.0425	24.9625
SDB5	0.0245	0.0525	24.9625
SDB6	0.0245	0.0525	151.772
SDB7	0.0225	0.0425	76.0857
SDB8	0.0225	0.0425	76.0857
SDB9	0.0225	0.0425	24.9625

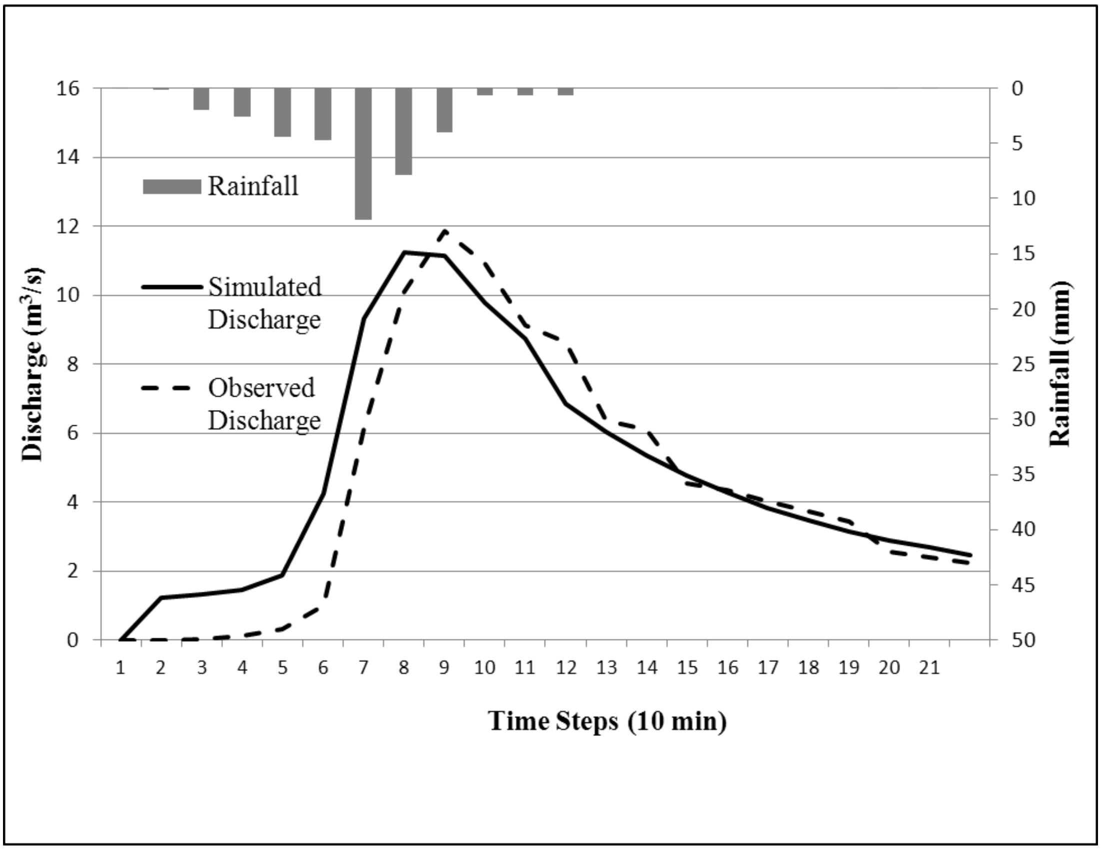


(a)

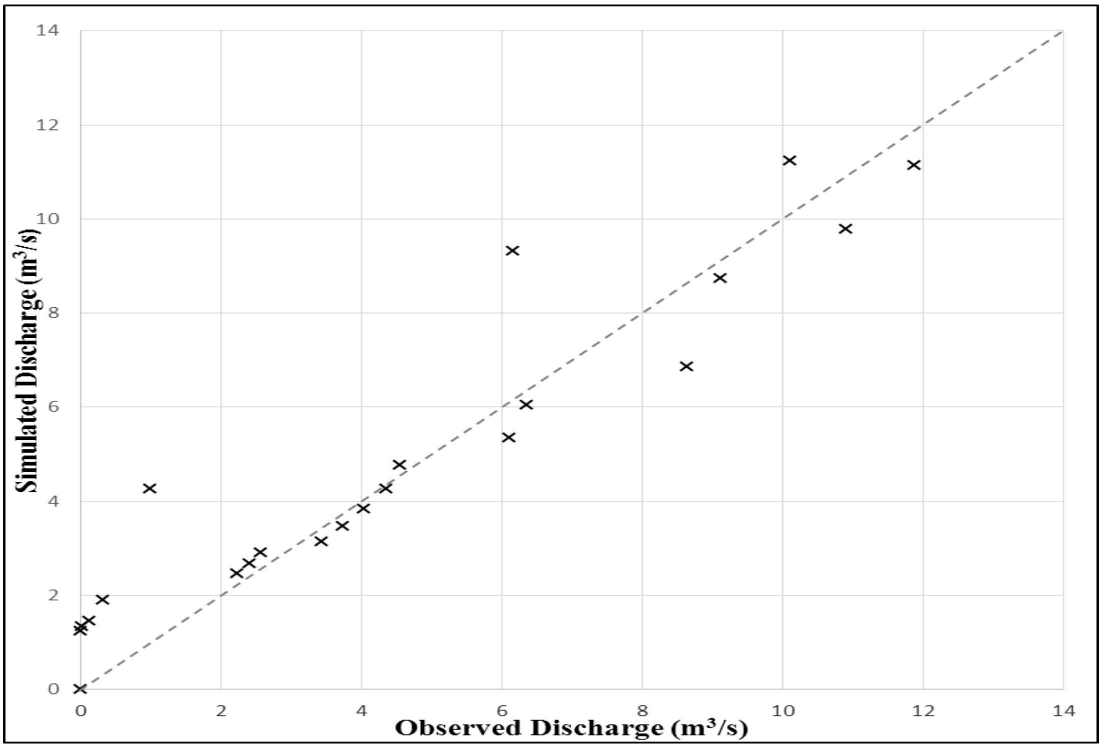


(b)

Figure 5.4: Observed versus Simulated Hydrograph by Calibrated XP-SWMM for Event 2/07/2000 in form of: (a) Hydrograph; (b) Scatter Plot (R^2: 0.894).



(a)



(b)

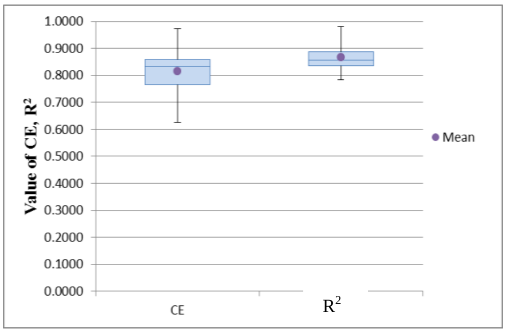
Figure 5.5: Observed versus Simulated Hydrograph by Calibrated XP-SWMM for Event 7/04/2004 in form of: (a) Hydrograph; (b) Scatter Plot (R^2: 0.914).

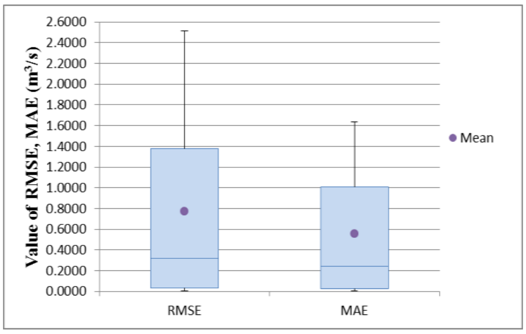
A total of 20 rainfall events (10 from 2000 and 10 from 2004) were employed to calibrate the rainfall-runoff model in estimating discharge and compared with observed values. The results of calibration stage is presented in Table 5.4. As can be seen, the performance of the model in predicting discharge river outlet is reasonably good as average CE value of 0.814 and R^2 value of 0.866 are indications of a very good level of goodness-of-fittness. The average value for RMSE and MAE is smaller with values of 0.771 m^3/s and 0.556 m^3/s. This indicated that the calibrated XP-SWMM model is not biased against errors in the simulation of flow events.

Table 5.4: Average, Minimum, Maximum and Standard Deviation values of CE, R^2, RMSE and MAE Obtained from 20 Calibration Events.

	CE	**R^2**	**RMSE (m^3/s)**	**MAE (m^3/s)**
Average	0.814	0.866	0.771	0.556
Min	0.625	0.785	0.005	0.004
Max	0.972	0.982	2.516	1.637
STDEV	0.086	0.050	0.863	0.611

Figure 5.6 show the box and whisker plot for CE, R^2, RMSE and MAE values obtained from simulations of the 20 events by XP-SWMM model. Generally, the variation CE and R^2 is relatively small. The median CE value of 0.834 and R^2 value of 0.857 attributed to the fact that the 20 events used in the calibration process performed well. The median value for RMSE and MAE is less than 0.400 m^3/s which indicates that the error is small.





(a) (b)

Figure 5.6: Box and Whisker Plot for (a) CE, R^2 (b) RMSE, MAE from 20 Calibration Events.

5.4 Model Validation

Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model adequately assesses the range of variables and conditions that are expected within the simulation. Moreover, validation is about testing the established parameter using an independent data set. The most effective procedure to validate a model is to use different data set of the available record of observed values for calibration and validation. The calibrated model was used to simulate runoff for the remaining events of year 2010 and 2015 (validation period) and compare it with observed runoff. Same as any calibration/validation process, the model parameters found during calibration were considered fixed during validation phase.

In recognition of the inherent variability in natural systems and unavoidable errors in field observations, the following characterization of the accuracy for peak discharge records are listed as below (Socolow et al., 1997):

Excellent Rating 95% of daily peak discharge are within 5% of the true value
Good Rating 95% of daily peak discharge are within 10% of the true value
Fair Rating 95% of daily peak discharge are within 15% of the true value

The records that do not meet these criteria are rated as 'poor value'. It is clearly shown that the model results for flow simulations from the calibration results are within these accuracy tolerances and considered acceptable for validation process as tabulated in Table 5.5 (Donigian 2000).

Table 5.5: Percentage Difference between Simulated and Observed Values of Peak Discharge for Calibration.

% Difference between Simulated and Observed Values	Peak Discharge
Very Good	<10
Good	10-15
Fair	15-25

In this study, validation of model was carried out using ten (10) (5 events from year 2010 and another 5 from year 2015). It is worth mentioning that, the land use map was available for year 2010 from Majlis Perbandaran Klang (MPK) land use maps; however, no land use map was available for the year 2015. Therefore, in the first stage of validation, the 5 events of year 2010 were simulated using the percentage of imperviousness from land use map while all other calibrated parameters (e.g. catchment width, catchment slope, etc.) were kept fixed. The performance of the model was evaluated by comparison between simulated runoff of the 5 rainfall-runoff events of 2010 and the observed runoff. In Phase II of validation, same approach was used for 2015 events except the percentage of imperviousness which was adopted from the the two proposed land use prediction scenarios (discussed in Chapter 4). Finally, in Phase III of validation, the percentage of imperviousness for 2015 events was adjusted to achieve the best fit between simulated and observed runoff. This procedure was done to revise the land use prediction scenarios which was supposed to lead the model towards better prediction for the year 2020.

5.4.1 Validation Results: Phase I – Year 2010 Events

The comparison between the simulated and observed runoff was carried out using several statistical measures including Nash-Sutcliffee Coefficient of Efficiency (CE), Coefficient of Determination (R^2), Root Mean Square Error (RMSE) , Mean Absolute Error (MAE) and Relative Peak Error (RPE). The average values of CE, R^2, RMSE, MAE, and RPE for the year 2010 events resulted by calibrated XPSWMM model are shown in Table 5.6. Before simulation, the percentage of imperviousness was changed from 60% in calibrated model to 72% based on the 2010 land use map. As it can be seen in Table 5.6, the average CE and R^2 values are reasonably high which is an indicatior of goodness-of-fit between observed and simulated runoff. This is also evident by small error measures (i.e. RMSE, MAE, RPE) obtained by the model.

Table 5.6: CE, R^2, RMSE, MAE and RPE Values Resulted by XP-SWMM Model for Events of Year 2010.

Event	**CE**	**R^2**	**RMSE (m3/s)**	**MAE (m3/s)**	**RPE**
2010-1	0.721	0.888	0.197	0.158	0.103
2010-2	0.854	0.885	0.061	0.037	0.037
2010-3	0.882	0.896	0.165	0.095	0.015
2010-4	0.747	0.890	0.235	0.179	0.191
2010-5	0.829	0.888	1.373	0.692	0.253
Average	**0.806**	**0.889**	**0.406**	**0.232**	**0.120**

5.4.2 Validation Results: Phase II – Year 2015 Events

In order to simulate the 2015 events, the percentage of imperviousness need to be predicted using the land use prediction scenarios of this study. Once calculated, this parameter will be considered in XP-SWMM model while all other parameters of the model will be kept fixed based on calibration values. From landuse study scenario (1), the projected imperviousness for year 2015 can be obtained as 80% (Detailed calculation can be found in Appendix 2).

The results of simulated runoff for 2015 events in terms of CE, R^2, RMSE, MAE, and RPE are presented in Table 5.7 and Table 5.8 for the land use data generated by scenarios 1 and 2, respectively. From the validation results of 2015 events, it can be infered that scenario 1 has produced slightly better results compared with the ones obtained by scenario 2.

Table 5.7: CE, R^2, RMSE, MAE and RPE Values Resulted by XP-SWMM Model for Validation Events of Year 2015 using Land Use Prediction of Scenario 1.

Event	**CE**	**R^2**	**RMSE (m3/s)**	**MAE (m3/s)**	**RPE**
2015-1	0.687	0.908	0.344	0.257	0.004
2015-2	0.656	0.869	0.461	0.398	0.190
2015-3	0.833	0.933	0.392	0.305	0.014
2015-4	0.871	0.887	0.581	0.380	0.025
2015-5	0.916	0.921	1.413	0.806	0.045
Average	0.793	0.904	0.638	0.429	0.056

Table 5.8: CE, R^2, RMSE, MAE and RPE Values Resulted by XP-SWMM Model for Validation Events of Year 2015 using Land Use Prediction of Scenario 2.

Event	**CE**	**R^2**	**RMSE (m3/s)**	**MAE (m3/s)**	**RPE**
2015-1	0.728	0.895	0.320	0.237	0.008
2015-2	0.783	0.898	0.366	0.317	0.014
2015-3	0.868	0.900	0.349	0.280	0.017
2015-4	0.857	0.877	0.611	0.391	0.048
2015-5	0.663	0.865	2.838	1.909	0.048
Average	0.780	0.887	0.897	0.627	0.027

5.4.3 Validation Results: Phase III – Adjustment of the land use prediction model

The next step in this study is to explore the best fitted value for imperviousness for year 2015. In this phase, imperviousness value of Scenario 1 (80% impervious ness) was adopted as basis since it produced better results compared to the one by scenario 2 (See Tables 5.7 and 5.8). Therefore, different imperviousness values around 80% were examined to identify the best goodness-of-fit between simulated and observed hydragraphs. For this 5%, 2%, -2%, -5%, -7%, -10%, -13%, and -15% changes were applied to imperviousness of 80% while the other model parameters were kept fixed. It is worth mentioning that the local council (Majlis Perbandaran Klang) has a more moderate prediction model for land use compared to the proposed Scenarios 1 and 2 (See Chapter 4). Assuming that the policies of local council in controling the urbanization has been implemented and it is ongoing, it is expected to find lower percentage of imperviousness for the 2015 events after this exercise. The results of simulated runoff for 2015 events in terms of CE, R^2, RMSE, MAE, and RPE are presented in Table 5.9 for different values of percentage of imperviousness used in this validation process.

Table 5.9: CE, R^2, RMSE, MAE and RPE Values Resulted by XP-SWMM Model for Events of Year 2015 for Different Imperviousness Values Around 80%.

Percentage	**Event**	**CE**	**R^2**	**RMSE (m3/s)**	**MAE (m3/s)**	**RPE**
+5% (i.e. 85%)	2015-1	0.642	0.877	0.368	0.272	0.048
	2015-2	0.765	0.895	0.381	0.331	0.014
	2015-3	0.849	0.887	0.373	0.305	0.004
	2015-4	0.842	0.861	0.643	0.429	0.048
	2015-5	0.600	0.864	3.090	2.138	0.085
	Average	0.740	0.877	0.971	0.695	0.040
+2% (i.e. 82%)	2015-1	0.728	0.895	0.320	0.237	0.008
	2015-2	0.783	0.898	0.366	0.317	0.014
	2015-3	0.868	0.900	0.349	0.280	0.017
	2015-4	0.857	0.877	0.611	0.391	0.048
	2015-5	0.663	0.865	2.838	1.909	0.048
	Average	0.780	0.887	0.897	0.627	0.027
-2% (i.e. 78%)	2015-1	0.700	0.909	0.339	0.253	0.004
	2015-2	0.661	0.870	0.458	0.394	0.190
	2015-3	0.839	0.931	0.384	0.292	0.014
	2015-4	0.873	0.889	0.575	0.372	0.025
	2015-5	0.917	0.922	1.408	0.801	0.045
	Average	0.797	0.904	0.633	0.422	0.056
-5% (i.e. 75%)	2015-1	0.741	0.955	0.312	0.249	0.057
	2015-2	0.660	0.915	0.459	0.360	0.116
	2015-3	0.836	0.932	0.388	0.298	0.007
	2015-4	0.881	0.892	0.557	0.353	0.010
	2015-5	0.921	0.926	1.370	0.745	0.045
	Average	0.808	0.924	0.617	0.401	0.047
-7% (i.e. 73%)	2015-1	0.770	0.957	0.295	0.233	0.055
	2015-2	0.687	0.915	0.440	0.346	0.113
	2015-3	0.842	0.932	0.381	0.286	0.005
	2015-4	0.886	0.897	0.546	0.335	0.010
	2015-5	0.922	0.927	1.362	0.733	0.044
	Average	0.821	0.926	0.605	0.387	0.045
-10% (i.e. 70%)	2015-1	0.795	0.975	0.278	0.224	0.057
	2015-2	0.718	0.916	0.418	0.329	0.103
	2015-3	0.844	0.932	0.378	0.282	0.007
	2015-4	0.912	0.917	0.480	0.322	0.004
	2015-5	0.924	0.929	1.351	0.724	0.045
	Average	**0.838**	**0.934**	**0.581**	**0.376**	**0.043**

Percentage	Event	CE	R^2	RMSE (m3/s)	MAE (m3/s)	RPE
-13% (i.e. 67%)	2015-1	0.768	0.957	0.296	0.234	0.053
	2015-2	0.682	0.914	0.443	0.351	0.131
	2015-3	0.841	0.932	0.383	0.288	0.005
	2015-4	0.887	0.899	0.543	0.335	0.009
	2015-5	0.923	0.927	1.357	0.729	0.044
	Average	0.820	0.926	0.604	0.387	0.049
-15% (i.e. 65%)	2015-1	0.749	0.958	0.308	0.246	0.057
	2015-2	0.662	0.914	0.457	0.357	0.133
	2015-3	0.840	0.931	0.383	0.291	0.007
	2015-4	0.884	0.894	0.551	0.346	0.010
	2015-5	0.922	0.927	1.361	0.735	0.045
	Average	0.811	0.925	0.612	0.395	0.050

As can be seen, the best results were obtained when imperviousness was reduced by 10% (i.e. was made to scenario 1 imperviousness value of 80%). Thus, the new value of imperviousness for the year 2015 will be 70% x 1765 ha = 1236 ha. Since a new data point is found for year 2015, the fitted equation of Scenario 1 was then revised accordingly and is presented in Figure 5.7 and 5.8.

The values of imperviousness for the year 1966, 1984, 2002, 2010 and 2015 were plotted to see the new trend for urbanized area and non-urbanized area.

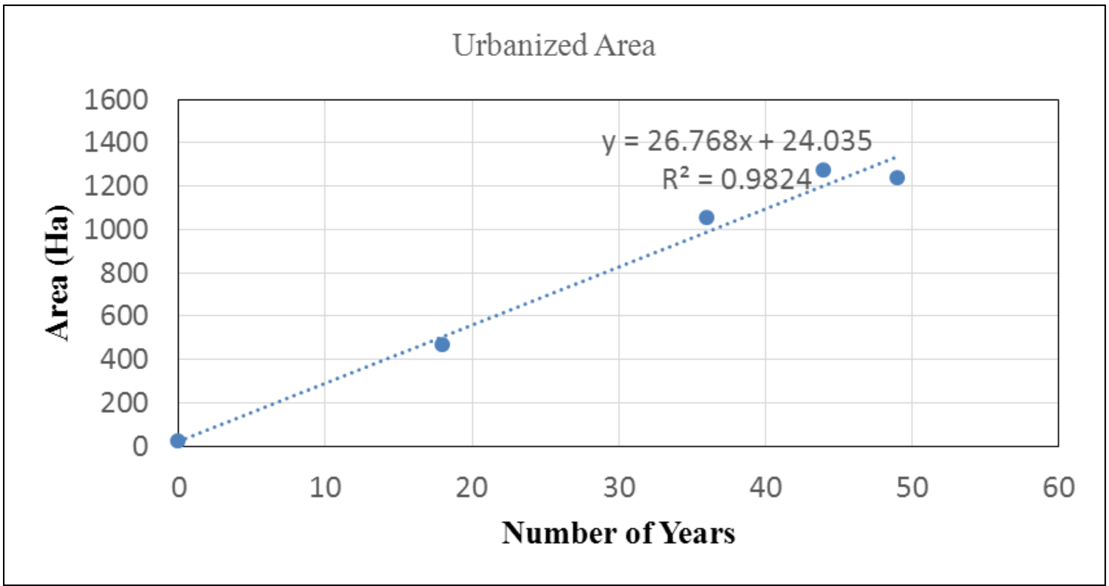


Figure 5.7: Plot of Urbanized Area for Years 1966, 1984, 2002, 2010 and 2015.

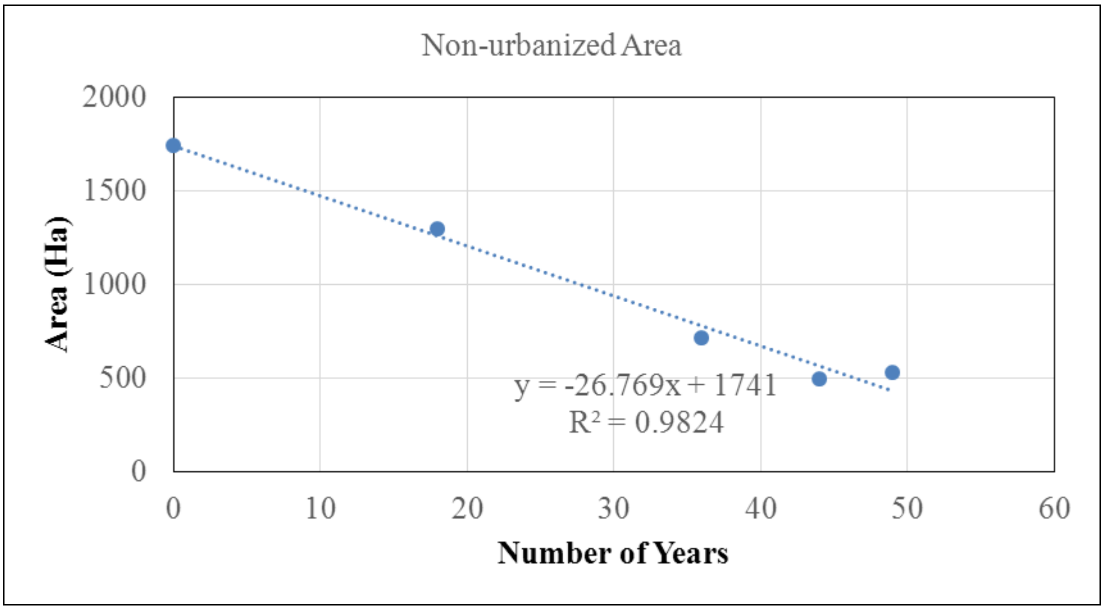


Figure 5.8: Plot of Non-Urbanized Area for Years 1966, 1984, 2002, 2010 and 2015.

The imperviousness for future land use year 2020 was obtained using the fitted equation of Scenario 1:

Y=26.768X + 24.035 where X=2020-1966=54 years

Y=26.768(54) + 24.035 Y=urbanized area 2020

Y=1470 ha (83%)

The non-urbanized area for future land use year 2020

=1765ha – 1470ha

=295ha

CHAPTER 6
HYDRAULIC MODEL DEVELOPMENT

6.1 Introduction

In this chapter, hydraulic modeling for Sungai Dua Besar is performed. Hydraulic model is used to simulate the flow in the river and to predict the flooded area. The runoff hydrographs generated from hydrological modeling (Chapter 5) are used as main input to the hydraulic model in this chapter. Other important inputs for this hydraulic modeling include geometry data of the river (such as Digital Elevation Model or DEM) and the river cross sections (resulted by river surveying). Similar to the hydrologic model, XP-SWMM is used to develop a hydraulic model for Sungai Dua Besar catchment. The calibrated XP-SWMM hydraulic model is then employed to simulate the peak discharge of various design storms in study site.

6.2 Hydraulic Model Development

6.2.1 XP-SWMM Model

The hydraulic model used in this study is XP-SWMM, which is a 2-D dimension model. XP-SWMM uses a node-link concept to represent the drainage system, whereby links represented hydraulic elements of the flow in the system. Model offers many different types of conduits for simulation including sewer pipes, channel reaches or culvert; nodes are represented as pond or lake, junctions, outfalls or other physical transition points along the links.

Flooding in Sungai Dua Besar is attributed mainly to its natural low ground levels as many coastal areas in this catchment fall below the high spring tide level of 2.25m RL. River levels at the more inland areas rises during the high spring tide level and severe storm due to backwater effect. During times of the astronomical tide of 3.08m RL, more places will be affected. However, such event is extreme and its occurrence is rare. Besides that, fragmentation and insufficient drainage system in the urbanized areas can be considered as the other major contributor to flooding issues in Sungai Dua Besar.

Hydraulic model was developed using surveyed cross-section data. The hydrographs were routed by the model. In developing the hydraulic model, the existing drainage network with the existing land use and drainage infrastructure was used. The future land use was then simulated to propose some improvement works to mitigate the effects of increased runoff due to urbanization.

For areas yet to be developed, the most optimal flood mitigation measure is to raise the property platform levels to 100 years ARI flood levels and fully compliance to MSMA in relation to the attenuation of post development flood discharges into the pre development flood discharge. The raising of the platform levels shall be implemented as a condition for the developers to comply at the time the area is developed or redeveloped.

6.2.2 Tides and Flood Levels at Main River Drainage Outlets

The outfall or discharge point in this study area is the existing stormwater drain or channel. The procedure for calculating the hydraulic grade line or backwater analysis through a storm drainage system begins at the discharge point/ outfall. Therefore, consideration of outfall/ discharge point is an important part of the storm discharge hydraulic modelling.

Sungai Dua Besar Catchment shows that tides are semidiurnal with two cycles of approximately equal heights occurring within a day (each cycle is about 12 hours). Table 6.1 shows the general tidal levels for Port Klang station, as extracted from Port Klang Marine Handbook Updated (May 2010).

Table 6.1: General Tidal Levels for Port Klang Station.

Tide	Water Level Chart Datum	Reduced Water Level (chart datum at +3.864m CD)
Highest Astronomical Tide (HAT)	6.10 m	3.08
Mean High Water Spring (MHWS)	5.27 m	2.25
Mean High Water Neaps (MHWN)	3.89 m	0.87
Mean Sea Level (MSL)	3.02 m	0.00
Mean Low Water Spring (MLWS)	2.52 m	-0.50
Mean Low Water Neaps (MLWN)	1.15 m	-1.87
Lowest Astronomical Tide (LAT)	0.00 m	-3.02

(Source: Admiralty Tide Tables Vol.3 & Malaysian Tide Tables Vol.1)

The Astronomical Tides are rare extreme events and generally used in the derivation of drainage outlets design flood levels of the high ARI (e.g. 100 years). The Mean Spring Tides, i.e. MHWS and MLWS are therefore used for design water levels at the drainage outlets for 10 years ARI.

All the catchments in the study area are discharging directly into the sea, the main river outlet design flood levels shall be the MHWS and MLWS of + 2.25 m RL and – 0.5 m RL for the 10 years ARI while HAT of +3.08 m RL and –0.5 m RL for 100 years ARI. The determination of an appropriate study tail water level is facilitated at channel or section where the flow velocity is effectively zero. It is not possible to provide specific recommendation but it can be referred to Table 6.2 (MSMA 1st Edition, DID 2000) on design water levels at various outlets for catchment.

Table 6.2: Design Water Levels at Various Outlets for Catchment.

Locations	**Design Tidal 0utfall Water Levels**
Location 1: Northport (Sg. Dua Besar)	MHWS (10 years ARI) HAT (100 years ARI)

6.2.3 Land Use Scenarios

In this chapter, the modelling was carried out for the following scenarios:

i. Existing drainage infrastructure under existing land use for year 2000 and 2004.
ii. Existing drainage infrastructure under existing land use for year 2010, and 2015.

Flooded areas were interpreted as the area for which High Ground Level (HGL) is equal or exceeding the spill crest value. Ground level is the level for which the HGL is between spill crest and invert while freeboard is defined as safety elevation to the spill crest. Crown is the level for which HGL is between highest crown value and invert.

6.2.4 Design Storm Return Periods and Tail Waters at Drainage Outlets

The study area is urbanized with a higher density in the region. Urbanisation is expected to spread from this focal point. For coastal and tidal outlets, the Highest Astronomical Tide (HAT) is recommended for the major storm while the Mean High Water Spring (MHWS) tide is recommended for the minor system. In general, the design storm for the drainage systems and the corresponding tail water conditions are tabulated in Table 6.3 below.

Table 6.3: Tail Water Condition.

Storm ARI (years)	Coastal Outlets
2	MHWS
10	MHWS
50	HAT
100	HAT

(Source: MSMA 1st Edition Chapter 46, DID 2000)

6.2.5 Input Data

The XP-SWMM hydraulic model uses the generated discharge of hydrologic modeling, to estimate water level in different given river cross sections. Once calibrated, model can help in assessing flow behavior in the river (or channel). To develop XP-SWMM hydraulic model, several inputs are required including: geometric data (river length, width, depth, Manning's n value etc.) and the inflow data (simulated data comes from hydrological model).

The geometric data contains all the relevant geometry necessary for hydraulic modeling. It establishes the connectivity of the river network (using Global Data – Natural Section Shapes for network referencing) and cross-section data (to include Manning's n resistance factors, left and right overbank). For this Study, a length of 2.55km main river of Sungai Dua, 51 cross sections at 50m interval were considered.

The LIDAR data supports the cross-sectional survey data in a way where the LIDAR data completes the floodplain area not covered by the survey data in XP-SWMM 2-D model. In the river flood hazard study in Sungai Dua Besar river basin, the TIN-based terrain model is used to differentiate stream banks from the rest of the terrain. The stream centreline is defined according to the lowest level in each point along the river. The extents of cross-sections are assigned as a wide width (1km) to be sure that generated flood will be included.

Visualization of river flood events in XP-SWMM requires a detailed representation of the river corridor including river and its floodplain terrain to accurately depict flood inundation. The LIDAR data can develop the terrain model but it is not the optimum data source. Availability of more accurate terrain depictions, like digital orthographic photo images, vector-based contour themes or Triangulated Irregular Networks (TIN's) usually provide more accurate terrain representations of the catchment. TINs are created by a random mesh of triangles that best fit the depiction of the terrain. Additional themes in GIS like roads, buildings, levees and railroad, can also be integrated into the spatial model to improve upon the accuracy of the terrain model. Since this research is GIS-based, the digital maps were purchased from Department of Survey and Mapping, Malaysia (JUPEM) instead of using traditional topographic maps (i.e. hardcopy form). The size of each segment of the digital topographic map is about 43.5 km^2 with 1:10,000 scaling. According to the location and area of the Sungai Dua Besar river basin, topographic maps were needed to cover the entire river basin area. All the maps were in the form of DXF files and they needed to be combined using AutoCAD. Then, all DXF maps were converted to Shape File (.SHP) in order to be used in GIS environment. Interval elevation for the digitized maps was considered to be 1m.

Once the geometric data were imported into the XP-SWMM Global Data – Natural Section Shapes editor, the Manning's n values were manually provided for each cross-section based on the Table 2.3 from MSMA 2^{nd} Edition (DID, 2012).

In order to eliminate the back water effect and also the effect of user-defined boundary conditions on the results in outlet, XP-SWMM hydraulic model was run to calculates the further upstream water level according to the generated hydrograph in Runoff Mode and respective geometry data. The overall input data is in Appendix 3.

6.3 Model Calibration

The calibration process of XP-SWMM hydraulic model for Sungai Dua Besar river basin includes a total of 20 flood events. Table 6.4 shows the flow discharge of calibration events. The lowest and highest discharges used in calibration process of XP-SWMM for Sungai Dua Besar river basin are 0.03 m^3/s and 66.36 m^3/s, respectively. The major events chosen for calibration are selected from the historical data from the years 2000 and 2004 for the water level station located at the outlet of the river.

In order to calibrate the hydraulic model, the sensitive parameters of the model were adjusted so the model can simulate discharge as close as possible to the observed values.

Table 6.4: Simulated and Observed Peak Discharge Values of Calibration Events in Sungai Dua Besar Hydraulic Model.

No	**Date of Events**	**Simulated Discharge(m^3/s)**	**Observed Discharge(m^3/s)**	**No**	**Date of Events**	**Simulated Discharge(m^3/s)**	**Observed Discharge(m^3/s)**
1	2000-3	2.099	2.233	11	2004-1	1.843	1.895
2	2000-1	1.308	1.342	12	2004-10	1.408	1.425
3	2000-6	1.265	1.277	13	2004-5	1.301	1.325
4	2000-5	1.160	1.193	14	2004-2	0.965	0.982
5	2000-10	1.111	1.140	15	2004-7	0.878	0.886
6	2000-2	1.081	1.116	16	2004-4	0.841	0.853
7	2000-9	0.798	0.805	17	2004-9	0.813	0.825
8	2000-8	0.439	0.459	18	2004-6	0.481	0.493
9	2000-4	0.223	0.246	19	2004-8	0.095	0.105
10	2000-7	0.104	0.111	20	2004-3	0.059	0.063

For further comparison, the simulated and observed water levels are compared in a scatter plot presented in Figure 6.1. As can be seen, a high goodness-of-fit was observed as the resulted R^2 was very close to 1.

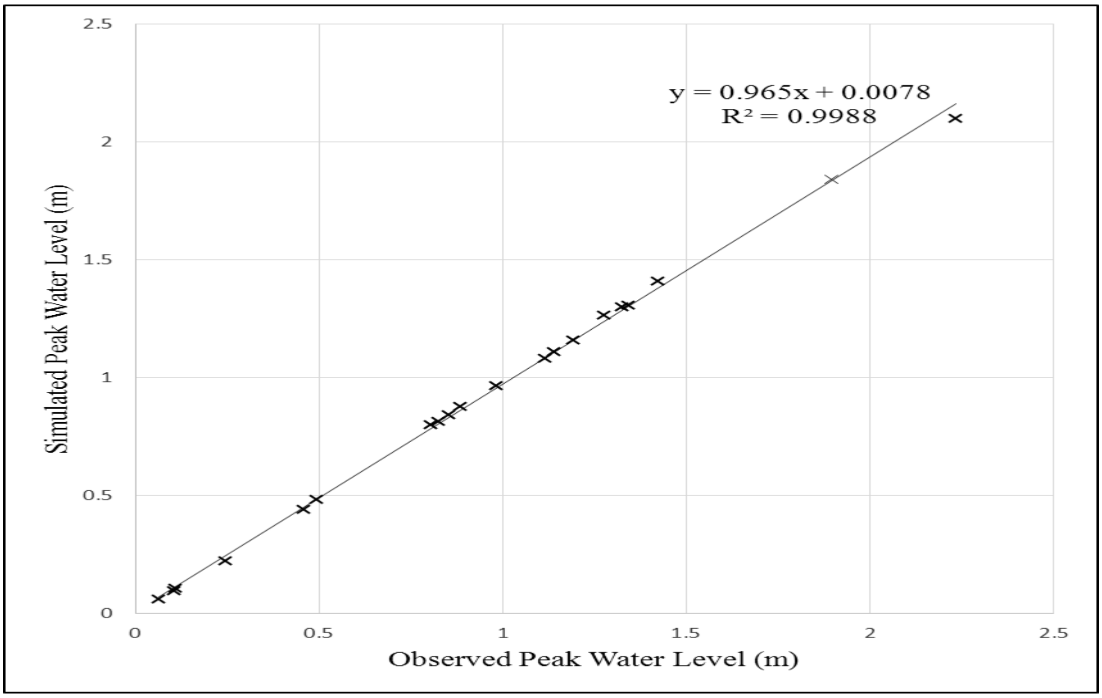


Figure 6.1: Scatter Plot of Observed versus Simulated Peak Water Level for Calibration Events.

Table 6.5: CE, R^2, RMSE, MAE and RPE for 20 Calibration Events.

Date of Events	**CE**	**R^2**	**RMSE(m)**	**MAE (m)**	**RPE**
2000-3	0.9412	0.9540	0.1016	0.085	0.060009
2000-6	0.8349	0.8969	0.1932	0.119	0.009397
2000-9	0.8019	0.8539	0.0626	0.053	0.008696
2000-2	0.8762	0.9711	0.0554	0.047	0.031360
2000-1	0.8231	0.9311	0.0973	0.079	0.025335
2000-5	0.8653	0.9349	0.0676	0.054	0.027661
2000-7	0.8010	0.8036	0.0101	0.008	0.063063
2000-8	0.8126	0.8587	0.0251	0.019	0.043990
2000-4	0.8525	0.9744	0.0111	0.009	0.093496
2000-10	0.9420	0.9509	0.1393	0.111	0.026289
2004-8	0.8147	0.8643	0.0119	0.009	0.095240
2004-5	0.8022	0.8904	0.0960	0.078	0.018113
2004-10	0.8949	0.9094	0.0787	0.069	0.011930
2004-2	0.9337	0.9546	0.0305	0.022	0.017312
2004-4	0.9004	0.9187	0.0890	0.076	0.014070
2004-3	0.8060	0.8191	0.0025	0.002	0.063492
2004-6	0.9140	0.9759	0.0166	0.015	0.024341
2004-1	0.8350	0.8874	0.1356	0.092	0.027441
2004-7	0.9302	0.9875	0.0143	0.012	0.009030
2004-9	0.8377	0.8895	0.0423	0.035	0.014550
Average	**0.8610**	**0.9113**	**0.0640**	**0.0497**	**0.0342**

More detailed comparison between observed and simulated water level time series are provided in Table 6.5 in terms of several statistics including CE, R^2, RMSE, MAE and RPE. As can be seen, all CE and R^2 values are above 0.8 which is an indication of a high goodness-of-fitness between observed and simulated values. Moreover, calibrated model was performed well in peak estimation as all RPE values fell below 10% with an average value of 3.4%.

6.4 Model Validation

Once the calibration of hydraulic model was completed, its performance was evaluated for validation events. In this study, 10 rainfall events from year 2010 and 2015 (5 from each) were selected from the historical data for validation of the model. It is worth mentioning that the validation dataset contains two major events with peak discharge values of 10.59m^3/s and 16.58m^3/s as shown in Table 6.6. In general the peak discharge values were changing in a range between 0.43m^3/s and 16.58m^3/s.

Table 6.6: Peak Discharge Values of Events (Initial) used to Validate Hydraulic Model in Sungai Dua Besar.

No	Date of Events	Observed Discharge (m^3/s)
1	2010-5	10.59
2	2010-3	1.95
3	2010-4	1.91
4	2010-1	1.09
5	2010-2	0.43
6	2015-5	16.58
7	2015-4	5.33
8	2015-3	3.26
9	2015-2	3.07
10	2015-1	1.80

During validation, all model parameters were kept fixed as what found after model calibration. Observed versus simulated peak water level by hydraulic model for validation events are shown in a scatter plot in Figure 6.2. As can be seen, the peak water level is predicted very well as the R^2 between observed and simulated peak water levels was very close to 1.

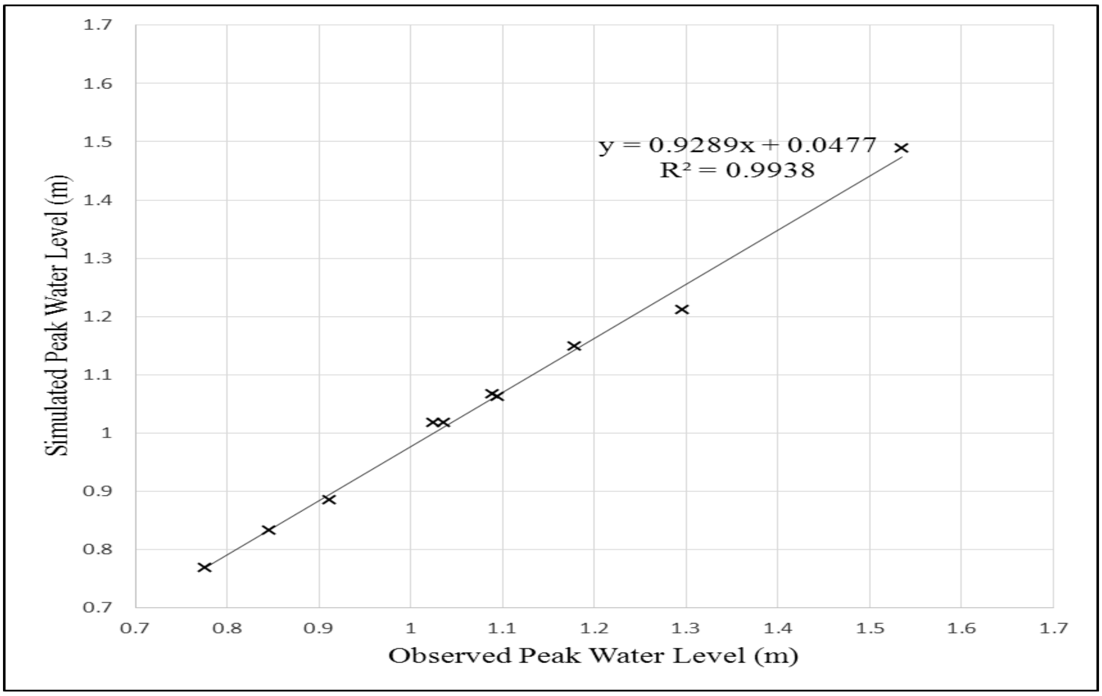


Figure 6.2: Scatter Plot of Observed versus Simulated Peak Water Level for Validation Events.

For further comparison, the goodness-of-fitness between observed and simulated water level time series are compared in terms of CE, R^2 , RMSE, MAE and RPE in Table 6.7. As can be seen, all validation events are simulated quite well as all CE and R^2 values are above 0.8 and 0.9, resepctively which is an indication of good fitness. Moreover, model performance in peak estimation was found to be well since the average RPE value was 2.52% which is signifcantly good.

Table 6.7: CE, R^2, RMSE, MAE and RPE for 10 Validation Events.

Date of Event	**CE**	**R^2**	**RMSE (m)**	**MAE (m)**	**RPE**
2010-1	0.8999	0.9446	0.0344	0.028	0.016548
2010-2	0.8099	0.8832	0.0335	0.029	0.01031
2010-3	0.8004	0.9632	0.0445	0.041	0.01834
2010-4	0.8135	0.8271	0.0425	0.036	0.00683
2010-5	0.8056	0.8904	0.1011	0.073	0.06481
2015-1	0.8966	0.9821	0.0929	0.081	0.0296
2015-2	0.8812	0.8902	0.1063	0.050	0.0202
2015-3	0.9422	0.9690	0.0741	0.059	0.0301
2015-4	0.9177	0.9691	0.0994	0.080	0.0254
2015-5	0.9312	0.9653	0.1308	0.093	0.02997
Average	**0.8698**	**0.92842**	**0.07595**	**0.057**	**0.0252**

Validation of a hydraulic model only in catchment outlet is basically not enough. As there was no mid-point water measurement station in the catchment river, it was decided to consider an on-site water level and discharge data collection in a point further upstream of the catchment outlet during the monsoon period of November-December 2016. These data were used for further validation of the hydraulic model in simulating water level in the study catchment. During this data collection period, total of 5 major events were captured for which the peak discharge values are provided in Table 6.8. The scatter plot of observed versus simulated peak water levels for the new validation data set (i.e. the mid-point data set) is illustrated in Figure 6.3. As can be seen, the performance of the model for an on-site water level measurement for a mid-point is quite promising as the R^2 was very close to 1.

Table 6.8: Flood Events for Hydraulic Model Validation in Sungai Dua Besar.

No	**Date of Events**	**Observed Discharge(m^3/s)**
1	2016-1	16.65
2	2016-2	15.92
3	2016-3	15.40
4	2016-4	0.81
5	2016-5	0.01

It also showed from Figure 6.3 that the coefficient of determination R^2 of observed and simulated water levels is 99% accurate.

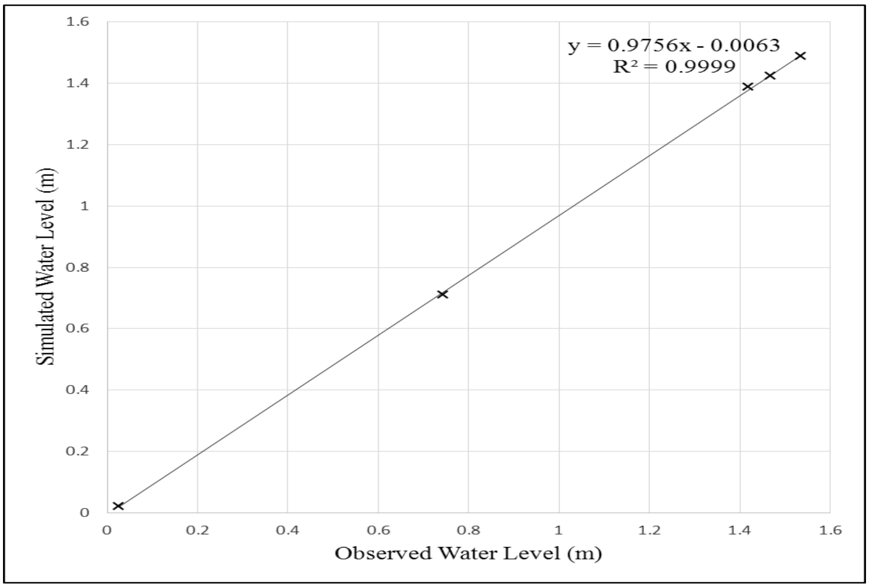


Figure 6.3: Plotted Graph for Simulated Water Level vs Observed Water Level (Year 2016).

For further comparison, the goodness-of-fitness between observed and simulated water level time series are again compared in terms of CE, R^2 , RMSE, MAE and RPE in Table 6.9. As can be seen, all validation events are simulated quite well as all CE and R^2 values are above 0.8, resepctively which is an indication of good fitness. Moreover, model performance in peak estimation was found to be well since the average RPE value was 2.09% which is signifcantly good.

Table 6.9: CE, R^2, RMSE, MAE and RPE for 5 Validation Events.

Date of Event	**CE**	**R^2**	**RMSE (m)**	**MAE (m)**	**RPE**
2016-1	0.8769	0.9236	0.0322	0.026	0.01553
2016-2	0.8012	0.8711	0.0356	0.022	0.01121
2016-3	0.8031	0.8734	0.0475	0.039	0.01762
2016-4	0.8146	0.8621	0.0433	0.033	0.00565
2016-5	0.8077	0.8808	0.1211	0.069	0.05443
Average	**0.8207**	**0.8822**	**0.05594**	**0.0378**	**0.020888**

CHAPTER 7
RIVER FLOOD MODELLING

7.1 Introduction

The key principal of river flood modelling is to ensure that it will be able to represent the real flood condition at site so the outcome of the model can be used in flood map and flood risk management. By practising the flood modelling in flood management, the stakeholders can plan and design infrastructures and mitigate the impact of this natural disaster.

7.2 Design Rainfall for Sungai Dua Besar

Design rainfall duration is an important parameter that defines the rainfall depth or intensity for a given frequency, and therefore affects the resulting runoff peak discharge and volume. The design rainfall must reflect required levels of protection, the local climate, and river basin conditions; it needs not be scientifically rigorous. Rainfall event should be defined in way that covers different range of applicability and also ensures safe, economical, and standardized design.

Design rainfalls can be categorized into two main types: synthetic and actual (historic) rainfall events. Synthetic rainfall event are normally made by generalization of a large number of actual rainfall events while the actual events are the ones which have occurred in the past and their impacts on drainage system may be well-documented. In urban drainage design, it is commonly practical to use synthetic design rainfalls. Intense rainfalls with short durations usually occur within longer-duration rainfalls rather than as isolated events. The theoretically correct practice is to compute discharge for several design rainfalls with different durations, and then choose the "critical" one that produces maximum discharge. However, the "critical" rainfall duration determined in this way may not be the most critical for storage design. Recommended practice for river basins containing storage is to compute the design flood hydrograph for several rainfalls with different durations equal to or longer than the time of concentration for the river basin and use the one which produces the most severe effect on the pond size and design discharge.

The temporal distribution of rainfall within the design rainfall is an important factor that affects the runoff volume, magnitude and timing of the peak discharge. Design rainfall temporal patterns are used to represent the typical variation of rainfall intensities during a typical rainfall burst. Standardization of temporal patterns allows standard design procedures to be adopted in direct runoff flow calculation. It is important to emphasize that the rainfall temporal patterns are intended for use in hydrograph generation for design storms. They should not be confused with the real rainfall data in historical storms, which is usually required to calibrate and validate hydrological and hydraulic simulation results. The standard time intervals recommended for urban stormwater modelling are listed in Table 7.1 (MSMA 1st Edition, DID 2000).

Table 7.1: Recommended Intervals for Design Rainfall Temporal Pattern.

Storm Duration (minutes)	**Time Interval (minutes)**
Less than 60	5
60 – 120	10
121 – 360	15
Greater than 360	30

The generation of design hydrograph is accomplished by using XP-SWMM model. The IDF curves for, three different ARI of 20, 50, and 100 years, were used to derive the design rainfall as an input to XP-SWMM runoff (hydrological) model. Duration of rainfall events were selected according to two criteria, first the time of concentration of the river basin which is equal to 1 hour, secondly with consideration to the availability of spatial temporal pattern in Storm Water Management Manual for Malaysia which is used as a reference in this research (rainfall temporal patterns derived for 15, 30, 60, 120, 180, and 360 minutes). Table 7.2 shows the calculated rainfall intensity for Sungai Dua Besar river basin for three different ARI and six different durations. To generate design storm hyetograph, standardized temporal pattern was used. Standardized profiles, also known as temporal patterns will transform a precipitation event to a dimensionless block with cumulative fraction of storm time on the horizontal axis and cumulative fraction of total rainfall on the vertical axis. Table 7.3 to 7.4 illustrate the rainfall depths and rainfall temporal distributions of 20 years, 50 years and 100 years ARI with event duration of 15, 30, 60, 120, 180, and 360 minutes. Figure 7.1 is the rainfall hyetograph for the station involved.

Table 7.2: Estimated Rainfall Intensity (mm/hr) for Pusat Kawalan JPS, T. Gong Station (2913001).

Rainfall intensity (mm/hr)	**15 min**	**30 min**	**60 min**	**120 min**	**180 min**	**360 min**
20	195	160	89	55	38	22
50	250	165	100	60	45	26
100	270	190	140	70	50	28

Table 7.3: Estimated Rainfall Depth (mm) for Pusat Kawalan JPS, T. Gong Station (2913001).

Rainfall Depth (mm)	**15 min**	**30 min**	**60 min**	**120 min**	**180 min**	**360 min**
20	48.75	80	89	110	114	132
50	62.5	82.5	100	120	135	156
100	67.5	95	140	140	150	168

Table 7.4: Temporal Distributions of Rainfall for different event duration in Pusat Kawalan JPS, T. Gong Station (2913001).

No of Rainfall Block According To Time Interval (Table 7.1)	**15 min**	**30 min**	**60 min**	**120 min**	**180 min**	**360 min**
1	0.255	0.124	0.053	0.053	0.053	0.044
2	0.376	0.13	0.059	0.06	0.061	0.081
3	0.37	0.365	0.063	0.063	0.063	0.083
4		0.152	0.087	0.084	0.08	0.09
5		0.126	0.103	0.115	0.128	0.106
6		0.103	0.153	0.152	0.151	0.115
7			0.11	0.12	0.129	0.114
8			0.088	0.193	0.097	0.09
9			0.069	0.074	0.079	0.085
10			0.06	0.061	0.062	0.081
11			0.057	0.056	0.054	0.074
12			0.046	0.044	0.042	0.037

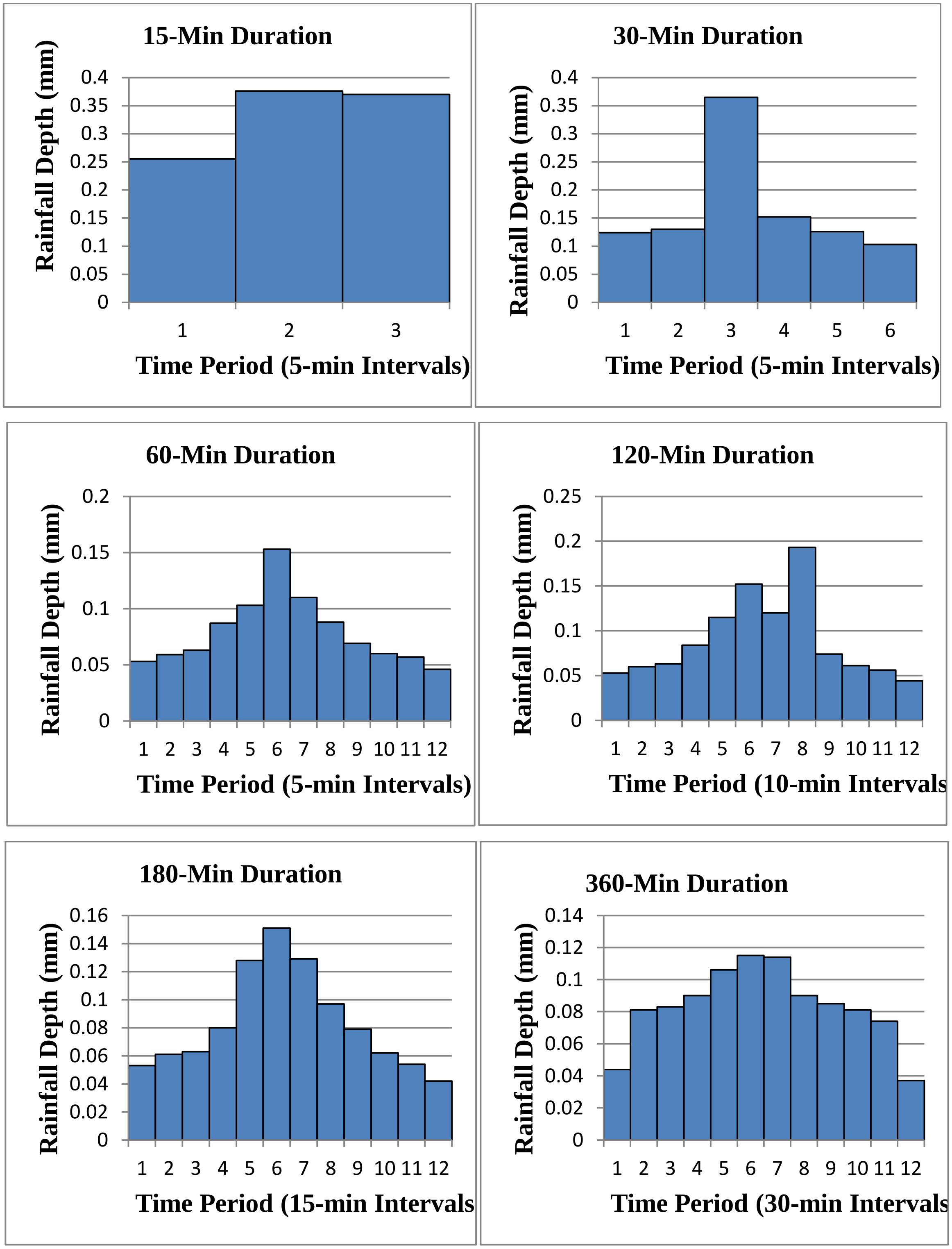


Figure 7.1: Rainfall hyetograph for Pusat Kawalan JPS, T. Gong Station (2913001).

7.3 Hydrological Modelling Results

The calibrated hydrological XP-SWMM model was used to generate runoff for the design rainfalls. In this simulation, two level of urbanization (for years 2010 and 2020) were examined for 18 design rainfall events resulted from combination of 3 different ARI (20, 50, and 100 years) and 6 different rainfall duration (15, 30, 60, 120, 180, and 360 minutes). Therefore, in total 36 different cases were considered for runoff generation by the hydrological model. Table 7.5 shows the simulated peak discharge values for the 36 cases. The case that caused the highest peak flow was considered as the critical design rainfall for each land use case (i.e. land use for years 2010 and 2020). As can be seen in Table 7.5, critical rainfall duration for all three ARI (i.e. 20, 50, and 100 years ARI) is 120 minutes for both land use cases of 2010 and 2020.

Table 7.5: Simulated Peak Discharge (m^3/s) for 36 different rainfall events.

Location 1: Northport (Sg. Dua Besar)						
Storm Duration	**Land use Year 2010 (Imperviousness:72%)**			**Adjusted Scenario 1 Land use Year 2020 (Imperviousness:83%)**		
	ARI (years)			**ARI (years)**		
(mins)	20	50	100	20	50	100
15	78.38	102.92	111.84	81.77	106.31	115.23
30	126.04	130.36	151.99	130.91	135.23	156.87
60	127.21	137.96	196.93	136.97	143.74	202.92
120	151.52	166.65	198.98	157.49	172.63	204.78
180	121.06	146.03	163.86	126.87	151.86	169.71
360	90.54	109.49	118.98	96.08	115.06	124.56

Comparison the critical peak values for 100-years ARI showed a minor change from 198.98 m^3/s in 2010 to 204.78 m^3/s in 2020 (2.9% increase). Table 7.5 showed that, increase in rainfall duration from 120 minutes to 360 minutes will decrease the peak discharge approximately 40% for ARI 100 while an increase in ARI from 20 years ARI to 100 years ARI, leads to approximately 31% increase in peak discharge.

7.4 Hydraulic Modelling Results

River flood modelling comprises of three main components those as follows: hydrological modelling, hydraulic modelling and river flood visualization in XP-SWMM 2D. Hydrological modelling is the primary step in the river flood modelling where in this procedure, the rainfall-runoff simulation is conducted to produce and obtain the design flood hydrographs in Runoff Mode. The design flood hydrographs are considered as an input to the hydraulic model in Hydraulics Mode. Typical hydraulic model needs boundary and initial conditions for determination and calculation of river flood characteristics such as flood extent and flood depth. The outcomes of the hydraulic modelling include the water level in each cross section. In order to visualize the results of hydraulic model, GIS can be used. The primary results that can be visualized in the GIS environment consist of flood extent map and flood depth map. These maps are essential as an ingredient for producing of river flood hazard map and river flood risk map prediction. The hydraulic model, XP-SWMM is applied for river flood modelling in Sungai Dua Besar river basin in this study. River flood modelling was carried out for the 20, 50, and 100 years ARI with different storm durations of 15, 30, 60, 120, 180, and 360 minutes. Detailed hydraulic modelling was carried out to evaluate flood profile under the existing (2010) and future condition (2020) for 20, 50 and 100 years ARI. The 100 years ARI events were simulated for evaluating the drainage system against major storm impacts on the drainage system in the study area.

A total of 36 different cases were identified and simulated during hydraulic modelling. In river flood modelling, only the most critical cases will be focused. The critical cases here are identified as the cases which cause higher water depth in each land-use development condition, flood event ARI and rainfall event duration. The studied cases in this research are defined in two different development conditions, different ARI and also different rainfall event durations. Two development conditions as in Table 7.6:

(i) Urbanized area for existing land use 2010 = 72%

(ii) Urbanized area for future land use 2020 predicted by adjusted scenario 1 = 1470 ha (83%)

Table 7.6: Percentage of Imperviousness Area in Different Development Conditions in Sungai Dua Besar.

Development Condition	**Imperviousness (%)**
Land Use 2010	72
Adjusted Scenario 1 Land Use	83

According to Table 7.7, it seems that development condition, rainfall event duration and ARI of the rainfall event have significant effect on the river water profile. For instance, in development condition for 2010 and 120 minutes duration, the water level increased from 2.004 m for 20 year ARI to 2.079 m for 100 year ARI. This means that, increase of ARI from 20 year to 100 year leads to 4% increase on the river water level. On the other hand, increase of the rainfall event duration from 120 minutes to 360 minutes gives 22% reduction on the river water level as the simulated water for development condition 2010 with 100 year ARI and 120 minutes duration. In addition, the simulated water level for rainfall event with 100 year ARI and 120 minutes duration in development condition for 2010 is 2.079 m while in the future development condition for 2020 with same duration and ARI is 2.125 m. It shows that, river basin land-use development condition causes 2% increase on the water level. In conclusion, the increase of imperviousness from 72% (for development condition year 2010) to 83% (development condition year 2020) causes the water level to raise as much as 0.046 meter based on critical rainfall 100 ARI and rainfall event duration 120 minutes.

By referring to Table 7.7, when the rainfall event duration increases, the water level will be decreased. This can be attributed that events with longer duration have lower peak discharge compare with events result from shorter duration rainfall which have higher peak discharge. This implies that among study rainfall event durations, the most critical rainfall event duration will be considered for river flood hazard mapping. According to Table 7.7, rainfall events with 120 minutes duration have the highest water level and consequently wider extents.

Table 7.7: Water Level at the Outlet of Sungai Dua Besar River Basin.

Location 1: Northport (Sg. Dua Besar)-Water Level (meter)						
Storm Duration	**Landuse Year 2010 (Imperviousness: 72%)**			**Adjusted Scenario 1 Landuse Year 2020 (Imperviousness: 83%)**		
	ARI (years)			**ARI (years)**		
(mins)	20	50	100	20	50	100
15	1.589	1.655	1.763	1.609	1.659	1.797
30	1.712	1.803	1.925	1.735	1.915	2.077
60	1.882	1.970	2.058	1.953	2.012	2.090
120	2.004	2.031	2.079	2.026	2.036	2.125
180	1.733	1.754	1.874	1.738	1.761	1.919
360	1.347	1.572	1.618	1.399	1.575	1.719

The effect of rainfall event ARI on the river flood can be studied according to the results demonstrated in Table 7.7. Rainfall events with higher ARI lead to higher runoff peak discharge. On the other hand, the higher runoff peak discharge causes higher and wider extents of flood water level along the study reach. This means that, for similar land-use condition and similar duration, the 100 year ARI generate more critical river flood in comparison with rainfall events with 50 year and 20 year ARI. The critical river flood is defined as river flood with higher water level and wider extents.

The condition of the development of the river basin has a significant role on the generated flood water level and extents. River basin land-use development (urbanization) increases the impervious area and generates considerable impact on the river basin. The imperviousness factor has important effect on the runoff peak discharge and runoff volume, as the increase of impervious area leads to increase of runoff peak discharge and runoff volume. According to Table 7.7, it appears that the flood water level in adjusted scenario 1 land use for year 2020 condition are more severe than land use in year 2010 condition.

In conclusion, rainfall event durations, rainfall event ARI and development condition of the river basin have significant effect on the generated river flood maps. To summarize, increase of rainfall events duration leads to reduction of flood water level and extents, increase of rainfall event ARI causes increase in the flood water level and extents and also, increases of the river basin development condition results to higher flood water level and extents. The next step in river flood mapping is river flood visualization in GIS environment.

Table 7.8: Area of Flood Extent at Sungai Dua Besar River Basin.

Duration	**Land Use / Development Condition**	**Average Recurrence Interval (ARI) of Flood**		
		20	**50**	**100**
		Flood Affected Area (km^2)		
15 min	2020	0.39	0.55	0.58
	2010	0.38	0.49	0.56
30 min	2020	0.69	0.75	0.95
	2010	0.65	0.69	0.90
60 min	2020	0.70	0.88	1.58
	2010	0.67	0.80	1.51
120 min	2020	1.13	1.35	1.72
	2010	1.06	1.29	1.67
180 min	2020	0.88	1.26	1.55
	2010	0.79	1.16	1.46
360 min	2020	0.64	0.94	1.16
	2010	0.56	0.83	1.10

By considering Table 7.8, it appears that, the calculated inundated area for rainfall event with 20 year ARI, rainfall duration 120 min, in development condition 2010 is 1.06 km^2 while it is 1.13 km^2 for future development condition 2020. As for rainfall event with 50 year ARI, rainfall duration 120 min, the flood extent for development condition 2010 is 1.29 km^2 and increased to 1.35 km^2 for future development condition 2020. The major storm with 100 year ARI, rainfall duration 120 min, showed that in development condition 2010, flooded area is 1.67 km^2 whereas for future development condition 2020, it is predicted that the inundated area extent to 1.72 km^2. This means that, when development condition increases the percentage of urbanization, it will tends to increase the flood inundated area.

Table 7.9: Flooded Area at Study Basin for rainfall duration of 120 minutes.

Year	**Average Recurrence Interval (ARI)**		
	20 years	**50 years**	**100 years**
	Flooded Area (km^2)		
2010	1.06	1.29	1.67
2020	1.13	1.35	1.72

Using topographical data of the catchment the flooding potential of the catchment was assessed and is provided in Table 7.9. As can be seen, for 20, 50, and 100 years ARI, flooded area has increased by 6.6%, 4.7%, and 3.0%, respectively from 2010 to 2020 for critical rainfall duration of 120 minutes. This shows the impact of urbanization on the flooding potential of the study area.

Figure 7.2 to 7.7 show the generated river flood water depth distribution maps for Sungai Dua Besar river basin in different development conditions and different rainfall event ARI for critical rainfall events durations 120min. In order to assess the effect of the river basin land-use development condition on the generated river flood depth distribution map, the inundated area for 120 minutes rainfall events with are compared for land use 2010 and future land use 2020 using adjusted scenario 1.

Figure 7.2: Flood extents for event with 20 year ARI, 120 min rainfall duration (land use 2010).

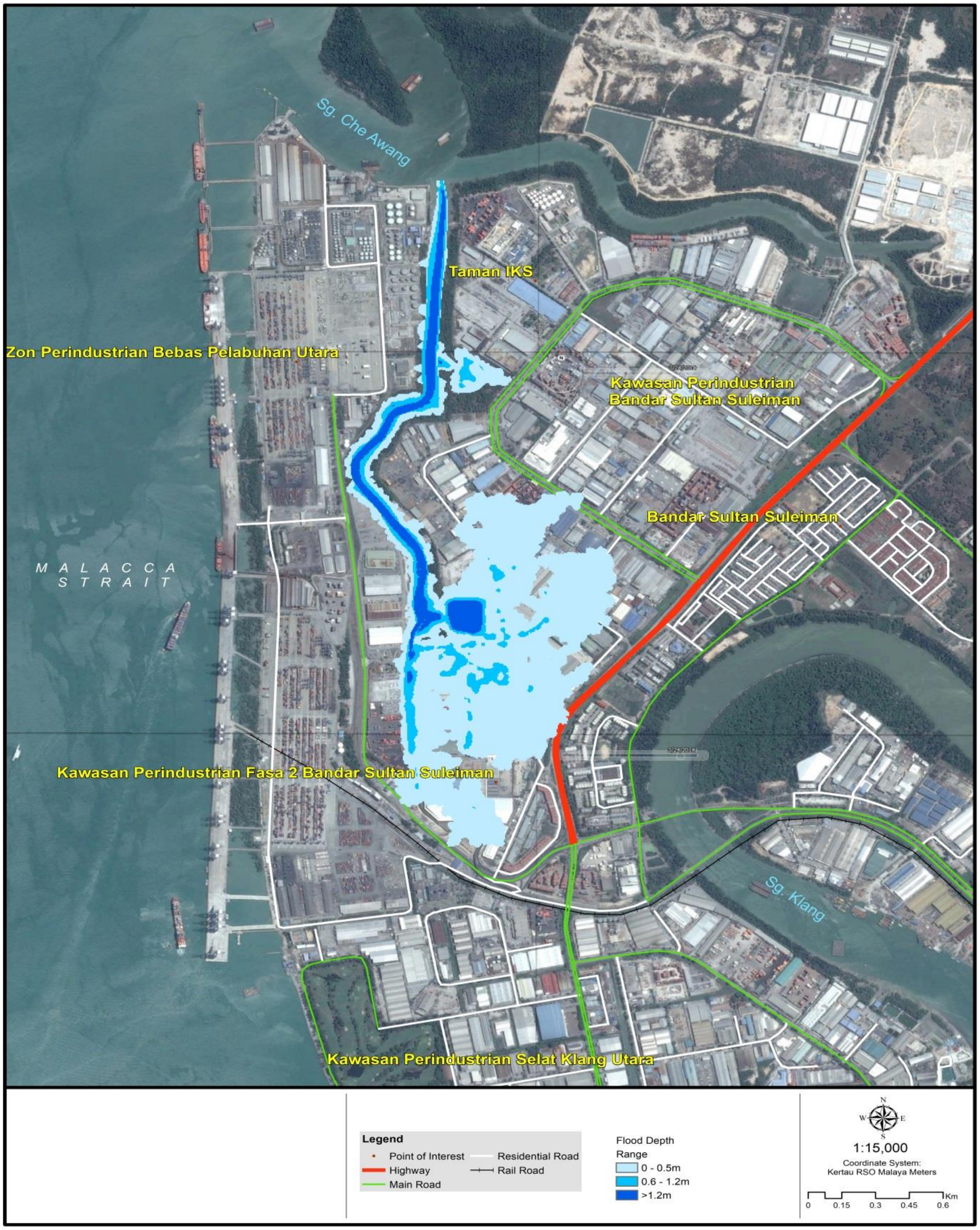


Figure 7.3: Flood extents for event with 50 year ARI, 120 min rainfall duration (land use 2010).

Figure 7.4: Flood extents for event with 100 year ARI, 120 min rainfall duration (land use 2010).

Figure 7.5: Flood extents for event with 20 year ARI, 120 min rainfall duration (land use 2020).

Figure 7.6: Flood extents for event with 50 year ARI, 120 min rainfall duration (land use 2020).

Figure 7.7: Flood extents for event with 100 year ARI, 120 min rainfall duration (land use 2020).

7.5 Time of Concentration Tc

Time of concentration, Tc is the time needed for water to flow from the most remote point in a catchment to the catchment outlet. Tc will vary depending upon slope and character of the watershed and the flow path. In Sungai Dua Besar catchment, the biggest storm duration (360 minutes) is larger than Tc (average of 60 minutes). This will inferred that rainfall intensity will be less than that at Tc. Therefore, the peak discharge estimated will be less than the optimal value. If the storm duration (lowest is 15 minutes in this study) is less than Tc, then the catchment is not fully contributing runoff to the outlet, and the optimal value will not be realized.

For Sungai Klang basin, Tc involved the time of concentration for each of the sub catchment contributing to the river basin. The value of Tc for Sungai Klang basin can be obtained from Kirpich Method. The Kirpich equation is normally used for natural basins with well-defined channels. Since this study covered only one of the sub catchment of Sungai Klang basin, the data available is insufficient to discuss details on Klang River Tc.

CHAPTER 8
SUMMARY AND CONCLUSION

8.1 Summary

Malaysia is rapidly transforming into a developed country with a more urbanized society. Urbanization in Malaysia has caused significant changes in watersheds hydrology as it has increased impervious area in catchments which in turn has reduced infiltration and surface storage and has increased surface water runoff. For Klang district, Malaysia, the problem of runoff, drainage and flooding has emerged in new dimensions with adverse impacts on landscape, vegetative cover, receiving waters and catchment values. As a result the Klang district is facing serious impacts such as flooding generated from continuous land use changes. Therefore, this study was focused to evaluate the potential flooding impact of such continuous change in land use for an urban catchment in Malaysia. The presented case study is aimed to understand the trend of land use changes in an urbanized tropical catchment, Sungai Dua Besar, located in Klang district and evaluate the potential impacts of land use change on flood-prone areas through hydrologic and hydraulic modeling.

This study is folded in three main stages. In the first stage land use change of the study site was studied using historical land use data (from years 1966, 1984, 2002 and 2010) to identify the trend for future land use prediction in year 2020. In second stage of this study, a rainfall-runoff model was developed using XP-SWMM tool; it was calibrated using historical data of years 2000 and 2004. This was followed by developing, calibrating and validating a hydraulic model using XP-SWMM to predict water level in main river of the study site. In the third stage, design rainfall storms were defined for different ARI of 20, 50, and 100 years to estimate the potential flooded area in 2020. The results were compared with the ones for 2010 to assess the potential change in flooding area after 10 years of growing urbanization (from 2010 to 2020).

8.2 A Review on Findings

8.2.1 Land Use Study

The land use change was assessed by four (4) land use maps of the study site obtained from various government agencies including Ministry of Agriculture and Lands Malaysia, Federal Department of Town and Country Planning Peninsular Malaysia and Klang Municipal Council for years 1966, 1984, 2002, and 2010. Moreover, a map for 2020 was also available which is provided by government based on the national development plans for the study region. Two different approaches were considered to project the land use change in year 2020 including: Scenario (1) which is based on summation of non-urbanized and urbanized areas; Scenario (2) which is based on three key-player land uses of urbanization.

The results of the two land use analyses were then compared with the projected MPK map which is provided based on the national development plans. The comparison between the results showed that scenario (2) predicts the highest urbanization area for year 2020 followed by Scenario 1 and MPK future land use plan. Scenario (2) predicted an urbanization of 93% while scenario (1) and MPK gave 88% and 72%, respectively. It was concluded that for a conservative flood risk analysis, the two proposed scenarios analyses could be better choices and have a more conservative prediction of land use for any flood risk analysis. However, further results during hydrology model validation helped to revise the two land use prediction scenarios. This revision resulted in 83% urbanization for 2020. This has achieved research objective two

8.2.2 Flood Modelling Study

For calibration of hydrological model, a total of 20 rainfall-runoff events were selected from years 2000 and 2004. After fine-tuning the model parameters through a sensitivity analysis, model was then evaluated in a validation process. Validation of the hydrological model was done using 10 events from years 2010 and 2015. Validation was carried out by changing the imperviousness (based on available land use maps) while the calibrated parameters were kept fixed for both scenarios (1) and (2). Since there was no land use map for year 2015, a theoretical value was found through trial and error that can simulate the observed runoff with the minimum possible error. The resulted theoretical value of imperviousness was then used to revise the land use prediction model. Results showed that calibrated model performs well in terms of all evaluation criteria. This has achieved research objective one.

For hydraulic model, calibration process was carried out using the same 20 events of years 2000 and 2004 which were used in calibration of hydrological model. After fine-tuning the model parameters, the model performance for calibration events was promising in terms of all evaluation parameters. For validation of hydraulic model, all model parameters were then kept fixed as what found after calibration. The same 10 validation events used in validating hydrological model were used in this stage as well. Comparison between observed and simulated peak water level indicated good fitness between them.

In the third and last step, hydraulic model was applied for river flood modelling in Sungai Dua Besar river basin. River flood modelling was carried out for the 20, 50, and 100 years ARI with different rainfall durations of 15, 30, 60, 120, 180, and 360 minutes. Detailed hydraulic modelling was carried out to evaluate flood profile under the existing development year 2010 and future condition year 2020. Results showed that rainfall duration of 120 min consistently produces the most critical runoff peak for 20, 50 and 100 years ARI. Comparison between flooded area for years 2010 and 2020 showed an increase of 6.6%, 4.7% and 3.0% for 20, 50 and 100 years ARI respectively. Moreover, the highest flood depth in year 2020 was found as 2.026m, 2.036m and 2.125m for 20, 50 and 100 years ARI. This has achieved research objective three.

8.3 Potential Use of Findings

This study can be used as a guide by various Government agencies (Department of Irrigation and Drainage, town council etc.), consultants and town planners in helping of tackling flood issues and future land use planning. Proper future planning will help to reduce the significant rise of impervious surface area which can lead to flash floods like in this study area (Sungai Dua Besar catchment). It is also possible to implement a controlled development condition based on the urbanized trend by using a network of laws to reduce the flood hazard.

One of the most important factors in designing sustainable stormwater drainage systems is the physical storage volume that needs to be provided to achieve flood control and to take into account the future land use development. It is important for engineers to realize that all drainage systems must be designed to a set of technical criteria that are subjected to land use constraint.

In conclusion, the findings in this study provide a useful support for land-use planning and management. Also, the results provide necessary inputs to decision makers and engineers that must balance trade-offs between the positive benefits of land-use change and potentially negative unintended consequences of flood.

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Appendix 1: Details of Calibration and Validation Rainfall Events used in this Study

Events Number	Date	Total Rainfall (mm)	Duration (min)	Peak Flow (m3/s)	
2000-1	2-July-00	51.7	200	13.9	Calibration events
2000-2	2-May-00	29.5	280	3.81	
2000-3	3-April-00	114.7	400	66.364	
2000-4	9-November-00	6.77	260	0.149	
2000-5	17-July-00	34	250	5.886	
2000-6	19-April-00	38.45	190	6.835	
2000-7	19-October-00	4.29	200	0.08	
2000-8	20-October-00	7.821	190	0.255	
2000-9	25-April-00	12.1	310	0.528	
2000-10	28-November-00	29.02	190	4.33	
2004-1	5-November-04	87.5	200	42.115	
2004-2	7-April-04	40.08	210	11.87	
2004-3	10-May-04	2.188	320	0.029	
2004-4	21-April-04	16.2	190	1.134	
2004-5	21-February-04	84.8	160	13.131	
2004-6	22-October-04	7.8	170	0.271	
2004-7	25-November-04	18.4	190	1.555	
2004-8	28-January-04	2.85	160	0.056	
2004-9	30-December-04	16.1	200	0.891	
2004-10	31-March-04	53.4	180	15.456	
2010-1	3-August-10	14.5	310	1.086	Validation events
2010-2	6-August-10	11.5	340	0.432	
2010-3	17-September-10	23.3	400	1.951	
2010-4	26-October-10	27.7	320	1.91	
2010-5	1-November-10	46	420	10.588	
2015-1	8-January-15	19.4	230	1.803	
2015-2	11-February-15	27.8	370	3.065	
2015-3	18-February-15	29.2	250	3.259	
2015-4	12-June-15	28.3	310	5.325	
2015-5	14-June-15	59	350	16.58	
2016-1	29-November-16	29	340	16.65	
2016-2	2-December-16	37.3	300	15.92	
2016-3	23-November-16	25	360	15.401	
2016-4	1-December-16	20	360	0.811	
2016-5	21-November-16	7.7	220	0.012	

Appendix 2: Calculation for Imperviousness using Equations of Scenario (1) and Scenario (2)

From landuse study scenario (1), the projected imperviousness for year 2015 can be obtained by using:

Y=28.882X-2.8456 where X=2015-1966 = 49 years

Y=28.882(49)-2.8456 Y= imperviousness 2015

Y=1412 Ha (80%)

From landuse study scenario (2), the projected imperviousness for year 2015 will be the summation of 3 main urban land uses including industrial, residential and transportation:

Equation for industrial:

Y=19.391X+18.086

Y=19.391(49)+18.086

Y=968 Ha

Equation for residential:

Y=8.4305X-134.71

Y=8.4305(49)-134.71

Y=278 Ha

Equation for transportation:

Y=4.7386X-0.92

Y=4.7386(49)-0.92

Y=231 Ha

Total imperviousness for year 2015 under scenario (2)

Ysum=968 Ha (industrial) +278 Ha (residential) + 231 Ha (transportation)

Ysum=1477 Ha (84%)

Appendix 3: Input Data in Hydraulic Model

Name	Storm	Link Name	Upstream Node Name	Downstream Node Name	Upstream Invert Elevation m	Downstream Invert Elevation m	Bottom Width m	Conduit Slope	Roughness	Shape	Length m	Diameter (Height) m
Link184	T.Gong100yr120min	Link184	nCAa 10	nCAa 9	-0.98	-1.34	17	0.082	0.03	Natural	440.8	3.2
outlet1 P2	T.Gong100yr120min	Link142	nCAa 12	nCAa 12.1	-0.53	-1.42	1.8	5.933	0.014	Rectangular	15	1.8
outlet2 P2	T.Gong100yr120min	Link142	nCAa 12	nCAa 12.1	-0.53	-1.42	1.8	5.933	0.014	Rectangular	15	1.8
outlet3 P2	T.Gong100yr120min	Link142	nCAa 12	nCAa 12.1	-0.53	-1.42	1.8	5.933	0.014	Rectangular	15	1.8
Link144	T.Gong100yr120min	Link144	nCAa 11	nCAa 10	-0.84	-0.98	10	0.015	0.03	Natural	930.4	2
Link185	T.Gong100yr120min	Link185	nCAa 9	nCAa 1	-1.34	-2	17	0.131	0.03	Natural	505	3
Link189	T.Gong100yr120min	Link189	nCAb 3	nCAb 2	0.34	0.27	1.9	0.018	0.014	Trapezoidal	387.1	2
inlet1 P2	T.Gong100yr120min	Link190	nCAb 2	nCAa 12	0.27	-0.53	6.2	8	0.014	Circular	10	1.7
inlet2 P2	T.Gong100yr120min	Link190	nCAb 2	nCAa 12	0.27	-0.53	0	8	0.014	Circular	10	1.7
inlet3 P2	T.Gong100yr120min	Link190	nCAb 2	nCAa 12	0.27	-0.53	0	8	0.014	Circular	10	1.7
Link191	T.Gong100yr120min	Link191	nCAb 5	nCAb 2	0.6	0.43	1.2	0.051	0.014	Trapezoidal	332.8	2
Link192	T.Gong100yr120min	Link192	nCAc 6	nCAc 5	0.68	0.65	4.2	0.008	0.014	Trapezoidal	359.3	1.6
Link193	T.Gong100yr120min	Link193	nCAc 5	nCAc 4	0.65	0.34	4.2	0.031	0.014	Trapezoidal	987.2	1.6
870.1	T.Gong100yr120min	Link194	nCAc 4	nCAc 1	0.34	0.25	8.2	0.225	0.014	Circular	40	1.8
870.2	T.Gong100yr120min	Link194	nCAc 4	nCAc 1	0.34	0.25	0	0.225	0.014	Circular	40	1.8
870.3	T.Gong100yr120min	Link194	nCAc 4	nCAc 1	0.34	0.25	0	0.225	0.014	Circular	40	1.8
870.4	T.Gong100yr120min	Link194	nCAc 4	nCAc 1	0.34	0.25	0	0.225	0.014	Circular	40	1.8
Link198	T.Gong100yr120min	Link198	nCAc 1	nCAc 1.1	0.25	-0.46	8.2	4.733	0.014	Trapezoidal	15	2.3

Name	Storm	Link Name	Upstream Node Name	Downstream Node Name	Upstream Invert Elevation m	Downstream Invert Elevation m	Bottom Width m	Conduit Slope	Roughness	Shape	Length m	Diameter (Height) m
Link195	T.Gong100yr120min	Link195	nCAc 7	nCAc 4	0.38	0.34	4.2	0.011	0.014	Trapezoidal	358.3	1.6
874.1	T.Gong100yr120min	Link196	nCAc 3	nCAc 1	0.79	0.25	1.8	0.151	0.014	Circular	358.3	1.8
874.2	T.Gong100yr120min	Link196	nCAc 3	nCAc 1	0.79	0.25	0	0.151	0.014	Circular	358.3	1.8
Link197	T.Gong100yr120min	Link197	nCAc 2	nCAc 1	0.63	0.25	1.1	0.139	0.014	Trapezoidal	274.3	1.6
outlet1 P1	T.Gong100yr120min	Link199	nCAc 1.1	nCAa 10	-0.46	-0.98	1.8	3.467	0.014	Rectangular	15	1.8
outlet2 P1	T.Gong100yr120min	Link199	nCAc 1.1	nCAa 10	-0.46	-0.98	1.8	3.467	0.014	Rectangular	15	1.8
outlet3 P1	T.Gong100yr120min	Link199	nCAc 1.1	nCAa 10	-0.46	-0.98	1.8	3.467	0.014	Rectangular	15	1.8
Link142.1	T.Gong100yr120min	Link142.1	nCAa 12.1	nCAa 11	-1.42	-0.84	10	-0.096	0.03	Natural	603.34	3.44