RAINFALL RUNOFF SIMULATION USING MODIFIED SCS-CN AND HEC-HMS MODEL IN KUANTAN WATERSHED

ALLYSON ANAK HILBERT

B.ENG (HONS.) CIVIL ENGINEERING
UNIVERSITY MALAYSIA PAHANG

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ALLYSON ANAK HILBERT

Thesis submitted in fulfilment of the requirements
for the award of the degree of
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ABSTRACT

Kuantan watershed located in the flood prone area and experienced flood event almost every year due to monsoon season on the Peninsular Malaysia in month of November to February. Based on the condition of the watershed that has high probability in subjected to the flood occurrence, it shows that there was a need to develop a hydrologic model for the watershed. The study aims to develop the rainfall-runoff relationship using hydrological model and GIS in Kuantan watershed, assess the performance of HEC-HMS model in runoff prediction and evaluate the accuracy of modified SCS-CN in tropical area. HEC-HMS model was used to stimulate the storm event that occurs in the watershed based on the selected event where the calibration and validation also were carried out. The method used in the model was the SCS Unit Hydrograph for the Transform Method, SCS-CN as the Loss Method, and Lag Time as the Flood Routing Method. The simulation was carried out based on two selected storm event which was on the month of December 2006 and month of January 2012. The value of initial abstraction ratio used was 0.2 and 0.05 which the result based on both application of the ratio will be compared. The model was calibrated based on the antecedent moisture condition which considering the wet condition in the watershed which was known as AMC III, where the calculated curve number based on the land use and hydrological soil groups criteria was assumed in the normal condition. The efficiency of the simulated result over actual result was access using the Nash-Sutcliffe Efficiency (NSE). For the simulated result based on selected event, the NSE value for the model before and after calibration was range from 0.7 to 0.9 for both value of initial abstraction ratio which shows that the model perform well but the model seem to underestimate the actual peak discharge in the watershed. The efficiency for the model based on event on December 2006 was higher without calibration with initial abstraction ratio of 0.2 while for event on January 2012; the efficiency of the model was higher after the model calibrated which has almost the similar efficiency for both ratio of abstraction use. The application of two different equations to calculate the Lag Time also gives slight changes in the result as the used of Kirpich Equation gives a better result compare to the use of SCS Lag Equation for the prediction of the peak discharge.

ABSTRAK

Kawasan tadahan Kuantan terletak di kawasan yang sering dilanda banjir dan hampir mengalami peristiwa banjir setiap tahun kerana musim tengkujuh di Semenanjung Malaysia pada bulan November hingga Februari. Berdasarkan kepada keadaan kawasan tadahan air yang mempunyai kebarangkalian yang tinggi untuk dilanda banjir, ia menunjukkan bahawa terdapat keperluan untuk membangunkan model hidrologi bagi kawasan tadahan . Kajian ini bertujuan untuk membangunkan hubungan hujan dengan air larian menggunakan model hidrologi dan GIS di kawasan tadahan Kuantan, menilai prestasi model HEC-HMS dalam ramalan aliran dan menilai ketepatan SCS-CN yang diubah suai bagi kawasan tropika. Model HEC-HMS digunakan untuk mensimulasikan kejadian ribut yang berlaku di kawasan tadahan berdasarkan tarikh yang dipilih di mana penentukuran dan pengesahan akan dilakukan juga. Kaedah yang digunakan dalam model ini ialah SCS Unit Hydrograph untuk kaedah Transform, SCS-CN sebagai kaedah Loss, dan Lag Time sebagai kaedah Flood Routing. Simulasi ini dilakukan berdasarkan kepada dua peristiwa ribut yang dipilih iaitu pada bulan Disember 2006 dan bulan Januari 2012. Nilai nisbah abstraksi awal yang digunakan adalah 0.2 dan 0.05 dan hasil daripada kedua-dua nilai akan dibandingkan. Model ini telah ditentukan berdasarkan daripada keadaan kelembapan yg di kawasan tadahan air yang dikenali sebagai AMC III, di mana nilai CN yang dikira adalah berdasarkan penggunaan tanah dan kumpulan tanah hidrologi dan dianggap berada dalam keadaan yang normal. Ketepatan hasil simulasi ke atas data sebenar akan ditentukan menggunakan kaedah Nash-Sutcliffe Efficiency (NSE). Berdasarkan hasil simulasi, nilai NSE untuk model sebelum dan selepas penentukuran berada dalam julat 0.7-0.9 untuk aplikasi kedua-dua nilai nisbah abstraksi awal dan menunjukkan bahawa model menunjukan prestasi yang baik tetapi model seolah-olah memandang rendah pelepasan puncak sebenar dalam kawasan tadahan air. Kecekapan untuk model berdasarkan peristiwa pada Disember 2006 adalah tinggi untuk keadaan biasa dengan nisbah abstraksi 0.2 manakala bagi peristiwa pada Januari 2012; kecekapan model adalah tinggi selepas model ditentukur yang mempunyai hampir kecekapan yang sama untuk penggunaan kedua-dua nisbah abstraksi. Penggunaan dua persamaan yang berbeza untuk mengira Lag Time juga memberikan perubahan dalam keputusan di mana bagi persamaan Kirpich, ia memberikan hasil yang lebih baik berbanding dengan penggunaan persamaan SCS Lag untuk ramalan perlepasan puncak.

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LIST OF SYMBOLS

%	Percentage
km^2	Kilometer square
°N	North
°E	East
∞	Infinity
I_a	Initial abstraction
S	Potential maximum retention
Q	Direct runoff
P	Total precipitation
λ	Initial abstraction ratio
L	Basin Length
S	Slope of the basin
T_c / t_c	Time of concentration
t_l	Lag time
ft	Feet
Q_o , Q_S	Observed discharge, Simulated discharge
m	Meter
mm	Millimeter
m^3/s	Cubic meter per second
min.	Minutes
hrs	Hours

LIST OF ABBREVIATIONS

GIS	Geographic Information Systems
HEC-HMS	Hydrologic Engineering Center -Hydrologic Modeling System
SCS-CN	Soil conservation service - curve number
CN	Curve number
DID	Department of Drainage and Irrigation
HEC-GeoHMS	Hydrologic Engineering Center - GeoHydrologic Modeling System
NSE	Nash-Sutcliffe efficiency
AMC	Antecedent moisture condition
DEM	Digital elevation model
ASTER GDEM	ASTER Global Digital Elevation Model
HSGs	Hydrologic soil groups
SI	10% of Plastic Aggregate
AMC I	Antecedent moisture condition (Dry)
AMC II	Antecedent moisture condition (Normal)
AMC III	Antecedent moisture condition (Wet)
USACE	United States Army Corps of Engineers

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF STUDY

Rainfall occurrence is a natural process defines as the amount of precipitation of water form in the specific area and time interval which expressed in units of millimeters or inches. The precipitated water is measured using rain gauge that is set in the specific area that functions as rain collector. In some region, the rainfall not always fall in the liquid form but also including solid precipitation such as snow, hail. This may occur due to surrounding condition of the region and the common condition is due to the weather.

When rain falls onto the earth, the water flows from the highest peak to the lower places with some of the precipitation portion will infiltrating into the ground and replenish the groundwater and most of the precipitation will flows as a runoff. The common factors affecting the precipitation are the intensity and the duration of the rainfall or the storm. Higher rain intensity caused the soil to be saturated and rate of infiltration will decreased causing the excess water to fall as the runoff. The type of soil also affecting the runoff as the non-porous soil has lower rate of infiltration compare to porous soil. The rate of runoff also affects by other factors such as the present of plant and the local topography of the area.

Rainfall runoff may cause the occurrence of flooding as if the runoff from the storm is higher, it may exceeding the capacity of the stream capacity which will causing flooding. Runoff also contributes on the reduction of ground water recharge. Most of the drinkable water is extract from the groundwater sources. Overuse of the groundwater without natural replenishing or slower rate of replenishing due to runoff will cause the land to collapse which known as the subsidence process. The groundwater fills the spaces in the soil gives an internal strength to the ground. When the water is removed, it will leave an opening spaces filled with air. The absence of the internal strength will cause the soil structure to collapse and filled the spaces, thus destroying the groundwater aquifer. There also will be a decreased in the stream base flow due to the runoff. Base flow is the water that continuously flows even on the dry periods. This flow is vital for the survival of the aquatic life in the stream. Other than that, runoff also increased the soil erosion and reduction of natural filtration of the water.

Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring on the watershed (Albek et al., 2004). The modeling is used for the purpose of forecasting and predicting flood peaks and runoff volumes due to heavy rain. The modeling of the model can be conduct and it can be used as a virtual model associated to the real condition which can be used to investigate the changes to the depth of the rainfall and the rate of runoff in the study area. For this modelling, simulating process is carried out using the HEC-HMS method with the modified SCS-Curve Number as the loss model, Lag method as the flood routing approaches and Constant Monthly as the base flow method. The parameter of the study area is delineated using the Geographic Information Systems (GIS) which is important as an input for the simulation process. The Soil Conservation Service curve number method, SCS-CN is essentially an empirical, one-parameter CN event rainfall-runoff model. It is a dimensionless curve number which takes into account the effects of land use/cover, soil types, and hydrologic soil groups on surface runoff, and basically will relates the direct surface runoff to rainfall in the watershed. The SCS-CN method has been widely used for estimating rainfall-generated surface runoff in watershed hydrologic modeling (Chu and Steinman, 2009). An importance aspect of watershed modelling processes is the ability to determine and obtain various parameter inputs for the watershed. Information on precipitation, soil properties, and land use/cover is of critical importance to watershed modelers and managers (Daniel et al., 2010).

For this research, a rainfall event data that occurred in Kuantan was selected to be used in the simulation. The selected rainfall event was used to setup the hydrologic model for the Kuantan watershed. The accuracy of the result can be analysis by comparing the simulated discharge to the actual discharge data from the stream flow station. Through this, I will be able to develop the rainfall-runoff relationship in Kuantan watershed. The relationship between rainfall and runoff is essential in a catchment for hydrologic analysis and design (Chang, 2009). The rainfall will change runoff in term of surface-runoff, interflow and base-flow after it subjected to losses due to evaporation, transpiration, interception and infiltration. The rainfall-runoff usually influenced by factors such terrain condition, geology condition, soil type, area, slope, and plant-types in the watershed.

Based on the developed model, the performance of the HEC-HMS model in the runoff prediction can also be assess by comparing the simulation data with the observe data. The model will performed well if the simulated result is almost fit to the observed data. Apart from that, Kuantan river basin is located in a tropical region which consists of wet and dry season throughout the year-round. Therefore, by using the develop model, the accuracy of the modified SCS-CN as the loss model on the runoff prediction on the tropical region can be evaluate based on the result obtained from the simulation.

1.1 PROBLEM STATEMENT

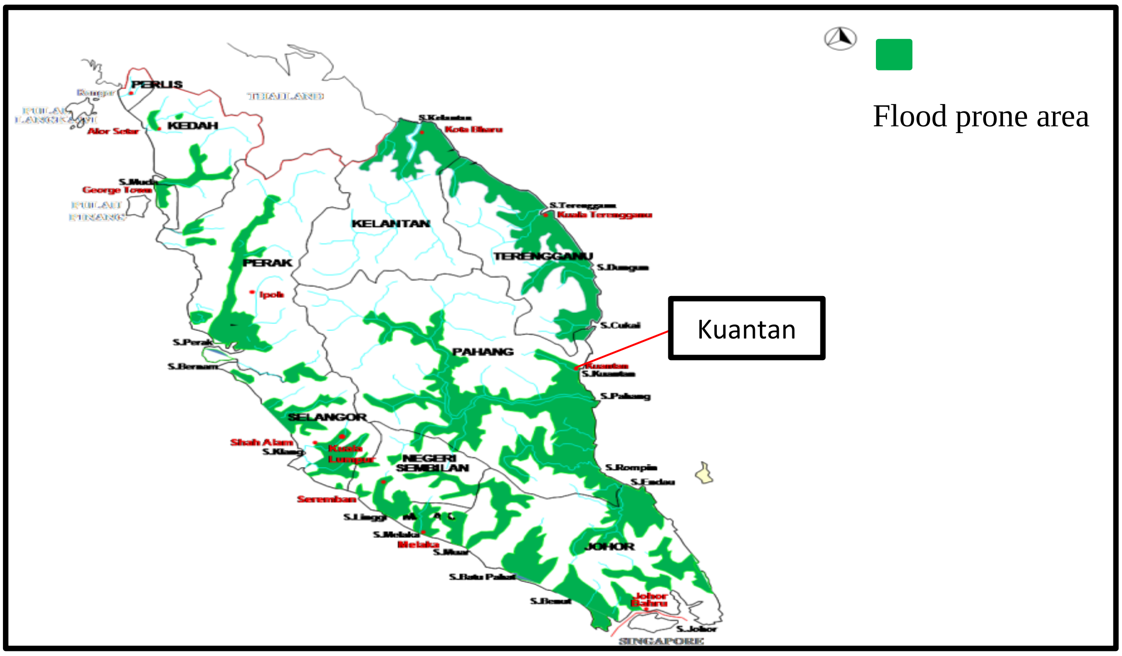


Figure 1.0: Flood prone area in Peninsular Malaysia (DID, Malaysia)

Malaysia has experienced extreme rainfall events during the monsoon seasons that last for several hours and lead to flash flood (Win and Win, 2014). The monsoon season is usually in the month of November until February which causing the increase number of flood events in several areas in the Peninsular Malaysia. Figure 1.0 shows the area of interest for this study which showing that Kuantan region is located in the flood prone areas in Peninsular Malaysia, which mean that flood is the main natural disaster, occur in the area. Malaysia has experiences many floods event before as a result of prolonged rain in some parts of Peninsular Malaysia which has brought negative impact to environment and society. Oversee the flood problem in the Kuantan area, it shows that there is a need to create a simulation model for the area to help in the estimation of discharge for the study area. Hydrological models are important for a wide range of applications, including water resources planning, development and management, flood prediction and design, and coupled systems modelling including, for example, water quality, hydro-ecology and climate (Pechlivanidis et al., 2011).

The runoff from the storm event also can be affected by the major land use changes for the study area as time pass by. The land use properties will be pair with the hydrologic soil groups which will produce the curve number map. Major land use changes as the time pass by will affect the value of the curve number for the study area which can affect the calculation or simulation calculation. Higher value of the curve number will significantly increase the result obtained in the simulated data

By using HEC-GeoHMS, the rainfall–runoff model for Kuantan watershed can be process as an input for HEC-HMS software. In the HEC-HMS, the simulation can be run in order to predict the discharge for the Kuantan watershed. By doing that, the hydrological parameters of Kuantan watershed can be obtained and the relationship between the relationship between observed flow and simulated flow due to extreme rainfall events can be access. The estimated discharge can be used as the guide in hydrologic design in the study area as a guideline in the flood mitigation works which can reduce the impact of flood in Kuantan. The analysis and prediction of flood hydrograph in a watershed can also bring benefit to the conservation of water resources and flood planning and mitigation in Kuantan, as well as the soil engineering planning.

1.2 OBJECTIVES

a) To developed the rainfall-runoff relationship using hydrological model and GIS in Kuantan watershed.
b) To assess the performance of HEC-HMS model in runoff prediction
c) To evaluate the accuracy of modified SCS-CN in tropical area

1.3 SCOPE OF STUDY

Pahang River Basin, which is the largest river basin in Peninsular Malaysia, covers a catchment area of 29,000 km^2. Kuantan is the state capital in Pahang and known as the third largest state in Peninsular Malaysia and located between 3°49’00”N and 103°20’00”E (3.81667°N and 103.33333°E). The total area of Kuantan is 2960 km^2 with the elevation of 21.95 m. The river bed slope information in the Pahang area is Sungai Pahang (0.016% (1/6200), Sungai Jerai (0.034% (1/2900)) and Sungai Tembeling (0.024% (1/4100) Kuantan experienced rainy season between the month of December until February and subjected to flood event. The area in Kuantan that subjected to flooding includes the path to Sungai Lembing and few areas along Kuantan River.

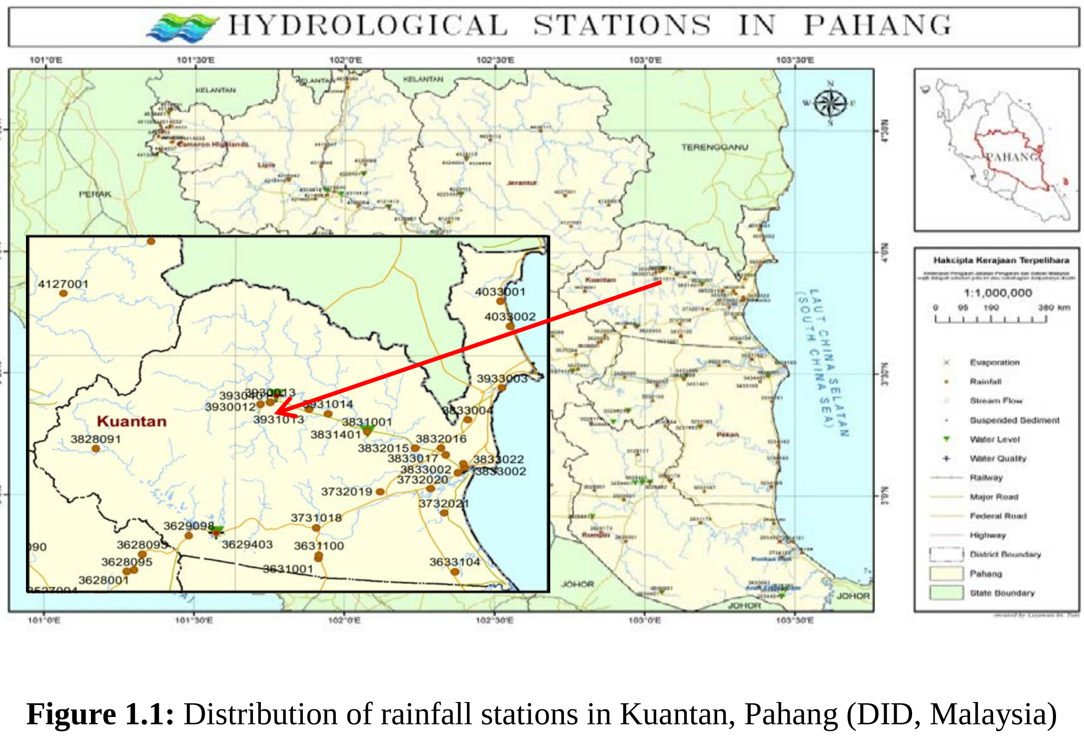


Figure 1.1: Distribution of rainfall stations in Kuantan, Pahang (DID, Malaysia)

STATION NO.	STATION NAME	FUNCTION	STATE	DISTRICT	RIVER	RIVER BASIN	LAT.DEG	LONG.DEG
3930012	Sg. Lembing P.C.C.L Mill	Rainfall	Pahang	Kuantan	Sg. Lembing	Sg.Kuantan	3.916666667	103.0361111
3930401	Sg. Kuantan, Bukit Kenau	Stream flow	Pahang	Kuantan	Sg.Kuantan	Kuantan	3.931944444	103.0583333

Table 1.0: Hydrological stations in Kuantan used in the study (DID, Malaysia)

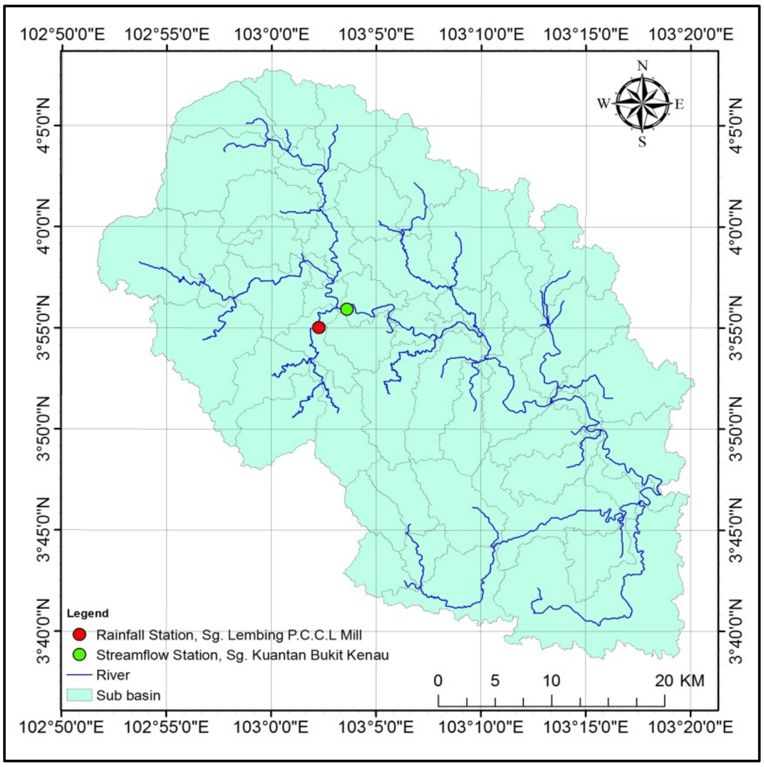


Figure 1.2: Watershed boundary and location of hydrological stations in Kuantan watershed used in the study

Figure 1.1 shows the distribution of rainfall stations in the Kuantan river basin in Pahang state. Table 1.0 and Figure 1.2 show the boundary of Kuantan watershed with the hydrological stations and it location in the watershed used in the study which were generated in the ArcMap. The rainfalls events data is collected through the rainfall station. To stimulate the rainfall-runoff, the data from the station which related to the rainfall events needed to be collected from Department of Irrigation and Drainage. Through the analysis of observed rainfall hydrographs and hyetographs, the selected rainfall events are used in the simulation in HEC-HMS model. However, not all the rainfall data from each station will be use since some rainfall station is not in the boundary of Kuantan watershed while some station mostly have an error in it reading, mostly due to the instrument error. The data from the streamflow station will be used to compare the simulated result with the observed result. Due to location of the streamflow station is located at the upper catchment which is at Sungai Kuantan in Bukit Kenau, the result of the outflow will be taken from the nearest junction from the streamflow station. Only rainfall data from one rainfall station also will be use due to the availability of the data is good at that particular rainfall station based on the selected events.

Based on the researched, the main task is to run a simulation run based on the created model in GIS application. In order to run a simulation, the important step is to produce a model as an input for the HEC-HMS. The model of Kuantan watershed will be created in the ArcMap which will involve with delineation process, parameterization procedure and model export. The Kuantan Watershed has a total of 59 sub basins in the watershed. The model export is basically a final step that will create an input file for the HEC-HMS from the ArcMap. In order to associate parameter of the land use and hydrological soil group with the basin, the next step is to produce a curve number map which is used in the ArcMap to calculate the value of curve number for each sub basin the watershed. Some of the parameter needed in the HEC-HMS for the model to run will be computed in the ArcMap automatically while some other parameter such as Lag Time for the routing method will be computed manually.

After the model of the Kuantan Watershed is exported to the HEC-HMS, the simulation process will be carry out and the simulated result will be compare with the observed result from the streamflow station to access the behaviour of the model. The input data for the model to run is the rainfall data, which selected based on the event of flood. In order to ensure the model to work accurately, the model calibration need to be done so the simulated result relatively matching the observed result. The model calibration is done by changing the model parameter such as the curve number. The model was calibrated for the identified sensitive parameters to improve the agreement between the simulated and observed data (Roy et al., 2013). The model efficiency will be evaluated using the factor such as the initial abstraction ratio and antecedent moisture condition. The efficiency of the model generated in this study will be evaluated using the Nash-Sutcliffe efficiency (NSE) method.

1.4 SIGNIFICANT OF STUDY

Malaysia experiences many major floods event in the past few years due to prolong rainfall occurrence. The flood occurrence has causing many negative impacts to the society such as properties loss and affecting the water quality. Due to the flood problem, Malaysian government has spent a lot of money in the flood mitigation work to reduce the impact of flood to the society. Flood occurrence is usually cause by the runoff of rainwater which occur because of the rain volume exceeding the storage capacity in the natural and artificial storage. The process of rainfall-runoff will be influenced by terrain, geology, soil, area, slope, and plant-types (Chang, 2009).

The modelling of the rainfall produces the flood hydrograph prediction which gives contribution to many aspects such as the hydrological planning and managing of flood event. The estimated rainfall also can be used as the guide in hydrologic design of rainfall runoff models. The computation of loses using the SCS-CN loss model also makes us understand more about runoff generation process and study the factors affecting rainfall runoff which can lead to flood. Besides that, the rainfall-runoff relationship is important for hydrological analysis and design. The information generates from the study can provides information important for the regulate the increase volume of the runoff, flood events, evaluation and upgrade of existing hydraulic structure from the changing in the hydrological data and contributes to flood mitigation works process.

1.5 LAYOUT OF THESIS

The thesis consist of five different chapters that and each chapter consist if own purposes. In the first chapter which is the introduction to the study, it generates general information about the study area. It then follows by the scope of study which determines the limit area of researched in term of location and method use. The problem statement indicates the purpose of the study been carried out which is derived from the background of study and the objectives for the study is set from the problem statement. The objectives of the study are the guideline that guides us along with our research. The significant of study indicates the contribution and effect of the research to the interested area of study.

The second chapter is the literature review, in which the researcher extracts information from the related study in the field. The review help me to understand more about the researched topic and what result should I expect from the study. The keyword that I used to searched for the related journal are the rainfall-runoff, HEC-HMS, SCS-CN, modified SCS-CN, and runoff modelling. The review will help in further understanding of the area of study and help to guide me to the correct direction during my research.

The third chapter is the methodology, which is the method I used in this study. The method I used in this study is the HEC-HMS modelling software with the calibrated or modified SCS-CN loss model to generate the runoff model for the study area. The delineation of the study area is done using GIS application which generates the data I needed before I run the simulation using HEC-HMS model.

Chapter 4 focuses on the experimental work or the simulation run process by the model after all the related information and component need in the model has been achieved. The result from the simulation then will be used to generate a curve number and computing runoff volumes using which will be compare with the observed data.

Finally, the data and result from the study will be summarized in chapter 5 and conclusions will be made whether the objectives of the study is achieved or not.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Many researched have been conducted for several years to study the rainfall characteristic and effects of the rainfall event to the surrounding using the HEC-HMS method with SCS-CN as the loss model. The Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) simulates the precipitation-runoff processes of watershed systems (Yuan and Qaiser, 2011). The Curve Number for the study area is determining by factors such as the land use and hydrological soil groups. Prior to the previous rainfall in the watershed which in cooperate with moisture condition; the antecedent moisture condition (AMC) for the development of CN Grid of the area also will need to be taken also. It is apparent that the CN-variability is primarily attributed to the antecedent moisture, and it has led to statistical and stochastic considerations of the curve number, undermining the physical basis of the SCS-CN methodology (Sidoeun et al., 2013). In cooperation of AMC with the curve number also allow sudden increase and decrease of the curve number variation. HEC-GeoHMS was used to delineate the watershed which provide input model for the HEC-HMS. By using HEC-HMS, the simulation of the selected watershed will be run and the simulation data will be comparing with the observed data. Rainfall simulation is also an effective technique to gather hydrologic data for different types of soil-vegetation-land use combinations (Narayan et al., 2012). The model efficiency in running the simulation will be evaluated based on the Nash–Sutcliffe model efficiency coefficient. The Nash–Sutcliffe Efficiencies can range from $-\infty$ to 1, which is the nearer the value of NSE to efficiency of, the higher the accuracy of the model.

2.1 APPLICATION OF GIS FOR WATERSHED DELINEATION

Geographic Information Systems is a computer-based tool that use for purpose of mapping and analyzing. The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the geo-referenced data (Bakir and Xingnan, 2008). It also permits GIS to function as an effective planning tool by making hydraulic data easily transferable to floodplain management, flood insurance rate determination, economic impact analysis, and flood warning systems (Tabyaoui et al., 2011)

A watershed describes the portion of land which contains a common set of rivers and streams which all drain into a single large body of water, such as a lake, a larger river or an ocean (Mallikarjuna and Lakshmi, 2014). A digital representation of the watershed is provide by GIS which can be in-cooperate with which the hydrological modelling. Hydraulic modelling is an important process because in can help in the activity such as hydrological planning and conservation of the water resources. On the uses, GIS will produce two types of data which are the vector data (Shape files) and the raster data (Grids, TINs (Triangulated Irregular Networks) and Image) which will be used in the hydrological model. GIS offers technologically suitable method for land resource assessment, delineating different land use patterns, flood management, irrigation water management, and assessment and monitoring of environmental impact of watershed projects (Aher et al., 2014).

ArcHydro Tools is an extension in ArcGIS and it is used to delineate the sub-basins along with the river flow network on the watershed from the digital elevation model (DEM) of the catchment while HEC-Geo HMS is an extension used to carry out parameterization process along with the model export. The processing of the Digital Elevation Model (DEM) to delineate the watersheds is known as the terrain pre-processing which in this researched, the process is done using ArcHydro Tools extension in the GIS application. The digital elevation model extracted from the ASTER Global Digital Elevation Model (ASTER GDEM) which has the spatial resolution of 30 m. The DEM is use to delineate the watershed as the drainage surfaces, stream network, sub basins and the longest flow along with the topographic parameters such as the watershed terrain slope, river slope and the length and area of the parameter in the watershed. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation (Alaghmand et al., 2012). The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed (Hasan et al., 2009).

The Curve Number (CN) for a watershed can be estimated as a function of land use, soil type and antecedent watershed moisture (Feldman, 2000) and will be associated to the delineated basin in order to compute the curve number for each sub basin. The advantage of runoff estimation using curve number method for a drainage basin are accounted by those interactive factors in combination of land use, soil, and antecedent soil moisture condition (AMC) (Amberber, 2014). HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons (Hasan et al., 2009). HEC-GeoHMS creates background map files, basin model files, meteorological model files and a grid cell parameter files which can be used in HEC-HMS to develop a hydrological model (Fleming and Doan, 2009).

2.2 HEC-HMS MODEL

2.2.1 INTRODUCTION

HEC-HMS is hydrologic modeling software developed by the US Army Corps of Engineers Hydrologic Engineering Centre (HEC). HEC-HMS uses separate sub-models to represent each component of the runoff process, including models that compute rainfall losses, runoff generation, base flow, and channel routing (Du et al., 2012). HEC-HMS can help to set up the hydrologic model system and simulate the rainfall-runoff process of a watershed (Chang, 2009). A GIS companion product called the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) has been developed to aid in the creation of basin models and meteorological models for use with this software (Gautam, 2014).

2.2.2 COMPONENTS OF HEC-HMS BASIN MODEL

To simulate the runoff using HEC-HMS, it will require three basic components to enable the model to run that is:

a) The Basin Model

The basin model is preparing using HEC-GeoHMS which is then exported to HEC-HMS by using a raw ASTER GDEM. The whole watershed of 1674.359 km^2 is divided into 59 sub basins which are set as an input for HEC-HMS. The basin model collects information about the physical characteristics of the basin or sub-basins and the method used for the simulation.

b) Meteorological Model

Describe the atmospheric conditions on the land surface of the watershed which includes the precipitation gages, rainfall distributions and rainfall events.

c) Control Specifications

The function of control specifications is to control the simulation start and stop time along with the time interval used for the simulation. Each control specifications will include the time interval which is directly proportional to the rainfall event and observed flow used to perform the computations of the simulation.

d) Time Series data

It the component where actual rainfall data are entered in the model as per the control specified. Time series data is a function where the rainfall data of the event is entered along with the date and duration of the rainfall. The time series data function also enable the input of coordinates of the rainfall station where the data of rainfall belong to. By using the time series data also, the observed flow data also can be entered to be compare with the simulated data.

2.2.3 APPLICATION OF HEC-HMS

In 2008, Mohamad Bakir and Zhang Xingnan conduct a study to compare the performance of HEC-HMS with Xinanjiang conceptual model using historical flood data from the Wanjiabu catchment in China. Their finding indicate that HEC-HMS is more convenient for flood stimulation especially in optimizing parameters but not quite accurate as compared with Xinanjiang model. They stated that the high accuracy of the Xinanjiang model is due to it has more parameters which making it flexible to fit the study flood event.

Zorkeflee Abu Hasan, Nuramidah Hamidon and Dr. Mohd Suffian access the hydrology response due to the land use changes in Sungai Kurau Basin based on the available data in Perak which used HEC-HMS to develop the hydrologic model for Sungai Kurau Basin in 2009. In their study, they conclude that the simulated model were fit with the observed data and shows that the HEC-HMS are suitable model to predict the hydrologic changes in Sungai Kurau Basin.

In 2011, Yongping Yuan and Kamal Qaiser used the HEC-HMS model to study the impacts of urbanization and wetlands for mitigation in Kansas River basin. From their study, the results their obtained show an appreciable increase in peak runoff and flood inundation extents for the various scenarios such as the land use scenarios, climate scenarios and future wetlands scenarios. They also explain that the models created can be used to test the impacts of land use changes, rainfall predictions, and channel modifications in the river basin of their study. Through their conclusion, they conclude that the limitation of the HEC-HMS model is that it is built on a macro scale, and if the results are applied to a small segment on the watershed, they might not be accurate. Yongping Yuan and Kamal Qaiser also conclude that an economic analysis would be needed to determine whether the savings in damages obtained from flood reductions as a result of increasing wetland volumes justify the cost of constructing and maintaining those wetlands.

D.Halwatura and M.M.M. Najim (Halwatura and Najim, 2013), applied the HEC HMS model for the runoff simulation in Attanagalu Oya, Sri Lanka to study the applicability of the model in tropical catchment. They used the SCS-CN method and Deficit and Constant method as the loss model in the HEC-HMS model. They conclude that the SCS CN method does not perform well in their study for the computation of losses in the catchment compare to the Deficit and Constant method. On the researched of simulation of event based runoff using HEC-HMS model for an experimental watershed done by Reshma, Venkata Reddy and Deva Pratap (T. et al., 2013), they applied the HEC-HMS model for Walnut Gulch watershed in Arizona, USA and used the model to simulate seven rainfall events which has been calibrated and validated. They has been calibrated four rainfall events and validated three rainfall events for the model. From their results, they observed that HEC-HMS model has performed satisfactorily for the simulation runoff for the different rainfall events. They then do a comparison on the simulated results with the observed hydrographs. They conclude that for the simulation of calibration events, it has more variation to the volume of runoff and time to peak compared to the observed hydrographs but the peak runoff has less variation in the simulated result.

2.3 SCS CURVE NUMBER LOSS METHOD

2.3.1 INTRODUCTION

The SCS Curve Number method is a method to compute runoff. The method was developed by the Natural Resources Conservation Service (NRCS) in 1954. Based on Soil Conversion Service (SCS) there are four types of runoff which is the channel runoff, surface runoff, subsurface runoff and base flow runoff. The SCS CN parameter was originally developed to predict changes in runoff due to a change in land use, and was not proposed as a deterministic model for estimating floods runoff from a particular rainfall, or as a probabilistic model to estimate a design flood. The SCS-CN method estimates direct runoff with the curve numbers indicating the proportions of surface and subsurface flow, larger curve numbers represent a greater proportion of surface runoff (Narayan et al., 2012). The Curve Number method are used to calculate the matched return period runoff from rainfall, generate time-distributed runoff pulses to from time-distributed rainfall in hydrograph models and it has been creatively applied in continuous soil moisture models – often on a daily time step - as inter-dependent runoff and soil moisture accounting components (Hawkin et al., 2010). The Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use and antecedent moisture (Abood et al., 2012). The major disadvantages of the method are sensitivity of the method to Curve Number (CN) values, fixing the initial abstraction ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions (AMC) (Patel, 2009).

The SCS-CN method is used in runoff estimation to specify the amount of infiltration rates of soils. The method uses an integration of land use and soil data to determine CN values of the watershed. In this regard, soils are categorized into hydrologic soil groups (HSGs). The HSGs consists of four categories A, B, C and D which A and D are the highest and the lowest infiltration rate, respectively (Kabiri, 2014). The main factor that influences the direct runoff of the rain from a basin is the precipitation. The relationship between precipitations and exceeding precipitation is obtained from precipitation loss. The loss from precipitation after rainfall event is usually caused by the evaporation, infiltration, water storage and interception. The major factors that determine CN are the hydrologic soil group (HSG), land use and antecedent moisture condition (AMC).

2.3.2 ORIGINAL SCS-CN METHOD

The method of SCS-CN basically based on the principle of the water balance which considers two fundamental assumptions:

a) The ratio of direct runoff to potential maximum runoff is equal to the ratio of infiltration to potential maximum retention.
b) The initial abstraction is proportional to the potential maximum retention.

The water balance equation and the two assumptions are expressed mathematically

$$P = I_a + F + Q \tag{1}$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

Where

P is the total precipitation (mm)

I_a is the initial abstraction (mm)

F is the cumulative infiltration after runoff start (mm)

Q is direct runoff (mm)

S is the potential maximum retention (mm)

λ is the coefficient for the initial abstraction

By combining the Equations (1) with Equation (2), it will generate the original SCS-CN method:

$$\begin{aligned} Q &= \frac{(P - I_a)^2}{P - I_a + S} \quad \text{for } P > I_a \\ Q &= 0 \qquad\qquad\quad\ \text{for } P \leq I_a \end{aligned} \tag{4}$$

Where

P is the total rainfall

I_a is the initial abstraction

Q is the direct runoff

S is the potential maximum retention.

Based on the second assumption, the amount of initial abstraction is a fraction of the potential maximum retention. The potential retention S is expressed in terms of the dimensionless curve number (CN) through the relationship.

This definition of the potential retention in the SI units (S in mm) is expressed in the following definition:

$$S = \frac{25\,400}{\text{CN}} - 254 \tag{5}$$

Where the value for CN is a dimensionless units, and it dependence on the land use, hydrological soil groups, hydrologic conditions, and the antecedent moisture conditions. Initial abstraction (I_a) is all losses before runoff begins and it includes water which is retained in surface depressions, vegetation interception, infiltration and evaporation. It is high in variability of value for variable I_a, but it usually more dependence on the parameters of soil and land cover. Through past studies, many researched is conducted which is normally in a small agricultural watersheds. The ideal approximation of I_a was shown in Equation (6):

$$I_a = 0.2S \tag{6}$$

By substituting the variable I_a in the Equation (4), the use of a combination of S and P will produce a unique runoff amount. Substituting the Equation (6) into Equation (4) gives:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{7}$$

2.3.3 MODIFIED SCS-CN LOSS METHOD

2.3.3.1 INITIAL ABSTRACTION ADJUSTMENT RATIO

Initial abstraction of a watershed is defined as the water that are loses before the runoff is begin. Water retained in surface depressions, infiltration and intercepted by vegetation are included in initial abstraction (Adham et al., 2014). For the initial abstraction on the SCS-CN, the original value of the initial abstraction ratio (λ) was established as 0.20. Several subsequent studies have re-examined that value and found λ values in the range of 0.02 to 0.07 which then considered as an identifying watershed variable and has been subjected to increased scrutiny (Hawkin et al., 2010). The relationship between $S_{0.05}$ and $S_{0.20}$ is shown in Equation, the new potential retention is expressed in Equation (9) where S is in inches and the new initial abstraction of ratio of 0.05 is shown in Equation (10).

$$CN_{0.05} = \frac{100}{1.879[\left(\frac{100}{CN_{0.2}}\right)-1]^{1.15}+1} \quad (8)$$

$$S_{0.05} = 1.33(S_{0.20})^{1.15} \quad (9)$$

$$I_a = 0.05S \quad (10)$$

2.3.3.2 ANTECEDENT MOISTURE CONDITION

Normally, the curve number that usually use in the watershed modelling is the normal moisture condition, AMC II. Antecedent Moisture Condition (AMC) is basically referring to the moisture condition of the soil in the watershed before the simulated event. The level of moisture condition in a watershed is divided into three categories which is the AMC I, AMC II and AMC III. The AMC I is referring the condition to be dry, AMC II in the normal condition and AMC III is the wet condition in the watershed. The higher the antecedent moisture or rainfall amount, the higher is the CN, therefore, the high runoff potential of the watershed, and vice versa (Mishra et al., 2004). These three levels of AMCs create physically unreasonable sudden jumps in curve numbers (CNs), and hence in estimated runoff (Sahu et al., 2012). The watershed antecedent moisture condition (AMC) is one of the most influential factors in determining CN (Hawkins et al., 1985). The conversion of the curve number from normal condition to dry and wet condition develops by Hawkins et al. in 1985 is expressed as:

$$CN\ (I) = \frac{CN_{II}}{2.281-0.01381CN_{II}} \quad (11)$$

$$CN\ (III) = \frac{CN_{II}}{0.427-0.00573CN_{II}} \quad (12)$$

The curve number also can be adjusted for the antecedent moisture condition by using the factors to convert it from AMC II to AMC I and AMC III as shown in Table 2.0. The factor is relatively less than 1 for the AMC I to reduce the curve number while the factor for AMC III is more than 1 which will increase the value of the curve number in the watershed due to moisture condition.

Curve Number (AMC II)	Factors to Convert Curve Number for AMC II to AMC I or III	
	AMC I (dry)	AMC III (wet)
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Table 2.0: Adjustments to select curve number for soil moisture conditions (https://en.wikipedia.org/wiki/Runoff_curve_number)

2.3.4 APPLICATION OF SCS-CN LOSS MODEL

Naturally, the rainfall that fall on the pervious surface of the earth will subject to losses. In HEC-HMS, there are seven loss models to compute losses from rainfall which are the initial and constant, deficit and constant, SCS curve number, soil moisture accounting (SMA), gridded soil moisture accounting. Green and Ampt and gridded SCS curve number (United States Army Corps of Engineers (USACE)). The Soil Conservation Service curve number method, SCS-CN is essentially an empirical, one-parameter CN event rainfall-runoff model. It is established by Soil Conservation Service (SCS) to describe the soil condition in United State which is empirical and area-limited method first use in United State. The dimensionless curve number takes into account, in a lumped way, the effects of land use/cover, soil types, and hydrologic conditions on surface runoff, and relates direct surface runoff to rainfall. The Curve Number method is applied in an off-the-shelf fashion to perform to a variety of roles in surface water hydrology (Hawkin et al., 2010). The SCS-CN method has been widely used for estimating rainfall-generated surface runoff in watershed hydrologic modeling (Chu and Steinman, 2009).

Hawkin et al. discussed in their study that the method has evolved via testing with field data, application adjustments, insights, and institutional alterations which leading to a more credible representation of rainfall-runoff hydrology. Based on their study on the continuing evolution of rainfall-runoff and the curve number precedent, they explained the application of the Curve Number (CN) which is used to calculate the matched return period runoff from rainfall, to generate time-distributed runoff pulses to from time-distributed rainfall in hydrograph models and it has been creatively applied in continuous soil moisture models.

Hawkin at el. also discussed the behavior classes of the curve number method which divided into three behavior classes;

a) Standard response

The observed curve numbers decrease with increasing rainfall depth but do approach stable or constant values. This stable value, denoted as infinity curve number, CN∞ is characterized as the watersheds identifying curve numbers which is applicable to larger design storms.

b) Complacent response

The observed curve numbers fall with increasing precipitation, but do not approach a near stable value, at least in the range of the observed data. In complacent response, a consistent curve numbers cannot be identified.

c) Violent response

The curve numbers initially declines with rainfall depth but rises abruptly at some threshold rainfall then approaches a near-stable higher value of infinity curve number, CN_{∞} with the increasing of rain depth. This violent response data usually obtained from humid forested watersheds.

While in the research done by Chi-Wen Chang in 2009, he used the SCS CN Method in HEC-HMS to simulate rainfall-runoff in ShihMen watershed. The purpose of his study is to study whether the SCS curve number (SCS CN) loss model method is appropriate for estimation of direct runoff in ShihMen, Taiwan. The result obtained from his study indicates that CN value has correlated to hydro-geo factors and has positive correlation with peak flow. He concludes that the CN value is a positive correlative with peak flow rate and average slope. He stated that the hydrologic model needs the Curve Number (CN) value to reflect the runoff hydrograph due to the relationship between infiltration with peak flow rate and average slope, which infiltration is negative correlative with peak flow rate and average slope. From his conclusion also, he stated that the Curve Number (CN) value is a negative correlative with initial abstraction and precipitation and when the precipitation becomes higher, the Curve Number (CN) value will drop.

In 2012, Abood et al. also conducted a researched to evaluate the performance of SCS-CN loss model with comparison with Green-Ampt loss model. They use the HEC-HMS model to run a rainfall-runoff simulation in Kenyir and Berang catchment in Terengganu, Malaysia. They conclude that both loss models was applicable in the catchment since it has high agreement with observed data but they highly recommended the use of SCS-CN loss model due to its high accuracy in the modelling results compare to the Green-Ampt loss model. Whereas, Reza Kabiri used the modified Curve Number (CN) loss model to simulate runoff in Klang watershed in Malaysia. He used the modified Curve Number (CN) is to make estimation on the results by some correlation coefficients and error indices. Instead of using the original value of the initial abstraction ($\lambda = 0.02$), he use the initial abstraction ($\lambda = 0.05$). His results revealed that initial abstraction ($\lambda = 0.05$) and $CN_{0.05}$ of daily rainfall by percent error in peak have given no significant difference results rather than using initial abstraction with 0.2 value and $CN_{0.2}$.

For precipitation-runoff-routing simulation, HEC-HMS provides the following components of precipitation-specification options, loss model, models of naturally occurring confluences and bifurcations and models of water control measures. HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems (Hasan et al., 2009). HMS provides precipitation- specification options, loss models which can estimate the volume of runoff, and direct runoff and hydrologic routing models, and also includes a calibration optimization package (Bakir and Xingnan, 2008). Each method in HEC-HMS has parameters and the values of these parameters should be entered as input to the model to obtain the simulated runoff hydrographs (Asadi and Boustani, 2013). HEC-HMS is used to simulate the flood events that occur to set up the rainfall-runoff model in watershed.

2.3.5 SCS UNIT HYDROGRAPH TRANSFORMS METHOD

The time of concentration, T_c is defined as the time required for the water to travel from the remote point in the watershed to the outlet of the watershed. It is also can be define as the peak runoff rate resulting from a rain in a certain period in the watershed where there will be a concentration of runoff from the entire sub basin in the watershed. The time of concentration can be calculated from various existing formula such as the SCS method and Kirpich method. The SCS method is a method developed by the soil conservation service for constructing synthetic unit hydrographs which is based on a dimensionless hydrograph, and which relates ratios of time to ratios of flow (Sule and Alab, 2013). The lag time is the difference in time between the center of the mass of effective rainfall and the center of the mass of direct runoff produced by the effective rainfall (Al-Shareef et al., 2013). It is an important factor used to quantifying the time response of the runoff in the watershed.

The SCS lag-time formula used to calculate the time of concentration, t_c is:

$$t_c = 0.057 \frac{L^{0.8}(\frac{1000}{CN} - 9)^{0.7}}{\sqrt{S}} \tag{13}$$

Where:

L is the basin length (km)

CN is the curve number of the basin

S is the slope of the basin

$$t_l = 0.6 t_c \tag{14}$$

The lag time shown in Equation (14) is the time require for the water to flow from the remote point to the outlet of the watershed. The calculation of lag time, t_l for the SCS Unit Hydrograph is expressed as: The calculate value of the lag time will be used as the input parameter for the SCS Unit Hydrograph method in HEC-HMS. However, due to the availability of the extension of HEC-GeoHMS in the ArcGIS, the computation of the lag time can be calculated automatically in the ArcGIS. This unit hydrograph was then used to predict peak discharge likely to be obtained from flood type rainfall, which tends to occur during cyclonic periods (Yahya et al., 2010).

2.3.6 SCS LAG TIME ROUTING METHOD

SCS Lag equation is used to calculate the time of concentration of the sub basin in the watershed. For application of the equation in mixed pervious and impervious area, this method tends to overestimate the flow in the watershed.

$$t_c = \frac{1.67 L^{0.8} \left\{ \frac{1000}{CN} - 9 \right\}^{0.7}}{1900 S^{0.5}} \tag{15}$$

Where:
CN is the curve number
S is the average watershed slope (%)
L is the hydraulic length of the watershed, m.

The Kirpich Method used to calculate the time of concentration:

$$t_{ch} = KL^{0.770} S^{-0.385} \tag{16}$$

Where:
t_{ch} is the time of concentration (minutes)
K is a units conversion coefficient where K = 0.0195 for SI units

L is the maximum hydraulic flow length (m)
S is the difference in elevation or slope (m)

2.4 MODEL EFFICIENCY

The Nash-Sutcliffe efficiency (NSE) was used to assess the SCS-CN model performance (Geetha et al., 2014). NSE is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). The Nash & Sutcliffe criterion can also be interpreted as a criterion that determines the improvement made by a given model in simulating flows in comparison with a reference model that would simulate a flow equal to Q_{obs} at each time step (Mathevet et al., 2006). The values can range from -∞ to 1 where value of 1 corresponds to a perfect match of modelled to the observed data and 0 indicates that the model predictions are as accurate as the mean of the observed data and $-\infty < NSE < 0.0$ indicates that the observed mean is a better predictor than the model. The NSE is obtained by Equation (17):

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n} ((Q_o)_i - (Q_s)_i)^2}{\sum_{i=1}^{n} ((Q_o)_i - \overline{Q_o})^2} \right) \tag{17}$$

Based on calculated value of efficiency by using the equation, the performance of the developed model can be evaluated. By using the HEC-HMS version 4.0, the software will generate automatically the efficiency value of the model based on the result after the computation of the simulation with the present of observed discharge which is entered manually in the model.

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

In performing the rainfall runoff simulation, it will involve a few steps of creating the model before the simulation is carried out in the HEC-HMS software which are data collection, watershed delineation, watershed parameterization, simulation run and model verification and calibration. The work flow of the whole process is shown in Figure 3.0.

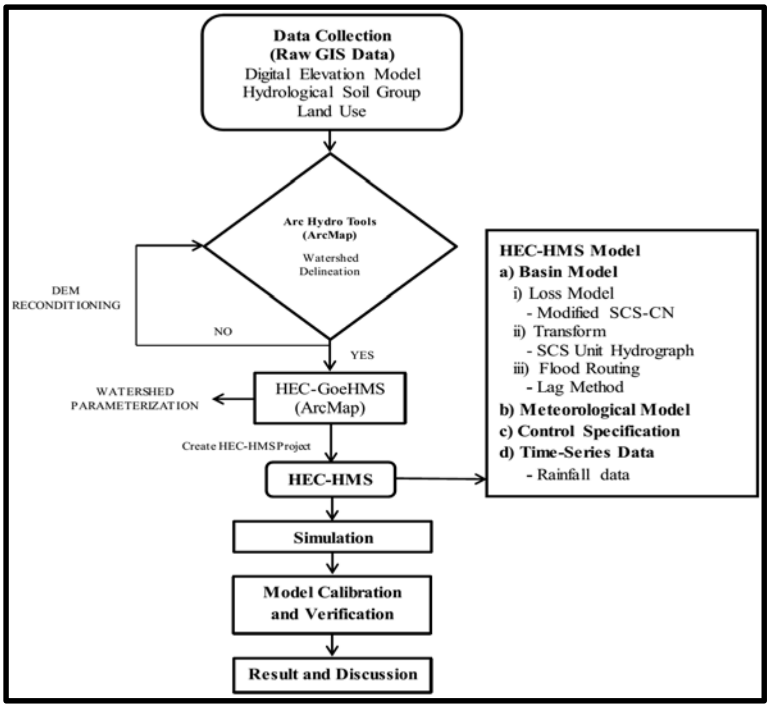


Figure 3.0: Work flow chart

3.1 DATA COLLECTION

In order to create a model for Kuantan watershed, there are a few data that need to be collected first. The first data that is required is the digital elevation model (DEM) for the study area. A digital elevation model (DEM) is a digital model that represents a terrain's surface of the study area which was created from terrain elevation data. The digital elevation model for this project is a 30m resolution model obtained from the ASTERGDEM official website (http://gdem.ersdac.jspacesystems.or.jp/). The model is use as an input for the delineation process in ArcGIS and it is shown in the Figure 3.1.

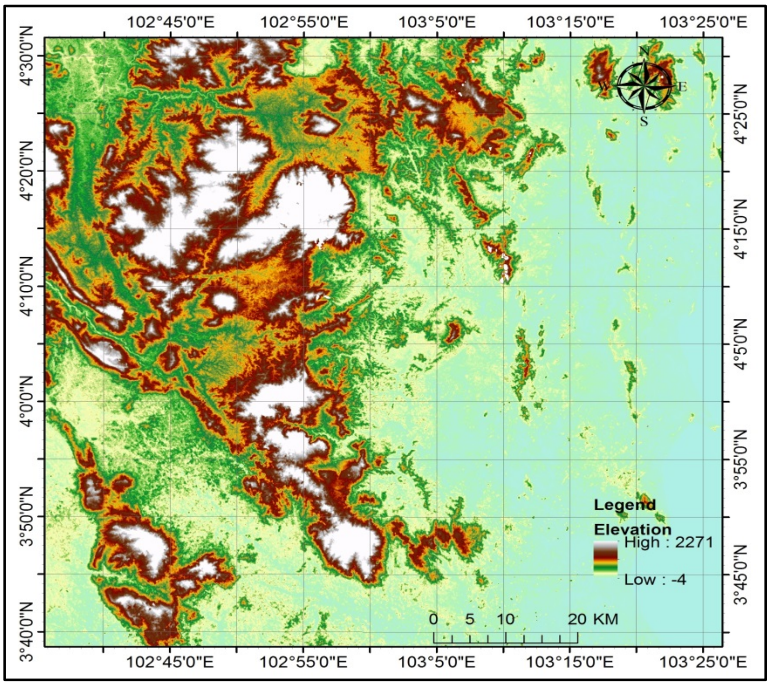


Figure 3.1: Digital Elevation Model (DEM) for the study area

The next data are the land use map and the hydrological soil group map. Land use map reflect the type of land resources and land use while hydrological soil group map define the type of soil distribution on the study area. Both maps, which are shown in Figure 3.2 and Figure 3.3, are needed to create a curve number (CN) map for the study area. The use of curve number map is for predicting condition such as direct runoff and infiltration from rainfall event.

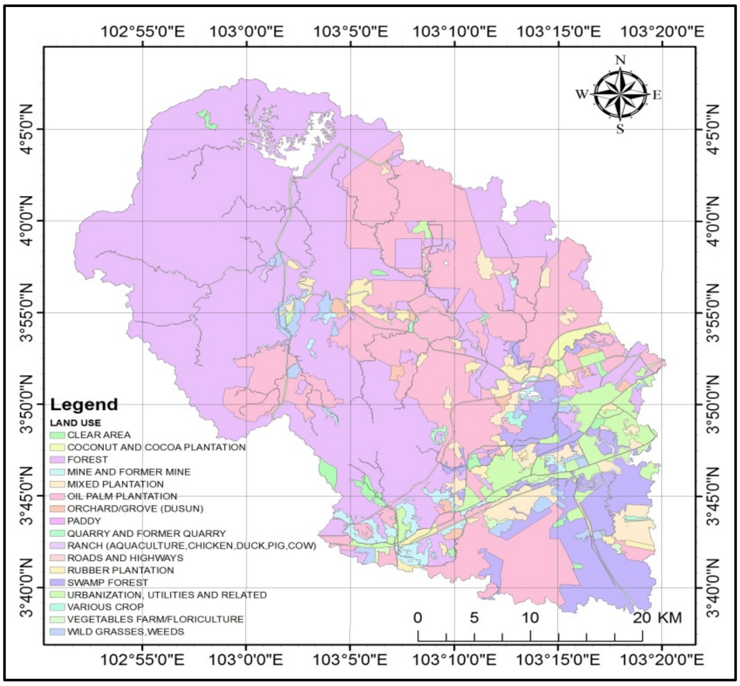


Figure 3.2: Land use map

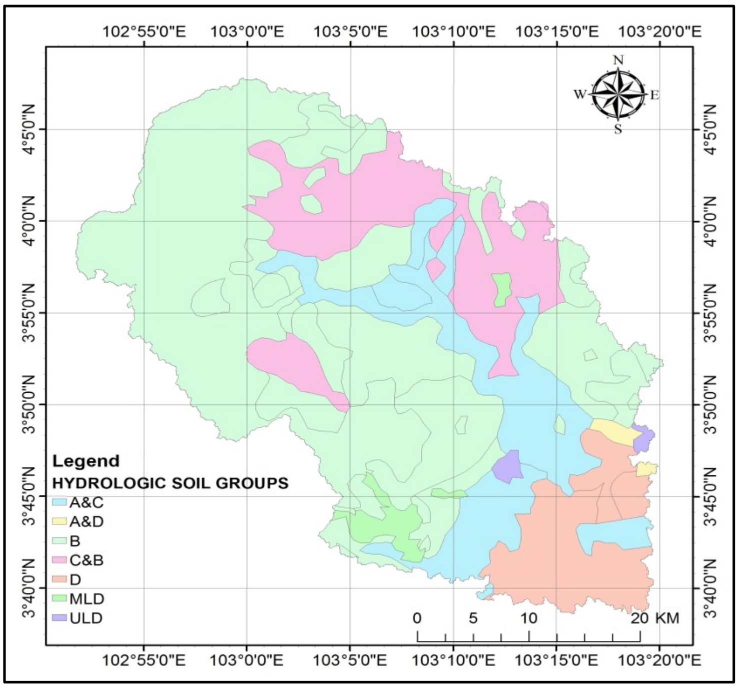


Figure 3.3: Hydrological soil groups map

3.2 CURVE NUMBER MAP

The important features in the simulation run are the variation of land use and hydrological soil groups in the study area. Each type of soil in the watershed may have different characteristic that have different effect on rainfall runoff. The high imperviousness of the soil will reduce the amount of the runoff while pervious soil will produce high runoff value. The variation of land used in the study area also needs to be taken in consideration because each type of land use also will have different imperviousness value. In order to take both of the land use and hydrological soil group into consideration, the curve number map of the study area need to be created based on the land use map and hydrological soil group map. The curve number for this project is create in ILWIS software based on the assign curve number that have assign for each characteristic of land use and hydrological soil groups which is shown in Figure 3.4.

	HYDROLOGICAL SOIL GROUP						
LAND USE	A	B	C	D	C&B	A&C	A&D
Roads and Highways	83	89	92	93	91	88	88
Mine and Former Mine	76	85	89	91	87	83	84
Urbanization, Utilities And Related	83	89	92	93	91	88	88
Quarry and Former Quarry	76	85	89	91	87	83	84
Mixed Plantation	64	75	82	85	79	73	75
Vegetables Farm/Floriculture	64	75	82	85	79	73	75
Coconut and Cocoa Plantation	32	58	72	79	65	52	56
Rubber Plantation	32	58	72	79	65	52	56
Oil Palm Plantation	32	58	72	79	65	52	56
Orchard/Grove	32	58	72	79	65	52	56
Paddy	64	75	82	85	79	73	75
Various Crop	64	75	82	85	79	73	75
Ranch (Aquaculture, Chicken, Duck, Pig, Cow)	54	74	82	86	78	68	70
Wild Grasses, Weeds	30	48	65	73	57	48	52
Forest	30	55	70	77	63	50	54
Swamp Forest	30	55	70	77	63	50	54
Clear Area	39	61	74	80	68	57	60

Table 3.0: Assign curve number based on land use and hydrological soil groups

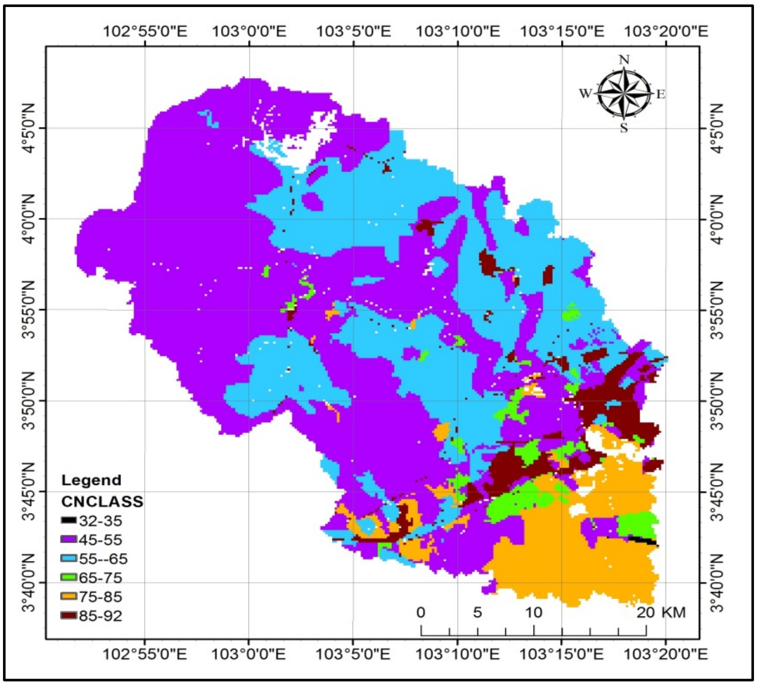


Figure 3.4: Curve number map

The curve number is an important aspect in the runoff determination and by using the curve number also, the model of the HEC-HMS can be calibrated to increase the accuracy of the result obtain. Based on the curve number for every sub basin, the initial abstraction for the each sub basin then can be calculated. The initial abstraction ratio is usually assumed as 0.2S but for this project, the formula of the initial abstraction that will be used is 0.05S which will be used in the loss model in HEC-HMS.

3.3 WATERSHED DELINEATION

The extraction of hydrologic information, such as flow direction, flow accumulation, watershed boundaries, and stream networks, from a DEM (Digital Elevation Model) was accomplished through GIS applications (Oleyiblo and Li, 2010). The generation of the hydrology parameters of the watershed was carried out using HEC-GeoHMS which is the geospatial hydrologic modeling extension and to be use in the rainfall-runoff modelling. HEC-GeoHMS works in an ArcView Geographic Information System (GIS) platform and helps develop hydrologic modeling units and generate initial model parameters that can be derived from spatial data (Demissie et al., 2010). The hydrologic models of the study area were generated using HEC-GeoHMS in the ArcGIS that will be parameterized after delineation steps which include a series of steps of terrain pre-processing and basin processing. The most important role of HEC-GeoHMS is to derive a watershed data structure under the platform of GIS that can be imported directly to HEC-HMS (Basarudin et al., 2014).

3.3.1 COMPUTING WATERSHED PARAMETERS IN ARCMAP

By using the digital elevation model, the watershed parameter can be extracted in the ArcMap by using ArcHydro Tools and HEC-GeoHMS extension. Acrhydro Tools is use for the terrain processing of the watershed which will extract the parameter such the drainage line and watershed slope. In this process also, the sub basin in the watershed also will be computed based on the process accumulated flow direction and drainage line in the watershed. After that, the HEC-GeoHMS procedure to extract the watershed boundary based on the define outlet of the watershed. The extension will further be used to extract the parameter inside the watershed boundary such as the river length and the sub basin area. HEC-GeoHMS also will be used to associate the sub basin wilt the curve number map, calculate the lag time and export the model to be used in HEC-HMS. The Archydro Process steps shown are based on the recondition DEM.

a) ArcHydro Process

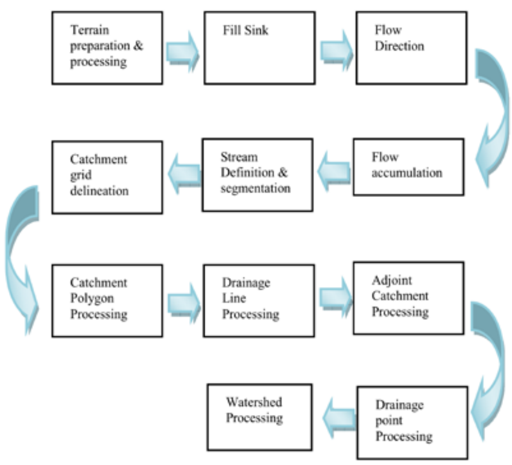


Figure 3.5: Watershed delineation process in ArcMap (Basarudin et al., 2014)

i) **Fill Sink**

This process will fill the sink in the grid. The cell that has lower elevation next to neighbor cell will trap the water.

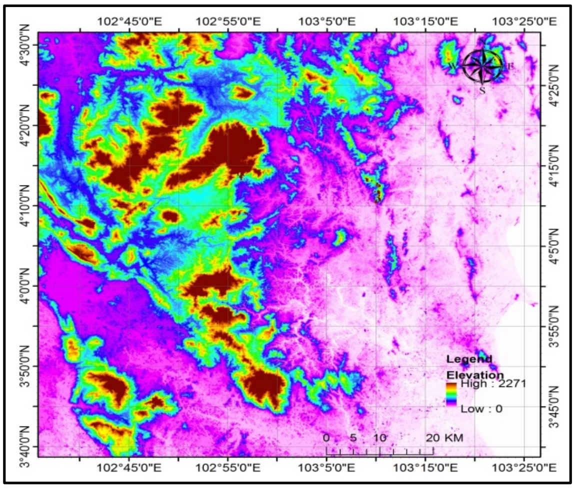


Figure 3.6: Fill Sink processed using ArcHydro Tools

ii) **Flow Direction**

This process determines the flow direction of trap water in the Fill Sink process.

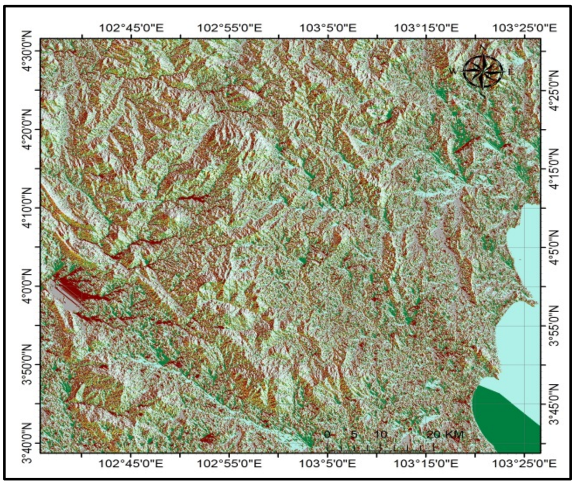


Figure 3.7: Flow Direction processed using ArcHydro Tools

iii) **Flow Accumulation**

This process creates an accumulated flow into each cell.

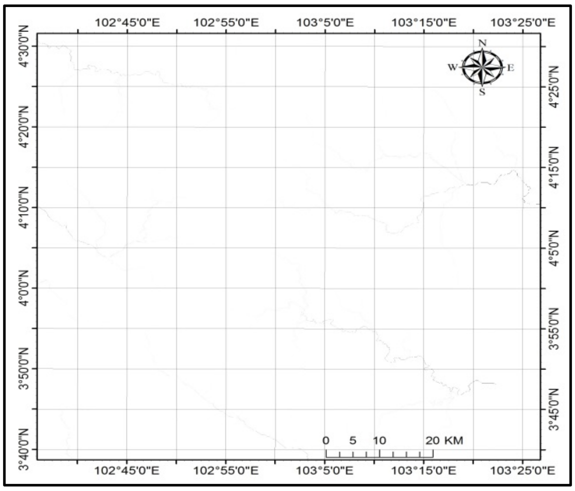


Figure 3.8: Flow Accumulation processed using ArcHydro Tools

iv) **Stream Definition**

Stream definition is the computation the grid cells which creates a stream network from flow direction and flow accumulation process.

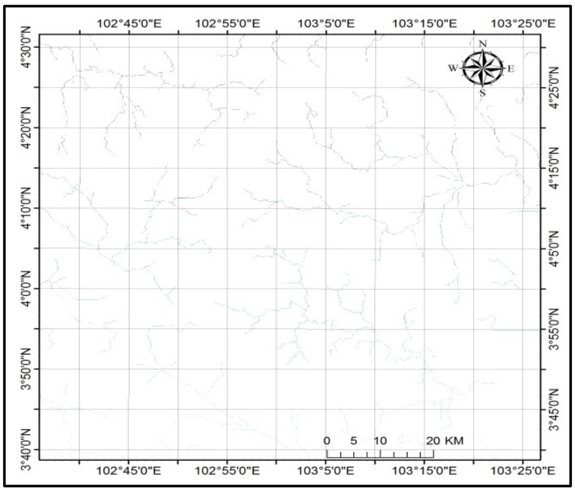


Figure 3.9: Stream Definition processed using ArcHydro Tools

v) **Stream Segmentation**

This process computed segments that have unique identification in which all the cells in the same segment have the same grid code.

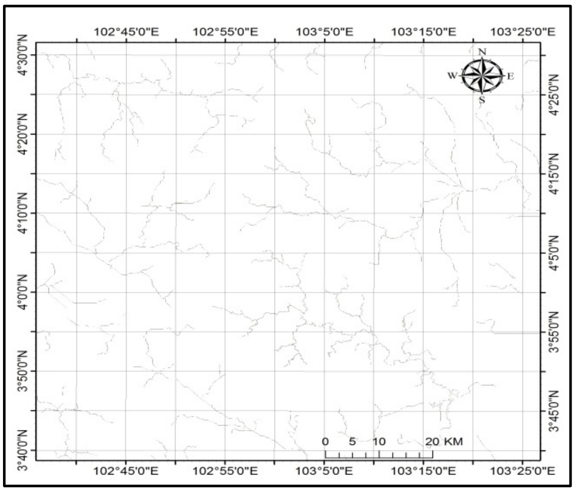


Figure 3.10: Stream Segmentation processed using ArcHydro Tools

vi) **Catchment Grid Delineation**

This process creates a grid in which each cell carries grid code which indicates to which the catchment the cell is in.

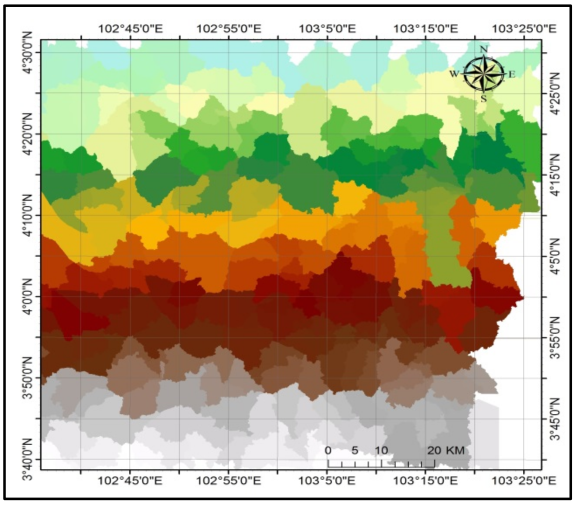


Figure 3.11: Grid Delineation processed using ArcHydro Tools

vii) **Catchment Polygon Processing**

This process will convert the catchment grid after grid delineation process to polygon features.

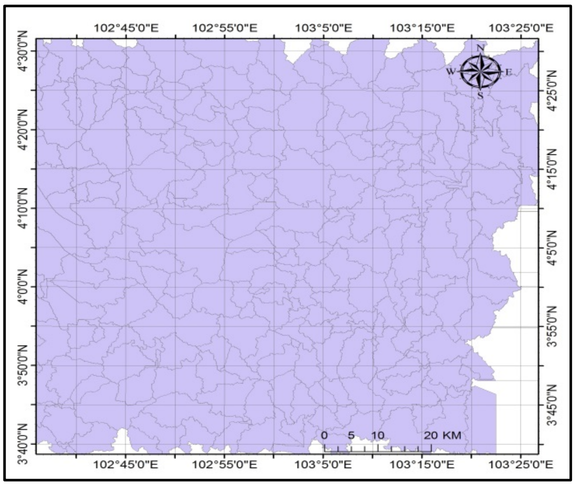


Figure 3.12: Catchment Polygon processed using ArcHydro Tools

viii) **Drainage Line Processing**

This process will convert the stream link grid into the feature class of drainage line.

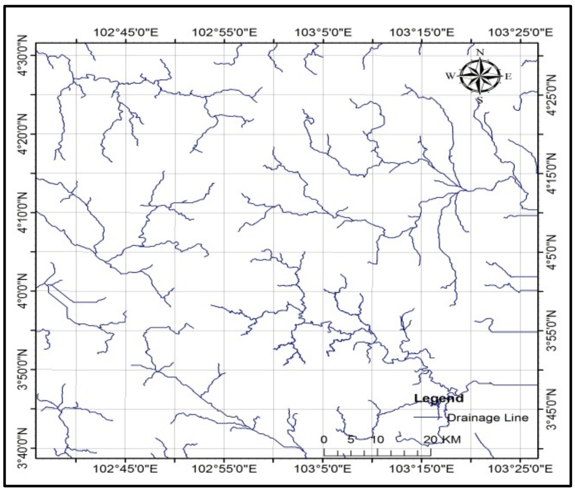


Figure 3.13: Drainage Line processed using ArcHydro Tools

ix) **Ad joint Catchment Processing**

This process will generate the aggregated upstream catchments which define from the catchment feature class.

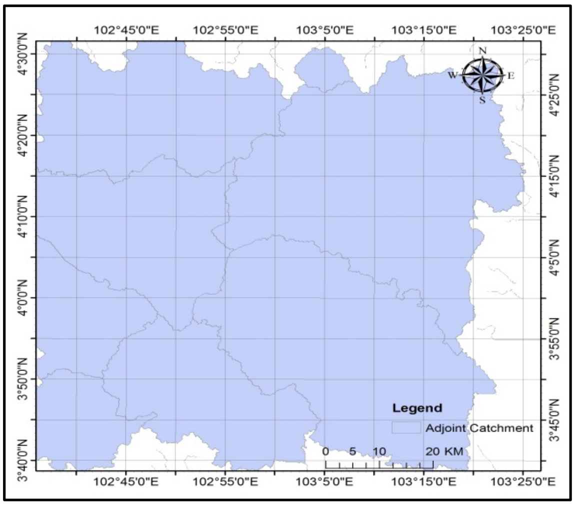


Figure 3.14: Ad joint Catchment processed using ArcHydro Tools

The completed process of all the steps will generate the input data that will be used in HEC-GeoHMS in order to compute the hydrologic parameters of the study area.

b) HEC-GeoHMS Process

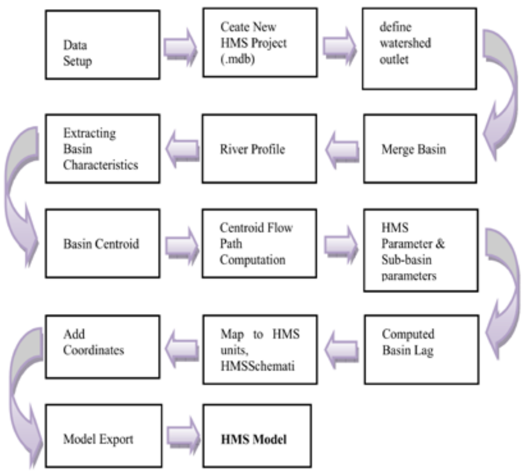


Figure 3.15: HEC-GoeHMS procedure (Basarudin et al., 2014)

Before the computation of the parameter in the HEC-GeoHMS, the first step is to generate or define our project in the HEC-GeoHMS toolbar in the ArcMap. Through this step, we will define the outlet of the watershed that will directly define the watershed boundary of the interest area of study based on the connectivity of the delineated drainage line with the outlet. Based on the process also, the accuracy of our delineated catchment can be check by comparing the drainage line from the existing map with the delineated drainage line. Figure 3.16 shows the watershed boundary and river network of Kuantan river basin before recondition process. Based on the comparison with the existing river network in the Kuantan watershed, the delineated river network was not matching with the actual river network on the lower catchment. The lower catchment of the Kuantan watershed is a flat area with urbanization. In the upper catchment, the river network delineated almost matching the actual river network in the Kuantan watershed.

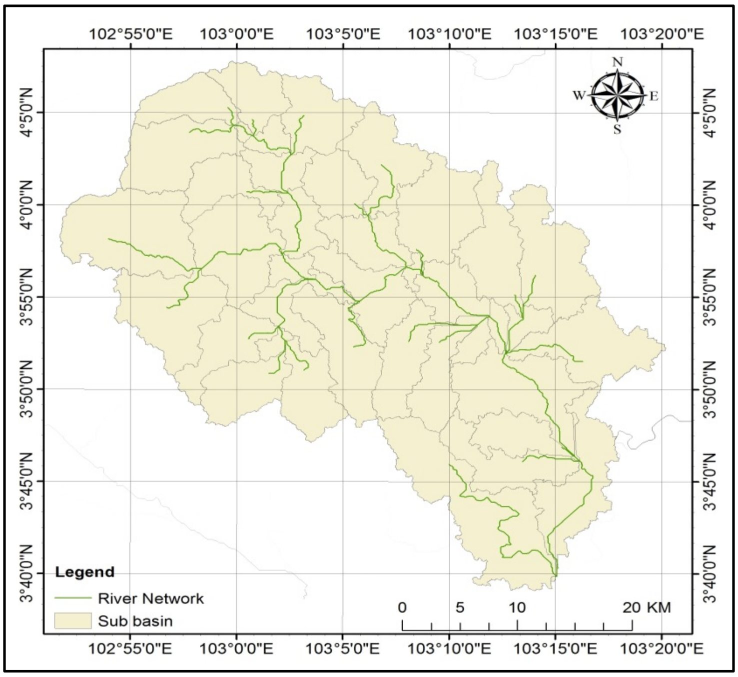


Figure 3.16: Sub Basin and River Network before recondition process

Based on the preliminary result, it indicates that by using the 30 meter resolution of ASTERGDEM model, the delineation process cannot be done precisely in the lower catchment and the model cannot generates the proper river network in a flat land. In order to delineate a matching river network with the actual river network, it is important to include a recondition process in the delineation process. Recondition process will use a stream network that is created in the Google Earth by drawing the actual path of the river network in the Kuantan watershed which will be known as the AGREE stream for the Kuantan watershed. The created stream will be combining with the digital elevation model that will force the model to follow that stream during delineation process. The purpose of the recondition process is to force the model to accept the stream network rather that it follow the process stream network during delineated process. This will ensure that the result obtained for the delineated river network will be matching to the actual stream network.

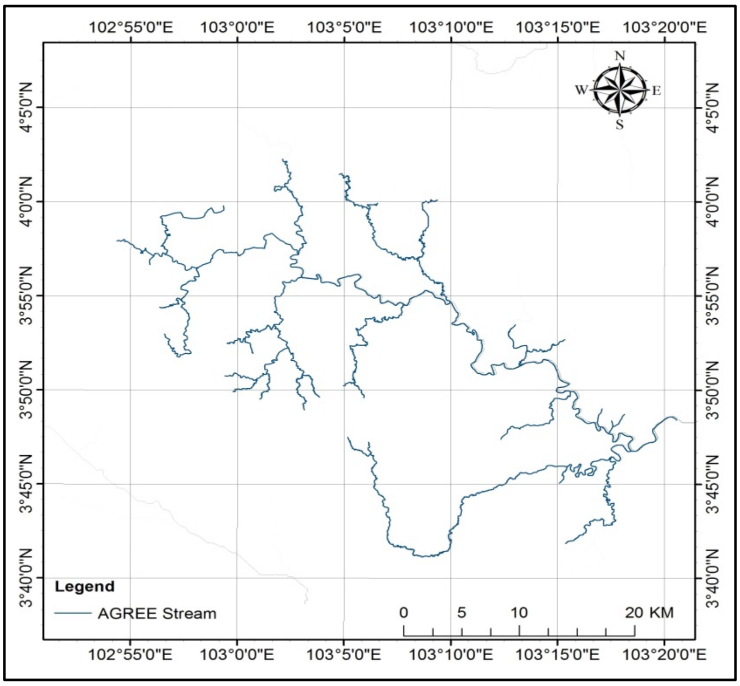


Figure 3.17: AGREE stream for recondition procedure

After the delineation process is complete using ArcHydro Tool extension in the ArcMap, the process of delineation is repeated again by using the recondition digital elevation model, in which all the steps using ArcHydro Tool is repeated. After the process is completed, repeated again the process of defining project and outlet using HEC-GeoHMS extension. After the outlet is determined, it will automatically generate the boundary of the study area based on the connectivity of the river network with the outlet. The watershed boundary, river basin and the river network of the Kuantan watershed after reconditioned process is shown in the Figure 3.18.

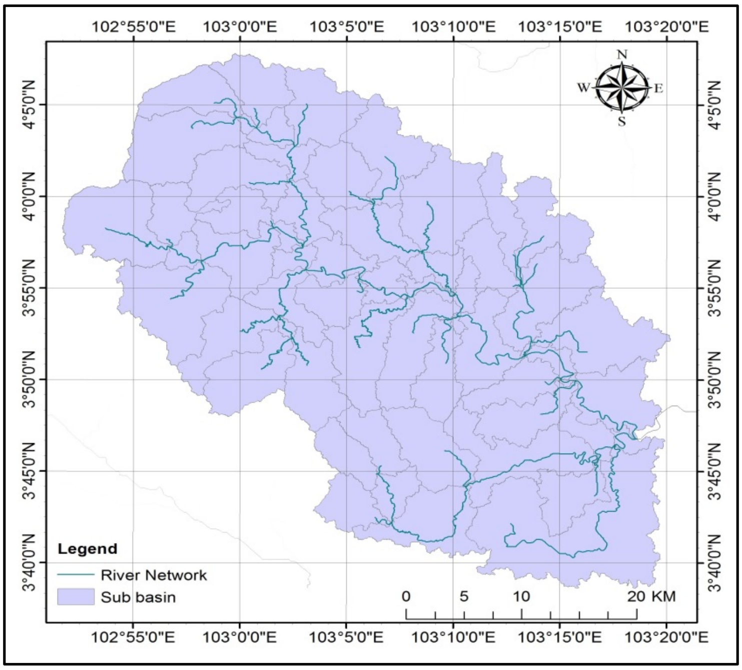


Figure 3.18: Watershed boundary, Sub Basin and River Network after recondition

After the delineation process is completed, the next step is the parameterization process and model export procedure. The parameterization process will calculate and generates the important parameters in the watershed such as river length and basin slope which will be process using HEC-GeoHMS extension in ArcMap. The process also will include the model export which will directly generate input of basin model to be used in the HEC-HMS. All the interactive steps require for the process is summarized and shown at the HEC-GeoHMS procedure in Figure 3.15.

i) Basin Merge

Small sub basin is merging with neighbor sub basin to make a single sub basin basically in basis of the rainfall station.

ii) River Merge

This process is carried or after basin merge to avoid the multi routing.

iii) River Parameters

The length of the river in the basin is calculated to be applying in HMS. The proses also will define the slope and elevation of the river profile.

Table

River Network

OBJECTID *	HydroID	DrainID	Shape *	Shape_Length	Slp	ElevUP	ElevDS	RivLen	Name
1	1	64	Polyline	4130.760981	0.009926	113	72	4130.760981	R10
2	2	68	Polyline	5729.590742	0.009076	124	72	5729.590742	R20
3	3	67	Polyline	2285.056756	0.000875	72	70	2285.056756	R30
4	4	66	Polyline	2470.513645	-0.003643	61	70	2470.513645	R40
5	5	69	Polyline	4957.788646	0.005043	70	45	4957.788646	R50
6	6	65	Polyline	5202.661961	0.00519	72	45	5202.661961	R60
7	7	71	Polyline	5152.267914	0.003688	45	26	5152.267914	R70
8	8	73	Polyline	4429.124432	0.005419	50	26	4429.124432	R80
9	9	76	Polyline	3019.676525	0.001325	11	7	3019.676525	R90
10	10	75	Polyline	7944.473332	0.00214	24	7	7944.473332	R100
11	11	80	Polyline	827.02781	-0.001209	38	39	827.02781	R110
12	12	82	Polyline	3779.81394	0.006614	39	14	3779.81394	R120
13	13	74	Polyline	9976.276059	0.001203	26	14	9976.276059	R130
14	14	86	Polyline	1316.77443	0.032656	143	100	1316.77443	R140
15	15	84	Polyline	8693.400347	0.014954	230	100	8693.400347	R150
16	16	78	Polyline	7332.610779	-0.002455	9	27	7332.610779	R160
17	17	79	Polyline	10755.098538	-0.00186	7	27	10755.098538	R170
18	18	83	Polyline	11105.184213	0.003692	80	39	11105.184213	R180
19	19	89	Polyline	4445.619881	0.004499	100	80	4445.619881	R190
20	20	87	Polyline	4655.953878	0.000644	14	11	4655.953878	R200
21	21	94	Polyline	9660.02463	0.000414	11	7	9660.02463	R210
22	22	85	Polyline	6531.553991	-0.000612	5	9	6531.553991	R220
23	23	92	Polyline	2688.321343	-0.001488	5	9	2688.321343	R230
24	24	98	Polyline	821.742932	0.006085	9	4	821.742932	R240
25	25	88	Polyline	3480.433835	0.000287	5	4	3480.433835	R250
26	26	106	Polyline	304.930607	-0.003279	4	5	304.930607	R260
27	27	106	Polyline	338.8291	0.011805	9	5	338.8291	R270

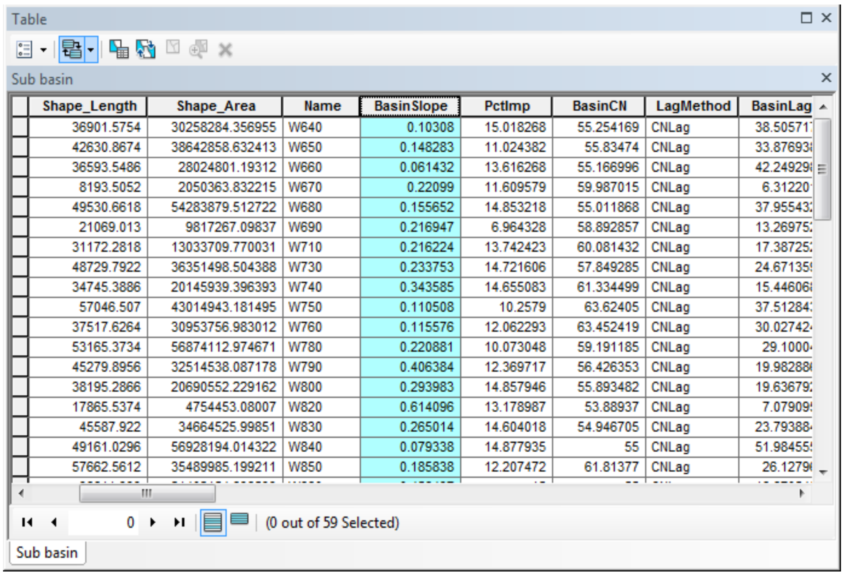
0 (0 out of 63 Selected)

River Network

Figure 3.19: Characteristic length of the delineated river

iv) Basin slope

The step calculates the slope profile of the sub basin.



Table

Sub basin

Shape_Length	Shape_Area	Name	BasinSlope	PctImp	BasinCN	LagMethod	BasinLag
36901.5754	30258284.356955	W640	0.10308	15.018268	55.254169	CNLag	38.50571
42630.8674	38642858.632413	W650	0.148283	11.024382	55.83474	CNLag	33.87693
36593.5486	28024801.19312	W660	0.061432	13.616268	55.166996	CNLag	42.24929
8193.5052	2050363.832215	W670	0.22099	11.609579	59.987015	CNLag	6.31220
49530.6618	54283879.512722	W680	0.155652	14.853218	55.011868	CNLag	37.95543
21069.013	9817267.09837	W690	0.216947	6.964328	58.892857	CNLag	13.26975
31172.2818	13033709.770031	W710	0.216224	13.742423	60.081432	CNLag	17.38725
48729.7922	36351498.504388	W730	0.233753	14.721606	57.849285	CNLag	24.67135
34745.3886	20145939.396393	W740	0.343585	14.655083	61.334499	CNLag	15.44606
57046.507	43014943.181495	W750	0.110508	10.2579	63.62405	CNLag	37.51284
37517.6264	30953756.983012	W760	0.115576	12.062293	63.452419	CNLag	30.02742
53165.3734	56874112.974671	W780	0.220881	10.073048	59.191185	CNLag	29.1000
45279.8956	32514538.087178	W790	0.406384	12.369717	56.426353	CNLag	19.98288
38195.2866	20690552.229162	W800	0.293983	14.857946	55.893482	CNLag	19.63679
17865.5374	4754453.08007	W820	0.614096	13.178987	53.88937	CNLag	7.07909
45587.922	34664525.99851	W830	0.265014	14.604018	54.946705	CNLag	23.79388
49161.0296	56928194.014322	W840	0.079338	14.877935	55	CNLag	51.98455
57662.5612	35489985.199211	W850	0.185838	12.207472	61.81377	CNLag	26.1279

(0 out of 59 Selected)

Sub basin

Figure 3.20: Characteristic slope of the sub basin

v) Longest Flow Length

This process calculates the longest flow length of each sub basin.

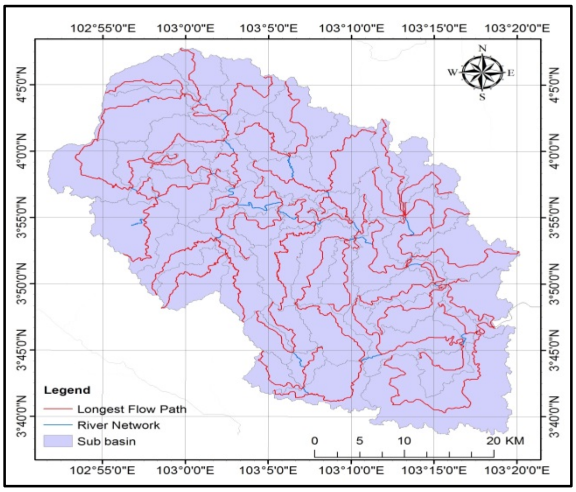


Figure 3.21: Characteristic of the Longest Flow Path computed using HEC-GeoHMS

vi) Basin Centroid

This process identified the centroids of every sub basin in the catchment.

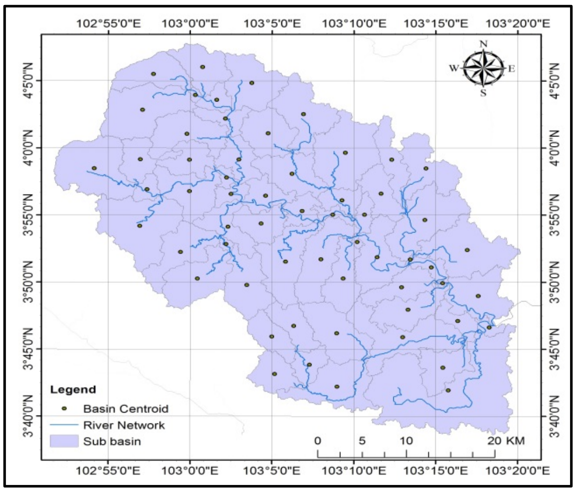


Figure 3.22: Basin Centroid computed using HEC-GeoHMS

vii) Centroid Elevation / Centroidal Longest Flow Path

It calculates the centroid elevation of the basin based on the define centroid and the longest flow path based on the basin centroid.

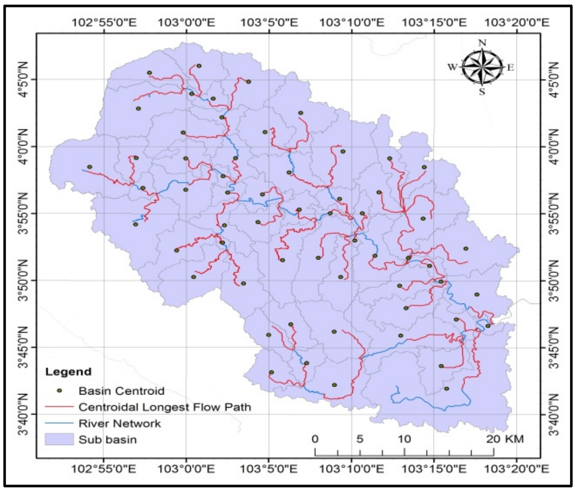


Figure 3.23: Centroidal Longest Flow Path

After computing the watershed parameterization procedure, the next step is defining the parameter for the HEC-HMS in the HEC-GeoHMS.

i) Select HMS Process

This procedure is used to define the Loss Method, Transform Method, Base flow Method and Route Method that will be use in the HEC-HMS. Basically, the method use also can be select manually in the HEC-HMS.

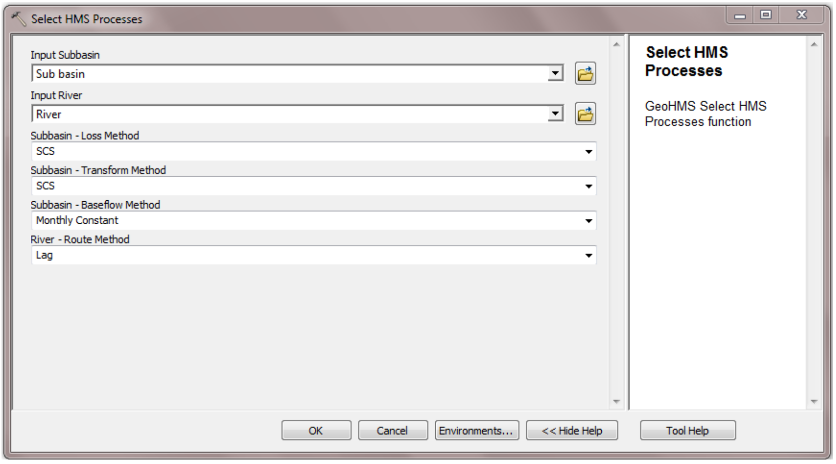


Figure 3.24: Determination of method to be used in HEC-HMS in HEC-GeoHMS

ii) River and Basin Auto name

This step will generate a unique name for the river and sub basin that will be used in HMS.

iii) Sub Basin Parameter from Raster

This step will generate assign every sub basin with the curve number value based on the created curve number map from land use map and hydrological soil groups map which shown in Figure 3.25.

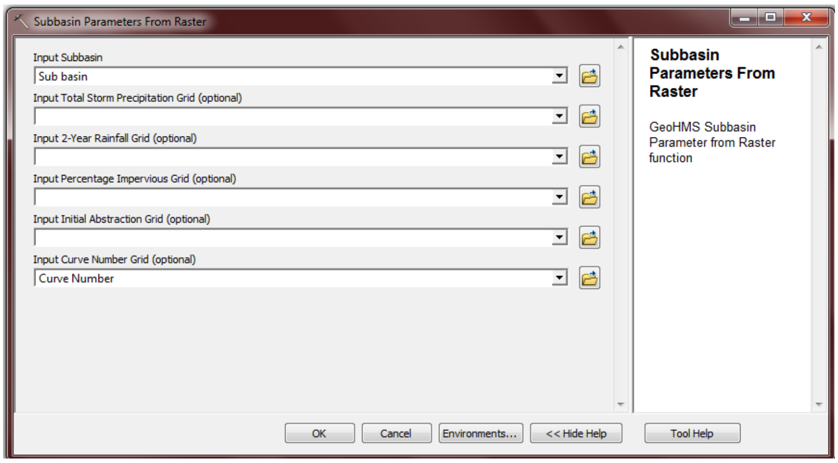
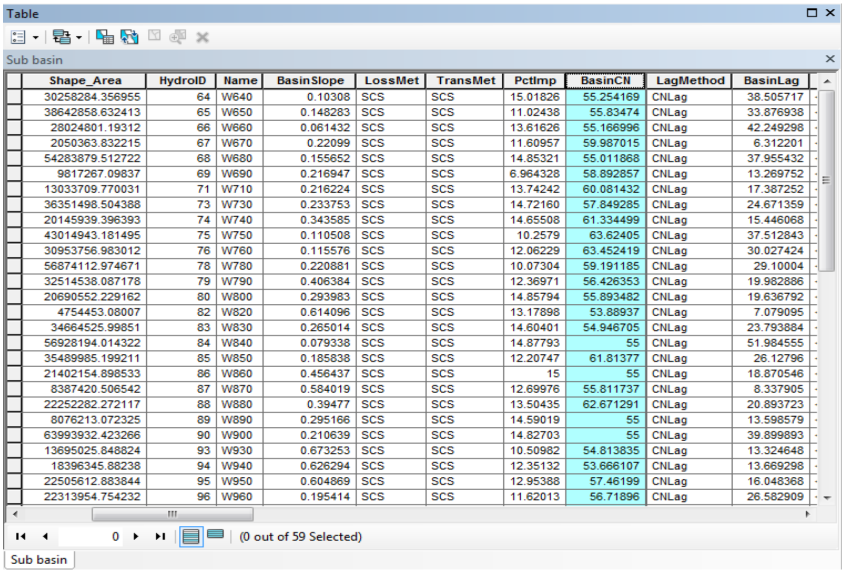


Figure 3.25: Associate curve number map with the Sub Basin



Table

Sub basin

Shape_Area	HydroID	Name	BasinSlope	LossMet	TransMet	PctImp	BasinCN	LagMethod	BasinLag
30258284.356955	64	W640	0.10308	SCS	SCS	15.01826	55.254169	CNLag	38.505717
38642858.632413	65	W650	0.148283	SCS	SCS	11.02438	55.83474	CNLag	33.876938
28024801.19312	66	W660	0.061432	SCS	SCS	13.61626	55.166996	CNLag	42.249298
2050363.832215	67	W670	0.22099	SCS	SCS	11.60957	59.987015	CNLag	6.312201
54283879.512722	68	W680	0.155652	SCS	SCS	14.85321	55.011868	CNLag	37.955432
9817267.09837	69	W690	0.216947	SCS	SCS	6.964328	58.892857	CNLag	13.269752
13033709.770031	71	W710	0.216224	SCS	SCS	13.74242	60.081432	CNLag	17.387252
36351498.504388	73	W730	0.233753	SCS	SCS	14.72160	57.849285	CNLag	24.671359
20145939.396393	74	W740	0.343585	SCS	SCS	14.65508	61.334499	CNLag	15.446068
43014943.181495	75	W750	0.110508	SCS	SCS	10.2579	63.62405	CNLag	37.512843
30953756.983012	76	W760	0.115576	SCS	SCS	12.06229	63.452419	CNLag	30.027424
56874112.974671	78	W780	0.220881	SCS	SCS	10.07304	59.191185	CNLag	29.10004
32514538.087178	79	W790	0.406384	SCS	SCS	12.36971	56.426353	CNLag	19.982886
20690552.229162	80	W800	0.293983	SCS	SCS	14.85794	55.893482	CNLag	19.636792
4754453.08007	82	W820	0.614096	SCS	SCS	13.17898	53.88937	CNLag	7.079095
34664525.99851	83	W830	0.265014	SCS	SCS	14.60401	54.946705	CNLag	23.793884
56928194.014322	84	W840	0.079338	SCS	SCS	14.87793	55	CNLag	51.984555
35489985.199211	85	W850	0.185838	SCS	SCS	12.20747	61.81377	CNLag	26.12796
21402154.898533	86	W860	0.456437	SCS	SCS	15	55	CNLag	18.870546
8387420.506542	87	W870	0.584019	SCS	SCS	12.69976	55.811737	CNLag	8.337905
22252282.272117	88	W880	0.39477	SCS	SCS	13.50435	62.671291	CNLag	20.893723
8076213.072325	89	W890	0.295166	SCS	SCS	14.59019	55	CNLag	13.598579
63993932.423266	90	W900	0.210639	SCS	SCS	14.82703	55	CNLag	39.899893
13695025.848824	93	W930	0.673253	SCS	SCS	10.50982	54.813835	CNLag	13.324648
18396345.88238	94	W940	0.626294	SCS	SCS	12.35132	53.666107	CNLag	13.669298
22505612.883844	95	W950	0.604869	SCS	SCS	12.95388	57.46199	CNLag	16.048368
22313954.754232	96	W960	0.195414	SCS	SCS	11.62013	56.71896	CNLag	26.582909

0 (0 out of 59 Selected)

Sub basin

Figure 3.26: Curve number value for each sub basin

iv) CN Lag Time

This step calculates the CN Lag time which will be used in SCS transform method in HMS. The computation of CN Lag Time is defined from the calculation of time of concentration of the basin.

Table

Sub basin

Shape_Area	HydroID	Name	BasinSlope	LossMet	TransMet	PctImp	BasinCN	LagMethod	BasinLag
30258284.356955	64	W640	0.10308	SCS	SCS	15.01826	55.254169	CNLag	38.505717
38642858.632413	65	W650	0.148283	SCS	SCS	11.02438	55.83474	CNLag	33.876938
28024801.19312	66	W660	0.061432	SCS	SCS	13.61626	55.166996	CNLag	42.249298
2050363.832215	67	W670	0.22099	SCS	SCS	11.60957	59.987015	CNLag	6.312201
54283879.512722	68	W680	0.155652	SCS	SCS	14.85321	55.011868	CNLag	37.955432
9817267.09837	69	W690	0.216947	SCS	SCS	6.964328	58.892857	CNLag	13.269752
13033709.770031	71	W710	0.216224	SCS	SCS	13.74242	60.081432	CNLag	17.387252
36351498.504388	73	W730	0.233753	SCS	SCS	14.72160	57.849285	CNLag	24.671359
20145939.396393	74	W740	0.343585	SCS	SCS	14.65508	61.334499	CNLag	15.446068
43014943.181495	75	W750	0.110508	SCS	SCS	10.2579	63.62405	CNLag	37.512843
30953756.983012	76	W760	0.115576	SCS	SCS	12.06229	63.452419	CNLag	30.027424
56874112.974671	78	W780	0.220881	SCS	SCS	10.07304	59.191185	CNLag	29.10004
32514538.087178	79	W790	0.406384	SCS	SCS	12.36971	56.426353	CNLag	19.982886
20690552.229162	80	W800	0.293983	SCS	SCS	14.85794	55.893482	CNLag	19.636792
4754453.08007	82	W820	0.614096	SCS	SCS	13.17898	53.88937	CNLag	7.079095
34664525.99851	83	W830	0.265014	SCS	SCS	14.60401	54.946705	CNLag	23.793884
56928194.014322	84	W840	0.079338	SCS	SCS	14.87793	55	CNLag	51.984555
35489985.199211	85	W850	0.185838	SCS	SCS	12.20747	61.81377	CNLag	26.12796
21402154.898533	86	W860	0.456437	SCS	SCS	15	55	CNLag	18.870546
8387420.506542	87	W870	0.584019	SCS	SCS	12.69976	55.811737	CNLag	8.337905
22252282.272117	88	W880	0.39477	SCS	SCS	13.50435	62.671291	CNLag	20.893723
8076213.072325	89	W890	0.295166	SCS	SCS	14.59019	55	CNLag	13.598579
63993932.423266	90	W900	0.210639	SCS	SCS	14.82703	55	CNLag	39.899893
13695025.848824	93	W930	0.673253	SCS	SCS	10.50982	54.813835	CNLag	13.324648
18396345.88238	94	W940	0.626294	SCS	SCS	12.35132	53.666107	CNLag	13.669298
22505612.883844	95	W950	0.604869	SCS	SCS	12.95388	57.46199	CNLag	16.048368
22313954.754232	96	W960	0.195414	SCS	SCS	11.62013	56.71896	CNLag	26.582909

0 (0 out of 59 Selected)

Sub basin

Figure 3.27: Characteristic of the lag time in the sub basin

After defining the parameter of the watershed that will be used in the HEC-HMS, the next procedure is to do a model export or the HMS process in the HEC-GeoHMS, in which the export model will be input in the HEC-HMS.

i) Map to HMS Units

This step map all the connection or parameter of the watershed in HMS units which is the representation of the watershed in HEC-HMS criteria.

ii) Check Data

Checking the data created to check for errors.

iii) HMS Schematics

Define and create the link and node of the HMS such as the river junction, sub basin and river reach.

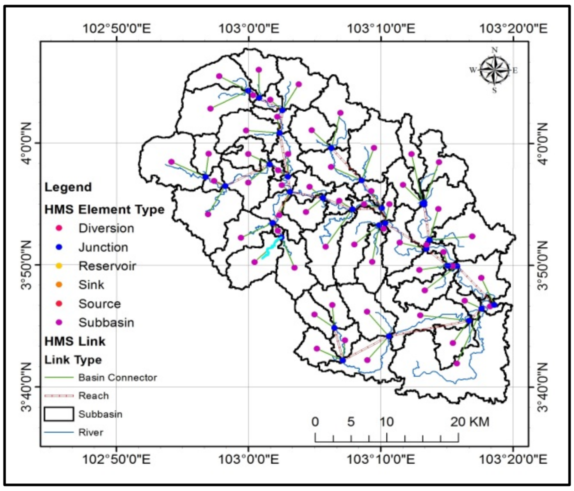


Figure 3.28: HMS schematics in the watershed

iv) Toggle Legend

Create the basic representation of the features such as junction and reach that commonly used in the HEC-HMS.

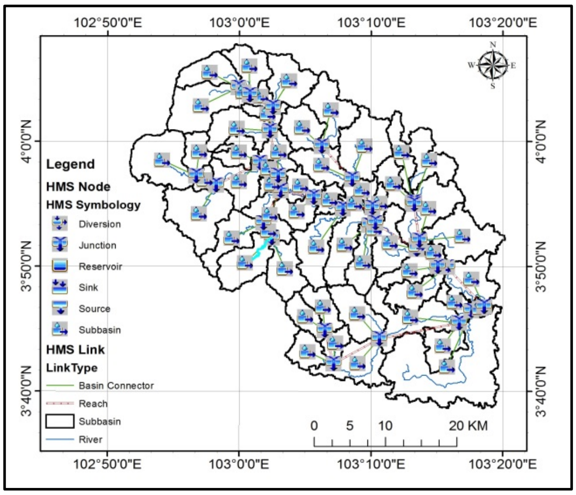


Figure 3.29: HMS toggle legend in the ArcMap for HEC-HMS

v) Add Coordinates

This process will define the coordinates for every parameter in the watershed.

vi) Prepare Data for Model Export

This process will allow for the selection of parameter that will be export to the HEC-HMS.

vii) Basin Model File

Create Basin Model that will be used in HEC-HMS.

viii) Meteorological Model File

Create Meteorological Model for HEC-HMS.

ix) Creates HEC-HMS Project

Define the project for the HEC-HMS which will automatically export the model that can be use in the HEC-HMS.

After the model is successfully export from ArcMap to HEC-HMS, the out model will be open in the HEC-HMS which is shown in figure

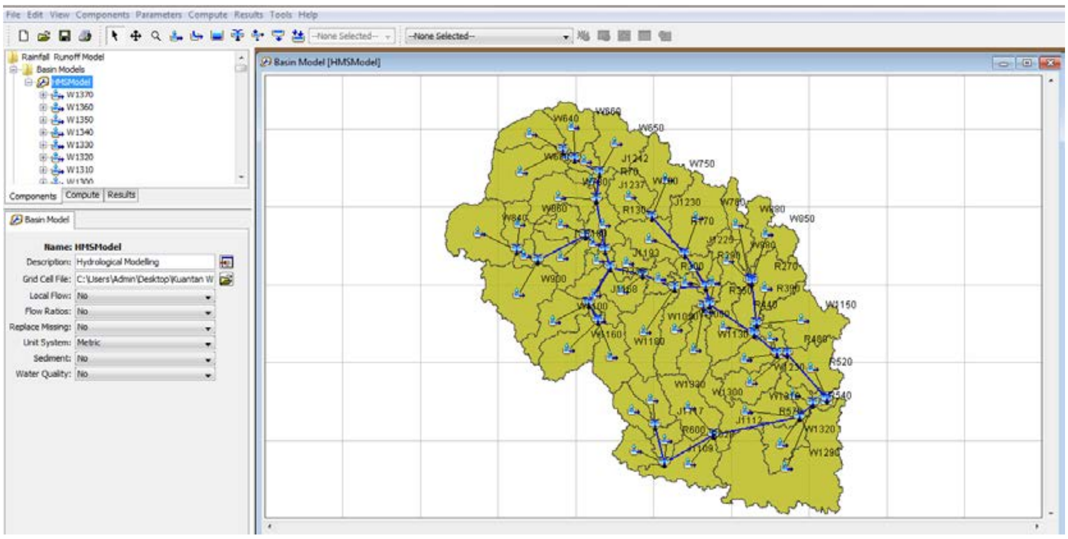


Figure 3.30: Successfully Model Export open in HEC-HMS

CHAPTER 4

RESULT AND DISCUSSION

Basin model is basically the most important input features in HEC-HMS to enable the simulation process to take place. Based on the delineated result of Kuantan watershed, it consist a total of 59 sub basin, 29 reaches and 31 junctions.

No.	Sub-Basin Name	Area (km^2)	CN	Imperviousness (%)
1	W1370	21.969	65	9.091
2	W1360	43.375	60	8.776
3	W1350	14.458	92	7.303
4	W1340	20.359	86	15.399
5	W1330	21.514	85	14.790
6	W1320	26.398	77	12.550
7	W1310	54.609	72	7.396
8	W1300	40.011	90	11.927
9	W1290	141.34	73	11.756
10	W1270	12.464	73	8.355
11	W1260	5.273	79	10.520
12	W1240	37.790	81	6.047
13	W1230	29.790	60	10.771
14	W1220	0.927	68	7.562
15	W1210	23.904	58	10.535
16	W1200	36.879	57	10.667
17	W1190	8.249	58	9.977
18	W1180	35.749	88	12.951
19	W1170	0.751	52	7.389
20	W1160	40.594	88	11.114
21	W1150	54.116	65	9.488
22	W1130	28.548	90	9.394
23	W1120	1.559	91	7.714
24	W1110	2.406	94	11.745

25	W1100	35.927	87	13.806
26	W1090	40.748	86	10.953
27	W1060	50.465	60	9.228
28	W1050	43.849	86	12.933
29	W1040	8.586	90	12.771
30	W1020	14.055	82	9.317
31	W980	22.149	97	9.464
32	W970	6.032	82	8.669
33	W960	22.314	86	11.62
34	W950	22.506	87	12.954
35	W940	18.396	83	12.351
36	W930	13.695	84	10.51
37	W900	63.994	85	14.827
38	W890	8.076	85	14.59
39	W880	22.252	92	13.504
40	W870	8.387	85	12.700
41	W860	21.402	85	15.000
42	W850	35.49	91	12.207
43	W840	56.928	85	14.878
44	W830	34.665	84	14.604
45	W820	4.755	83	13.179
46	W800	20.691	85	14.858
47	W790	32.515	86	12.37
48	W780	56.874	89	10.073
49	W760	30.954	93	12.062
50	W750	43.015	93	10.258
51	W740	20.146	91	14.655
52	W730	36.351	87	14.722
53	W710	13.034	90	13.742
54	W690	9.817	88	6.964
55	W680	54.284	85	14.853
56	W670	2.050	89	11.61
57	W660	28.025	85	13.616
58	W650	38.643	85	11.024
59	W640	30.258	85	15.018

Table 4.0: Generated curve number on each sub basin based on the land use and hydrological soil group criteria and it imperviousness.

During the process of basin parameter from raster data of curve number map, it will assign each sub basin with its own unique curve number which will be one of the important parameter for the simulation run. The characteristic value area, of the curve number and imperviousness for each sub basin is shown in Table 4.0. The imperviousness of the sub basin is generally calculated during the delineation and parameterization process based on the generated area of each sub basin and the value is representing in percentages.

The model will be verify based on selected event on January 2006 and validate using event in January 2012 and the simulated result will be compare with the observed flow from the stream flow station for the determination of the model performance. The detail of the selected event is shown in the Table 4.1 for 2006 events and Table 4.2 for 2012 event.

December 2006		
Day	Rainfall Depth (mm)	Observed Discharge (m^3/s)
9	6	11.5
10	3.5	10.9
11	0	10.5
12	1	11.7
13	21.5	11.3
14	0	11.3
15	94.5	12.6
16	28.5	118.3
17	58	109.6
18	88	285.1
19	40	378
20	168	803.9
21	102	830.6
22	5	330.9
23	0	204.7
24	0	102.7
25	0.5	71.5
26	7.5	59.1
27	3.5	53.5

Table 4.1: Observed data for event on December 2006

January 2012		
Day	Rainfall Depth (mm)	Observed Discharge (m^3/s)
6	0	91.6
7	0.5	89.4
8	5	88.3
9	2	90.4
10	9	101.1
11	61	150.6
12	164	876.1
13	27.5	385.2
14	4.5	255.8
15	0	204.8
16	0	173.4
17	0.5	164.3
18	10.5	162.1
19	0.5	156.2
20	18.5	185.1
21	61	258.5
22	0	195.4
23	0	149.5
24	0	127.8
25	0	118
26	0	114.3
27	6.5	116.5
28	0.5	116.9
29	0	111.3
30	1	107.8

Table 4.2: Observed data for event on January 2012

The characteristic parameters of Lag Time for the sub basin is calculated based on the define time of concentration of the basin. Basin lag time is the time elapsed between the occurrences of the rainfall with the event runoff hydrograph. It is important as a parameter to determine the time to peak for the unit hydrograph and the peak discharge intensity. Meanwhile, the Lag Time for the reach is the time require for the water to flow from the remote point to the outlet of the basin or to the location of the stream flow station which the discharge will be recorded based on the selected time interval. The Time of Concentration and Lag Time for the unit hydrograph for the basin is shown in Table 4.3 while the Lag Time for the reach is shown in Table 4.4.

Sub Basin	Basin Lag(min)	Basin Lag (hrs.)	Time of concentration (hrs.)
W1370	33.014	0.550	0.917
W1360	42.833	0.714	1.190
W1350	15.038	0.251	0.418
W1340	21.078	0.351	0.586
W1330	16.670	0.278	0.463
W1320	16.323	0.272	0.453
W1310	27.815	0.464	0.773
W1300	25.559	0.426	0.710
W1290	81.348	1.356	2.260
W1270	10.489	0.175	0.291
W1260	6.2462	0.104	0.174
W1240	18.169	0.303	0.505
W1230	24.838	0.414	0.690
W1220	2.488	0.041	0.069
W1210	28.946	0.482	0.804
W1200	22.842	0.381	0.634
W1190	14.929	0.249	0.415
W1180	20.663	0.344	0.574
W1170	3.270	0.054	0.091
W1160	41.820	0.697	1.162
W1150	24.309	0.405	0.675
W1130	20.221	0.337	0.562
W1120	3.099	0.052	0.086
W1110	4.149	0.069	0.115
W1100	21.863	0.364	0.607
W1090	27.477	0.458	0.763
W1060	23.927	0.399	0.665
W1050	36.741	0.612	1.021
W1040	9.247	0.154	0.257
W1020	13.729	0.229	0.381
W980	9.186	0.153	0.255
W970	10.086	0.168	0.280
W960	26.583	0.443	0.738
W950	16.048	0.267	0.446
W940	13.669	0.228	0.380
W930	13.325	0.222	0.370
W900	39.900	0.665	1.108
W890	13.599	0.227	0.378
W880	20.894	0.348	0.580
W870	8.338	0.139	0.231
W860	18.871	0.315	0.524

W850	26.128	0.435	0.726
W840	51.985	0.866	1.444
W830	23.794	0.397	0.661
W820	7.079	0.118	0.196
W800	19.637	0.327	0.545
W790	19.983	0.333	0.555
W780	29.100	0.485	0.808
W760	30.027	0.500	0.834
W750	37.513	0.625	1.042
W740	15.446	0.257	0.429
W730	24.671	0.411	0.685
W710	17.387	0.290	0.483
W690	13.270	0.221	0.369
W680	37.955	0.633	1.054
W670	6.312	0.105	0.175
W660	42.249	0.704	1.174
W650	33.877	0.565	0.941
W640	38.506	0.642	1.070

Table 4.3: Sub basins time of concentation and lag time

Reach	Lag Time (min)
R170	78.816
R210	62.147
R260	3.620
R270	5.667
R290	52.790
R300	47.117
R310	37.686
R340	21.961
R350	8.781
R390	58.79
R420	12.081
R440	96.711
R470	96.432
R480	13.096
R510	4.988
R520	154.470
R530	57.952
R540	40.379

R570	164.963
R600	148.218
R620	190.470
R190	53.926
R180	116.131
R120	34.445
R30	33.431
R50	69.505
R70	69.545
R130	87.930
R200	36.118
R380	23.637

Table 4.4: SCS Lag Time computation for routing method on the reach

Before the simulation run is computed, the control specification for the selected event need to be set up which define the model start and stop time based on the selected date of the event. The next important parameter is the Baseflow Method which is the Constant Monthly. The baseflow of the watershed is determine by selecting the constant value of the discharge before the event begin. Is is important because without the baseflow value, the hydrograph will start at zero discharge which mean there is no baseflow for the watershed. Baseflow is define the constant flow of the river event in the dry session which is essential for the survival of the aquatic live in it.

Based on the assign curve number, the value of the initial abstraction from each sub basin can be determined. The initial abstraction is the minimum amount of the rainfall which is observed by the soil without producing the runoff. The value of initial abstraction is depending on the initial abstraction ratio used. Based on this study, the model will be run using two value of initial abstraction ratio where the generated result based of the apply ratio will be compare. The value of the initial abstraction ratio apply in the study is 0.2 and 0.05 which the value of the 0.2 is based on the original SCS method. The calcululated value of the initial abstraction based on initial abstraction ratio is shown in Table 4.5.

Sub-Basin Name	CN	Retention, S	Ia (0.2), mm	Ia (0.05), mm
W1370	65	136.769	27.354	6.838
W1360	60	169.333	33.867	8.467
W1350	72	98.778	19.756	4.939
W1340	57	191.614	38.323	9.581
W1330	55	207.818	41.564	10.391
W1320	77	75.870	15.174	3.794
W1310	73	93.945	18.789	4.697
W1300	60	169.333	33.867	8.467
W1290	74	89.243	17.849	4.462
W1270	74	89.243	17.849	4.462
W1260	80	63.500	12.700	3.175
W1240	81	59.580	11.916	2.979
W1230	61	162.393	32.479	8.120
W1220	69	114.116	22.823	5.706
W1210	59	176.508	35.302	8.825
W1200	57	191.614	38.323	9.581
W1190	59	176.508	35.302	8.825
W1180	58	183.931	36.786	9.197
W1170	52	234.462	46.892	11.723
W1160	58	183.931	36.786	9.197
W1150	65	136.769	27.354	6.838
W1130	61	162.393	32.479	8.120
W1120	62	155.677	31.135	7.784
W1110	64	142.875	28.575	7.144
W1100	57	191.614	38.323	9.581
W1090	57	191.614	38.323	9.581
W1060	60	169.333	33.867	8.467
W1050	56	199.571	39.914	9.979
W1040	60	169.333	33.867	8.467
W1020	53	225.245	45.049	11.262
W980	67	125.104	25.021	6.255
W970	53	225.245	45.049	11.262
W960	57	191.614	38.323	9.581
W950	57	191.614	38.323	9.581
W940	54	216.370	43.274	10.819
W930	55	207.818	41.564	10.391
W900	55	207.818	41.564	10.391
W890	55	207.818	41.564	10.391
W880	63	149.175	29.8345	7.459
W870	56	199.571	39.914	9.979
W860	55	207.818	41.564	10.391

W850	62	155.677	31.135	7.784
W840	55	207.818	41.564	10.391
W830	55	207.818	41.564	10.391
W820	54	216.370	43.274	10.819
W800	56	199.571	39.914	9.979
W790	56	199.571	39.914	9.979
W780	59	176.508	35.302	8.825
W760	63	149.175	29.835	7.459
W750	64	142.875	28.575	7.144
W740	61	162.393	32.479	8.120
W730	58	183.931	36.786	9.197
W710	60	169.333	33.867	8.467
W690	59	176.508	35.302	8.825
W680	55	207.818	41.564	10.391
W670	60	169.333	33.867	8.467
W660	55	207.818	41.564	10.391
W650	56	199.571	39.914	9.979
W640	55	207.818	41.564	10.391

Table 4.5: The value for the intial abstracton for each sub basin

Based on the model develop, the simulation result will be taken from the J1193, which is the junction features in the HEC-HMS that is the nearest to the location of the stream flow station. The stream flow station of the watershed is located at the sub basin W940 where the junction J1193 is located. The data for the rainfall station is taken from the Station 3930012, Sg. Lembing P.C.C.L Mill. There is other existing of the rainfall station in the watershed but only one rainfall station data is used in this study due to the availability of the data. Most of the rainfall data in the other station content missing value which is essential data for the simulation. The error in the rainfall data collected for the particular station is mostly due to the instrument error of the station. Due to the problem in the rainfall data, a single rainfall station is choosing based on the assumption that the distribution of the rainfall is constant in the watershed. After all the require parameter is set up, the simulation is computed based on the selected event.

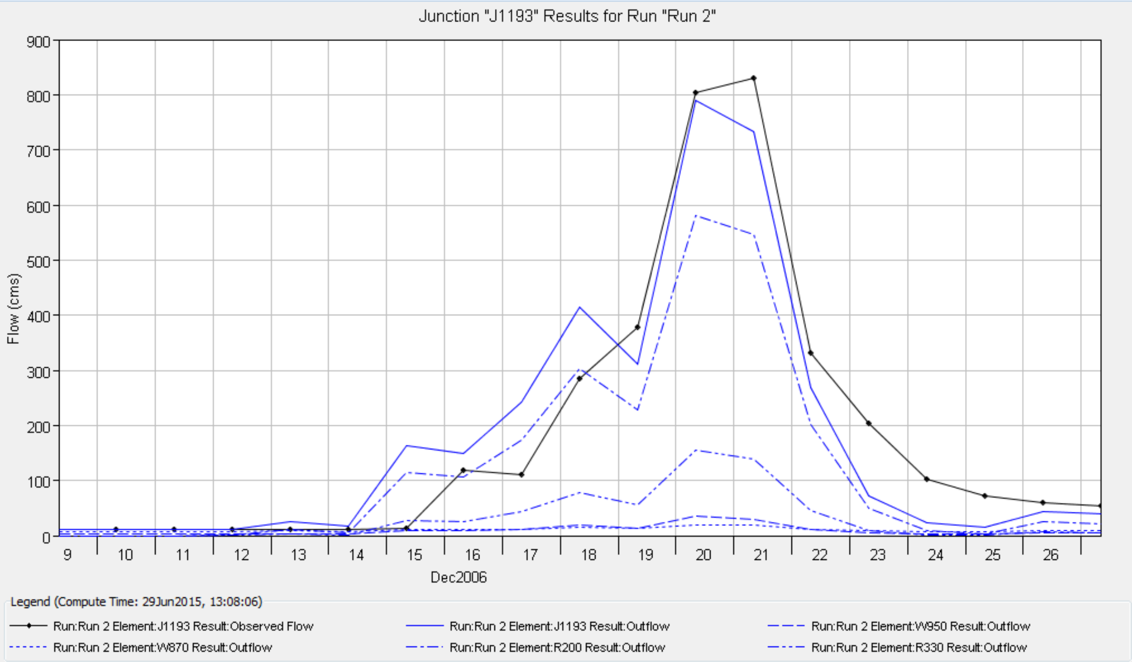
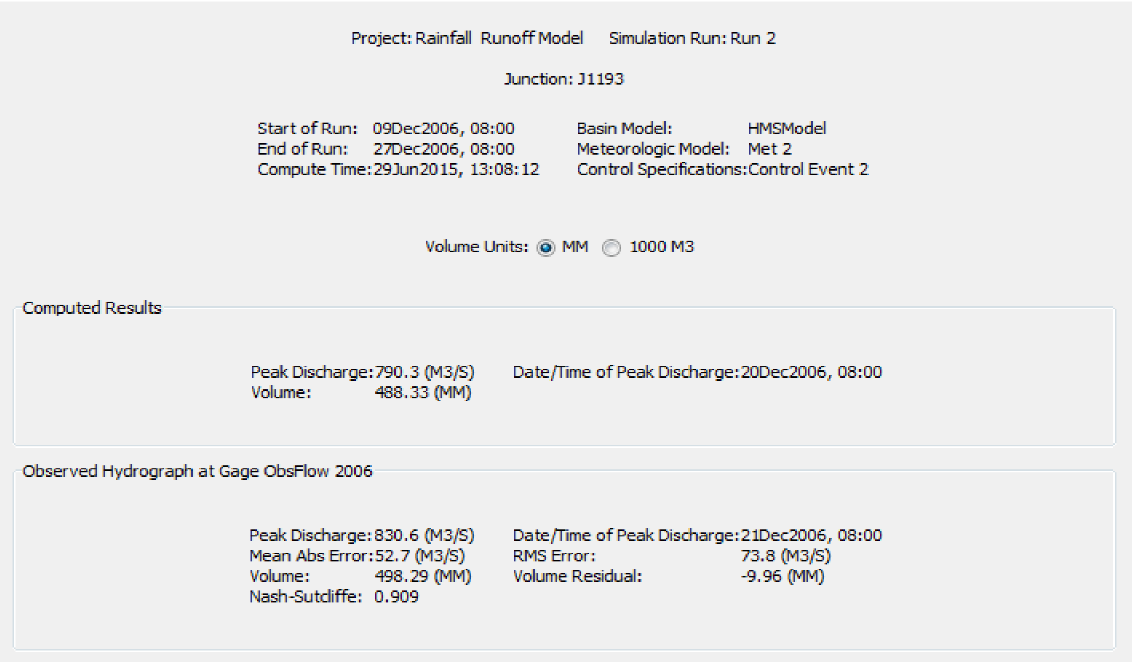


Figure 4.0: Hydrograph for event on December 2006 with 0.2 initial abstraction ratio


Project: Rainfall Runoff Model Simulation Run: Run 2

Junction: J1193

Start of Run: 09Dec2006, 08:00 Basin Model: HMSModel
End of Run: 27Dec2006, 08:00 Meteorologic Model: Met 2
Compute Time: 29Jun2015, 13:08:12 Control Specifications: Control Event 2

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 790.3 (M3/S) Date/Time of Peak Discharge: 20Dec2006, 08:00
Volume: 488.33 (MM)

Observed Hydrograph at Gage ObsFlow 2006

Peak Discharge: 830.6 (M3/S) Date/Time of Peak Discharge: 21Dec2006, 08:00
Mean Abs Error: 52.7 (M3/S) RMS Error: 73.8 (M3/S)
Volume: 498.29 (MM) Volume Residual: -9.96 (MM)
Nash-Sutcliffe: 0.909

Figure 4.1: Summary of result for event on December 2006 with 0.2 initial abstraction ratio

Project: Rainfall Runoff Model Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00
End of Run: 27Dec2006, 08:00
Compute Time: 29Jun2015, 13:08:12

Basin Model: HMSModel
Meteorologic Model: Met 2
Control Specifications: Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	11.9	11.7
13Dec2006	08:00	3.9	8.1	10.3	2.6	24.9	11.3
14Dec2006	08:00	3.5	8.0	4.3	0.9	16.6	11.3
15Dec2006	08:00	9.2	10.8	115.1	28.1	163.1	12.6
16Dec2006	08:00	8.2	10.1	106.7	24.8	149.8	118.3
17Dec2006	08:00	12.2	11.7	174.0	43.8	241.7	109.6
18Dec2006	08:00	19.0	14.3	302.7	77.9	414.0	285.1
19Dec2006	08:00	14.0	12.2	228.5	55.7	310.5	378.0
20Dec2006	08:00	34.8	20.2	580.5	154.8	790.3	803.9
21Dec2006	08:00	30.2	18.3	546.3	138.4	733.2	830.6
22Dec2006	08:00	11.1	10.9	202.5	44.6	269.0	330.9
23Dec2006	08:00	5.0	8.5	49.5	9.8	72.8	204.7
24Dec2006	08:00	3.6	8.0	9.2	1.7	22.6	102.7
25Dec2006	08:00	3.5	7.9	2.6	0.6	14.6	71.5
26Dec2006	08:00	4.8	8.4	24.4	6.7	44.3	59.1
27Dec2006	08:00	4.4	8.3	21.1	5.3	39.1	53.5

Figure 4.2: Time series table for event on December 2006 with 0.2 initial abstraction ratio

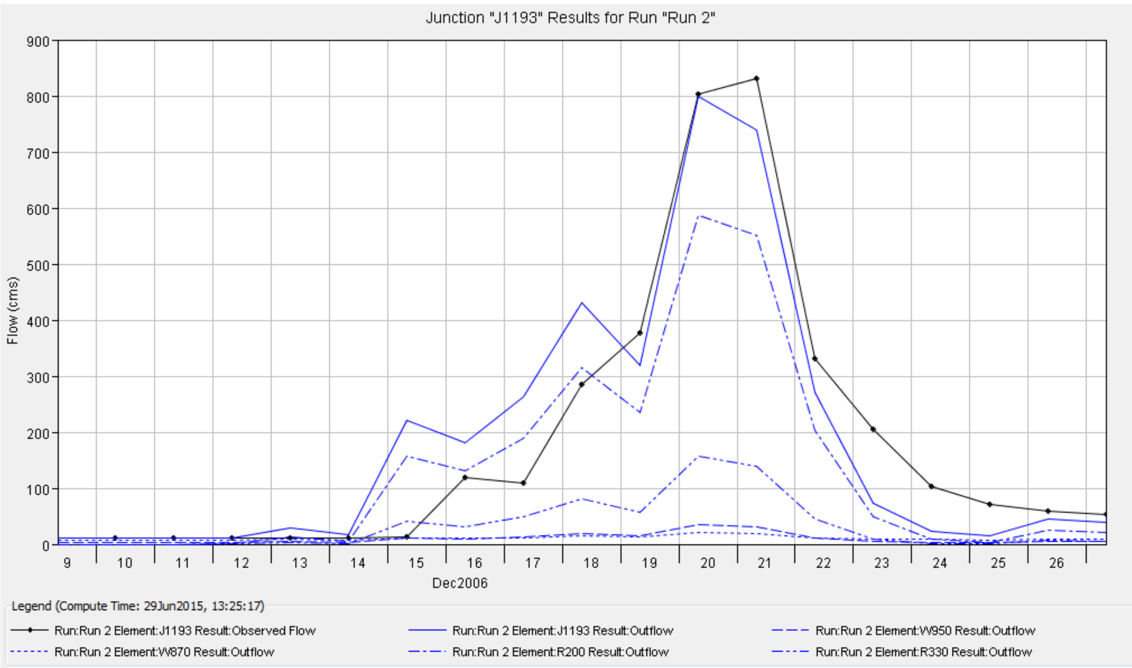


Figure 4.3: Hydrohraph for event on December 2006 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 2

Junction: J1193

Start of Run: 09Dec2006, 08:00   Basin Model: HMSModel
End of Run: 27Dec2006, 08:00   Meteorologic Model: Met 2
Compute Time: 29Jun2015, 13:25:17   Control Specifications: Control Event 2

Volume Units: MM   1000 M3

Computed Results

Peak Discharge: 799.9 (M3/S)   Date/Time of Peak Discharge: 20Dec2006, 08:00
Volume: 511.41 (MM)

Observed Hydrograph at Gage ObsFlow 2006

Peak Discharge: 830.6 (M3/S)   Date/Time of Peak Discharge: 21Dec2006, 08:00
Mean Abs Error: 58.3 (M3/S)   RMS Error: 84.3 (M3/S)
Volume: 498.29 (MM)   Volume Residual: 13.12 (MM)
Nash-Sutcliffe: 0.882

Figure 4.4: Summary of result for event on December 2006 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00   Basin Model: HMSModel
End of Run: 27Dec2006, 08:00   Meteorologic Model: Met 2
Compute Time: 29Jun2015, 13:25:17   Control Specifications: Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	11.9	11.7
13Dec2006	08:00	4.0	8.2	12.9	3.1	28.3	11.3
14Dec2006	08:00	3.6	8.0	5.3	1.0	18.0	11.3
15Dec2006	08:00	11.8	11.6	156.9	40.6	220.8	12.6
16Dec2006	08:00	9.3	10.5	130.3	31.1	181.1	118.3
17Dec2006	08:00	13.0	11.9	189.3	48.2	262.4	109.6
18Dec2006	08:00	19.7	14.5	315.0	81.6	430.9	285.1
19Dec2006	08:00	14.3	12.3	234.7	57.5	318.8	378.0
20Dec2006	08:00	35.3	20.3	587.3	157.0	799.9	803.9
21Dec2006	08:00	30.5	18.3	550.4	139.6	738.9	830.6
22Dec2006	08:00	11.1	10.9	203.8	45.0	270.8	330.9
23Dec2006	08:00	5.0	8.5	49.8	9.9	73.2	204.7
24Dec2006	08:00	3.6	8.0	9.3	1.7	22.6	102.7
25Dec2006	08:00	3.5	7.9	2.6	0.6	14.6	71.5
26Dec2006	08:00	4.8	8.4	24.5	6.7	44.5	59.1
27Dec2006	08:00	4.4	8.3	21.2	5.3	39.2	53.5

Figure 4.5: Time series table for event on December 2006 with 0.05 initial abstraction ratio

Based on the result obtained for event in December 2006, it show that the value of initial abstraction ratio of 0.2 produce a high accuracy result compare to the 0.05 ratio based of the Nash Sutcliffe Efficiency calculate by the HEC-HMS. For the use of initial abstraction ratio of 0.2 which is the results shown in Figure 4.0, 4.1 and 4.2 , the efficiency of the simulated result over an observed discharge is 0.909 with a peak discharge of 790.3 m^3/s occuring in 20 December 2006. The observed peak discharge is 830.6 m^3/s which is occuring in 21 December 2006. While for the use of initial abstraction ratio of 0.05 which is the results is shown in Figure 4.3, 4.4 and 4.5, the efficiency of the simulated result over an observed discharge is 0.882 with a peak discharge of 799.9 m^3/s which occuring in 20 December 2006 which is different compare to the observed peak which is occuring in 21 December 2006. The use of initial abstraction ratio of 0.2 significantly produce a high efficiency result compare to the use of ratio of 0.05 but time to peak of both result is the same but different time to peak when comparing to the observed peak discharge.

The validation of the model is done by using a event in January 2012 with the same application of adjustment of the initial abstraction ratio using initial abstraction ratio of 0.2 and 0.05.

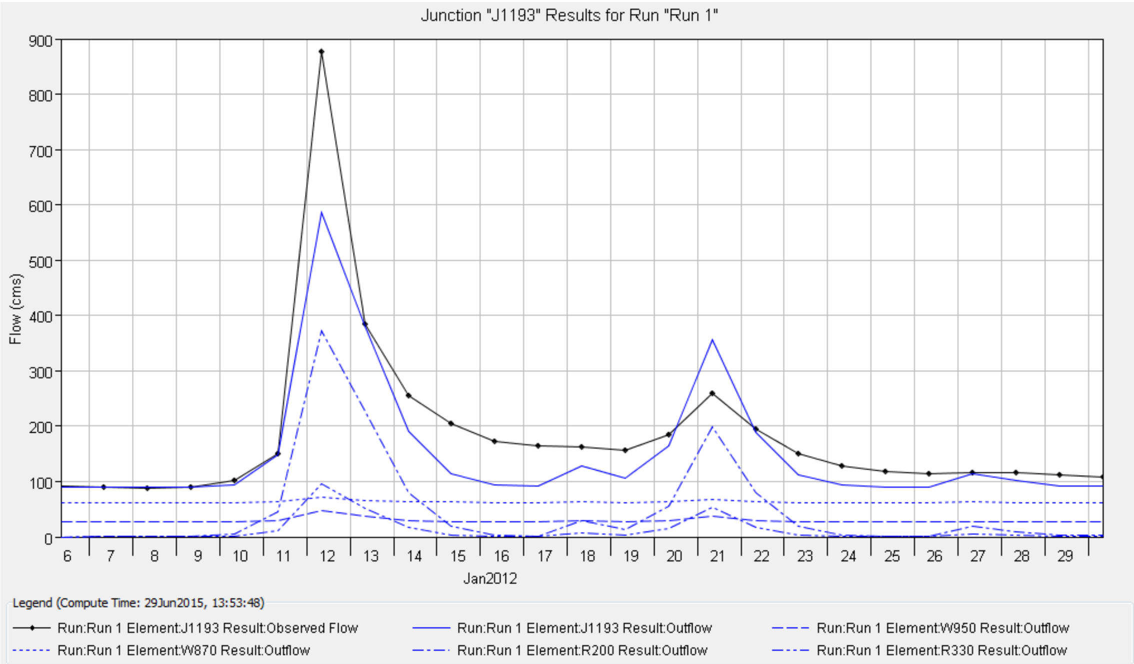


Figure 4.6: Hydrograph for event on January 2012 with 0.2 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 13:53:48   Control Specifications: Control Event 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 586.4 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Volume: 542.14 (MM)

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge: 876.1 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Mean Abs Error: 40.1 (M3/S)   RMS Error: 71.2 (M3/S)
Volume: 659.09 (MM)   Volume Residual: -116.95 (MM)
Nash-Sutcliffe: 0.792

Figure 4.7: Summary of result for event on January 2012 with 0.2 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1
Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 13:53:48   Control Specifications: Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.2	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	26.9	62.4	4.3	1.1	94.6	101.1
11Jan2012	08:00	28.9	63.4	45.6	10.6	148.5	150.6
12Jan2012	08:00	46.5	71.0	372.5	96.4	586.4	876.1
13Jan2012	08:00	36.3	66.4	226.1	52.2	381.1	385.2
14Jan2012	08:00	29.6	63.5	79.9	17.0	190.0	255.8
15Jan2012	08:00	27.3	62.6	20.1	3.9	113.9	204.8
16Jan2012	08:00	26.8	62.3	3.5	0.6	93.2	173.4
17Jan2012	08:00	26.8	62.3	1.8	0.4	91.4	164.3
18Jan2012	08:00	28.4	63.0	29.7	8.0	129.1	162.1
19Jan2012	08:00	27.2	62.5	13.7	3.1	106.5	156.2
20Jan2012	08:00	29.7	63.5	55.5	14.8	163.6	185.1
21Jan2012	08:00	37.5	66.6	198.7	53.1	355.9	258.5
22Jan2012	08:00	29.7	63.5	78.8	17.3	189.2	195.4
23Jan2012	08:00	27.3	62.5	18.9	3.7	112.3	149.5
24Jan2012	08:00	26.8	62.3	3.8	0.7	93.6	127.8
25Jan2012	08:00	26.7	62.3	0.4	0.0	89.4	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.8	62.7	19.2	5.2	114.9	116.5
28Jan2012	08:00	27.1	62.5	9.5	2.2	101.2	116.9
29Jan2012	08:00	26.8	62.3	2.5	0.5	92.2	111.3
30Jan2012	08:00	26.8	62.3	2.0	0.5	91.7	107.8

Figure 4.8: Time series table for event on January 2012 with 0.2 initial abstraction ratio

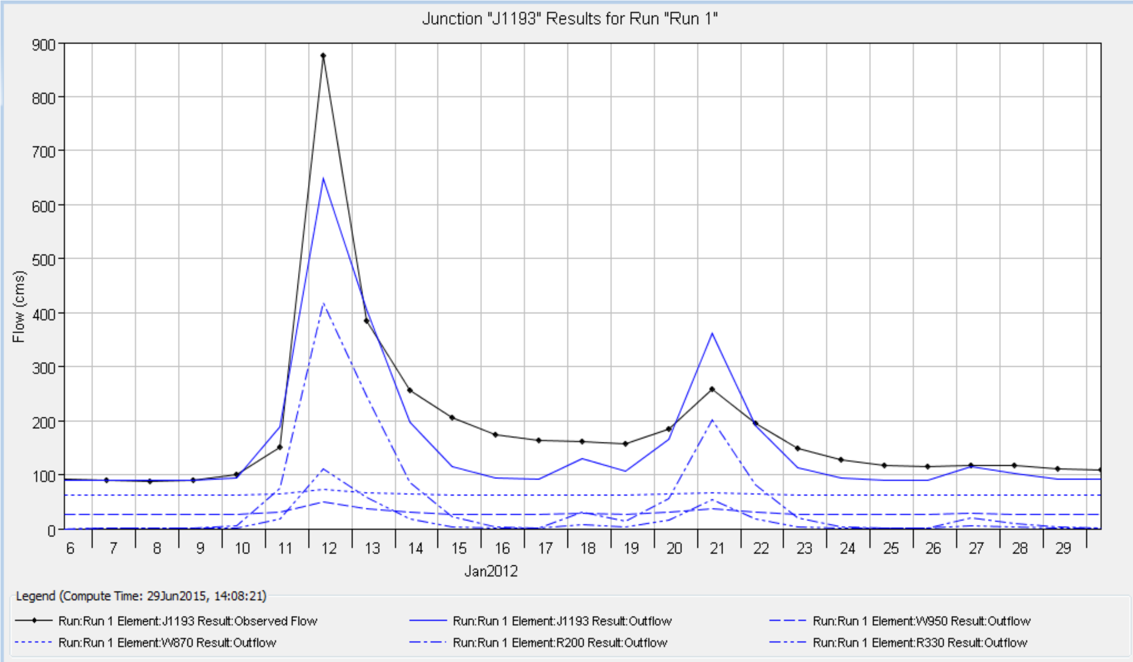


Figure 4.9: Hydrograph for event on January 2012 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run:	06Jan2012, 08:00	Basin Model:	HMSModel
End of Run:	30Jan2012, 08:00	Meteorologic Model:	Met 1
Compute Time:	29Jun2015, 14:08:21	Control Specifications:	Control Event 1

Volume Units: MM   1000 M3

Computed Results

Peak Discharge:	648.6 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Volume:	563.50 (MM)		

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge:	876.1 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Mean Abs Error:	39.3 (M3/S)	RMS Error:	62.0 (M3/S)
Volume:	659.09 (MM)	Volume Residual:	-95.58 (MM)
Nash-Sutcliffe:	0.843		

Figure 4.10: Summary of result for event on January 2012 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model Simulation Run: Run 1
Junction: J1193

Start of Run: 06Jan2012, 08:00 Basin Model: HMSModel
End of Run: 30Jan2012, 08:00 Meteorologic Model: Met 1
Compute Time: 29Jun2015, 14:08:21 Control Specifications: Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.2	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	26.9	62.4	4.3	1.1	94.6	101.1
11Jan2012	08:00	30.6	64.1	74.3	18.7	187.6	150.6
12Jan2012	08:00	49.2	71.7	417.8	109.9	648.6	876.1
13Jan2012	08:00	37.2	66.6	245.2	57.2	406.2	385.2
14Jan2012	08:00	29.8	63.6	85.1	18.2	196.7	255.8
15Jan2012	08:00	27.4	62.6	21.2	4.2	115.3	204.8
16Jan2012	08:00	26.8	62.3	3.6	0.6	93.4	173.4
17Jan2012	08:00	26.8	62.3	1.9	0.4	91.4	164.3
18Jan2012	08:00	28.4	63.0	30.4	8.3	130.1	162.1
19Jan2012	08:00	27.3	62.5	14.0	3.2	106.9	156.2
20Jan2012	08:00	29.8	63.5	56.7	15.2	165.3	185.1
21Jan2012	08:00	37.8	66.7	202.1	54.2	360.7	258.5
22Jan2012	08:00	29.7	63.5	80.1	17.7	191.0	195.4
23Jan2012	08:00	27.3	62.5	19.2	3.7	112.7	149.5
24Jan2012	08:00	26.8	62.3	3.8	0.7	93.7	127.8
25Jan2012	08:00	26.7	62.3	0.4	0.0	89.4	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.8	62.7	19.4	5.3	115.3	116.5
28Jan2012	08:00	27.1	62.5	9.6	2.2	101.4	116.9
29Jan2012	08:00	26.8	62.3	2.6	0.5	92.2	111.3
30Jan2012	08:00	26.8	62.3	2.1	0.5	91.7	107.8

Figure 4.11: Time series table for event on January 2012 with 0.2 initial abstraction ratio

Based on the result obtained for event in 2012 January , it show that the value of initial abstraction ratio of 0.2 produce a high accuracy result compare to the 0.05 ratio based of the Nash Sutcliffe Efficiency calculate by the HEC-HMS. In comparison both of the simulated result underestimate the peak discharge during the event. For the use of initial abstraction ratio of 0.2 which is the results shown in Figure 4.6, 4.7 and 4.8 , the efficiency of the simulated result over an observed discharge is 0.792 with a peak discharge of 586.4 m^3/s occuring in 12 January 2012. The observed peak discharge is 876.1 m^3/s which is also occuring in 12 January 2012. While for the use of initial abstraction ratio of 0.05 which is the results is shown in Figure 4.9, 4.10 and 4.11, the efficiency of the simulated result over an observed discharge is 0.843 with a peak simulated peak discharge of 648.6.9 m^3/s which also occuring in 12 January 2012 which is the same time to peak of observed peak which is occuring in 12 January 2012. The use of initial abstraction ratio of 0.05 significantly produce a high efficiency result compare to the use of ratio of 0.2 and the result of simulated peak discharge have the same time to peak with the observed time to peak for the event 2012.

Based on the simulated result for 2006 and 2012, the result obtained is underestimating the actual peak discharge during the occurence of the storm event. In order to produce a best fit result, the model for the Kuantan watershed needs to be calibrated. The calibration process is done by calculating the new curve number based on the antecedent moisture condition factors. The condition applies for the calibration is a wet condition where the factor is more that 1 which will significanly increase the curve number value in the sub basin. The current antecedent moisture condition apply is AMC II which is then converted to AMC III by using the antecedent wet condition (AMC III) factors. The new value of curve number assign for each sub basin is shown in Table 4.6.

AMC II	AMC FACTORS	AMC III
65	1.3	85
60	1.3	78
72	1.21	87
57	1.4	80
55	1.4	77
77	1.21	93
73	1.21	88
60	1.3	78
74	1.21	90
74	1.21	90
80	1.14	91
81	1.14	92
61	1.3	79
69	1.3	90
59	1.4	83
57	1.4	80
59	1.4	83
58	1.4	81
52	1.4	73
58	1.4	81
65	1.3	85
61	1.3	79
62	1.3	81
64	1.3	83
57	1.4	80
57	1.4	80
60	1.3	78

56	1.4	78
60	1.3	78
53	1.4	74
67	1.3	87
53	1.4	74
57	1.4	80
57	1.4	80
54	1.4	76
55	1.4	77
55	1.4	77
55	1.4	77
63	1.3	82
56	1.4	78
55	1.4	77
62	1.3	81
55	1.4	77
55	1.4	77
54	1.4	76
56	1.4	78
56	1.4	78
59	1.4	83
63	1.3	82
64	1.3	83
61	1.3	79
58	1.4	81
60	1.3	78
59	1.4	83
55	1.4	77
60	1.3	78
55	1.4	77
56	1.4	78
55	1.4	77

Table 4.6 Adjusted curve number from AMC II to AMC III

The calibration procedure is applicable since that in the month of November until December, Peninsular Malaysia is having a monsoon season where there will be high rate of precipitation. High rate of precipitation will increase the saturation of water in the soil which will contributes to higher runoff from the rainfall. There are various methods to covert the condition of AMC II to AMC III but conversion can be simplify by using the assign factors for each value of the curve number as shown in Table 2.0. After the new curve number is calculated, the new value of initial abstraction based on ratio of 0.2 and 0.05 also need to be calculated which is shown in Table 4.7. By assigning the value of the new curve number and initial abstraction to the model in the HEC-HMS, the model is now run based on the wet condition, AMC III which will produce higher discharge compare to normal condition, AMC II.

Sub-Basin Name	**CN**	**Retention, S**	**I_a (0.2), mm**	**I_a (0.05), mm**
W1370	85	46.592	9.318	2.330
W1360	78	71.641	14.328	3.582
W1350	87	37.552	7.510	1.878
W1340	80	64.296	12.859	3.215
W1330	77	75.870	15.174	3.794
W1320	93	18.620	3.724	0.931
W1310	88	33.558	6.712	1.678
W1300	78	71.641	14.328	3.582
W1290	90	29.672	5.934	1.484
W1270	90	29.672	5.934	1.484
W1260	91	24.509	4.902	1.225
W1240	92	21.070	4.214	1.054
W1230	79	66.303	13.261	3.315
W1220	90	29.166	5.833	1.458
W1210	83	53.506	10.701	2.675
W1200	80	64.296	12.859	3.215
W1190	83	53.506	10.701	2.675
W1180	81	58.808	11.762	2.940
W1170	73	94.901	18.980	4.745
W1160	81	58.808	11.762	2.940
W1150	85	46.592	9.318	2.330
W1130	79	66.303	13.261	3.315
W1120	81	61.136	12.227	3.057
W1110	83	51.288	10.258	2.564
W1100	80	64.296	12.859	3.215
W1090	80	64.296	12.859	3.215
W1060	78	71.641	14.328	3.582
W1050	78	69.980	13.996	3.499
W1040	78	71.641	14.328	3.582
W1020	74	88.318	17.664	4.416
W980	87	37.619	7.524	1.881
W970	74	88.318	17.664	4.416

W960	80	64.296	12.859	3.215
W950	80	64.296	12.859	3.215
W940	76	81.979	16.396	4.099
W930	77	75.870	15.174	3.794
W900	77	75.870	15.174	3.794
W890	77	75.870	15.174	3.794
W880	82	56.134	11.227	2.807
W870	78	69.980	13.996	3.499
W860	77	75.870	15.174	3.794
W850	81	61.136	12.227	3.057
W840	77	75.870	15.174	3.794
W830	77	75.870	15.174	3.794
W820	76	81.979	16.396	4.099
W800	78	69.980	13.996	3.499
W790	78	69.980	13.996	3.499
W780	83	53.506	10.701	2.675
W760	82	56.134	11.227	2.807
W750	83	51.288	10.258	2.564
W740	79	66.303	13.261	3.315
W730	81	58.808	11.762	2.940
W710	78	71.641	14.328	3.582
W690	83	53.506	10.701	2.675
W680	77	75.870	15.174	3.794
W670	78	71.641	14.328	3.582
W660	77	75.870	15.174	3.794
W650	78	69.980	13.996	3.499
W640	77	75.870	15.174	3.794

Table 4.7: New initial abstraction value based on AMC III condition

The significant changes based on the new assign value of curve number and initial abstraction is now can be observed by computed a simulation run based on the calibrated data. The calibration process is an important process to relate the model created based on the actual condition of the watershed. A significant of model calibration is to obtained the best result of best fit data between the simulated data with observed data. The most important value to look into it is the highest peak flow and time to peak since that most of the hydrologic structure is design based on the peak discharge. Therefore, the closer the simulated peak discharge to the actual peak discharge is important for the design of hydrologic structure.

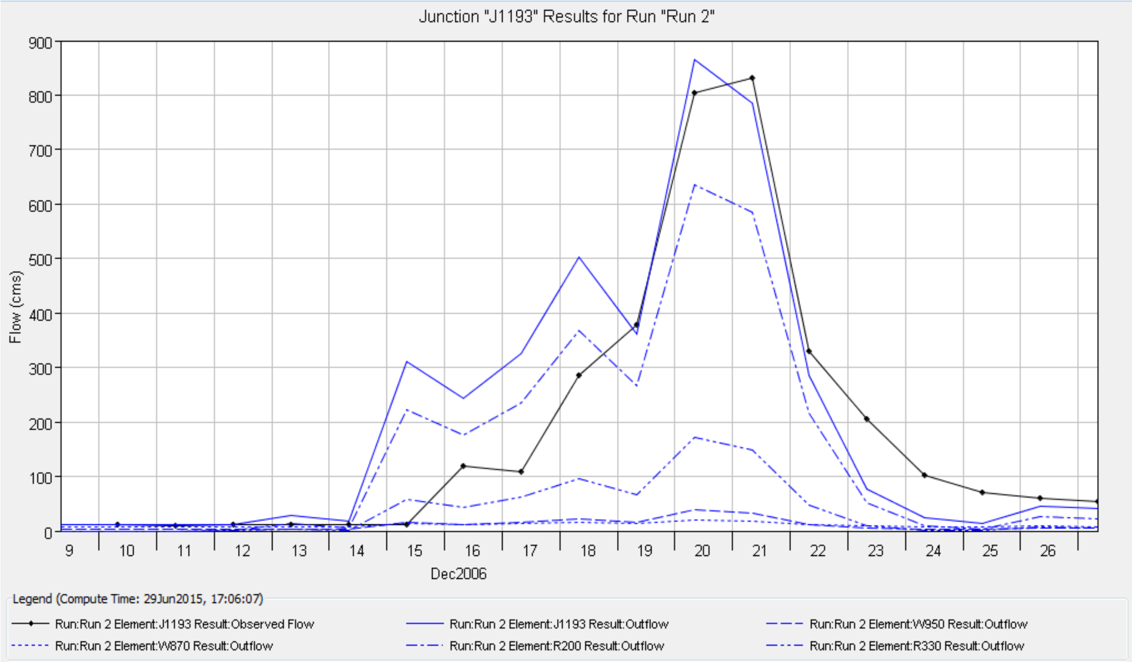


Figure 4.12: Hydrograph after calibration for event on December 2006 with 0.2 initial abstraction ratio

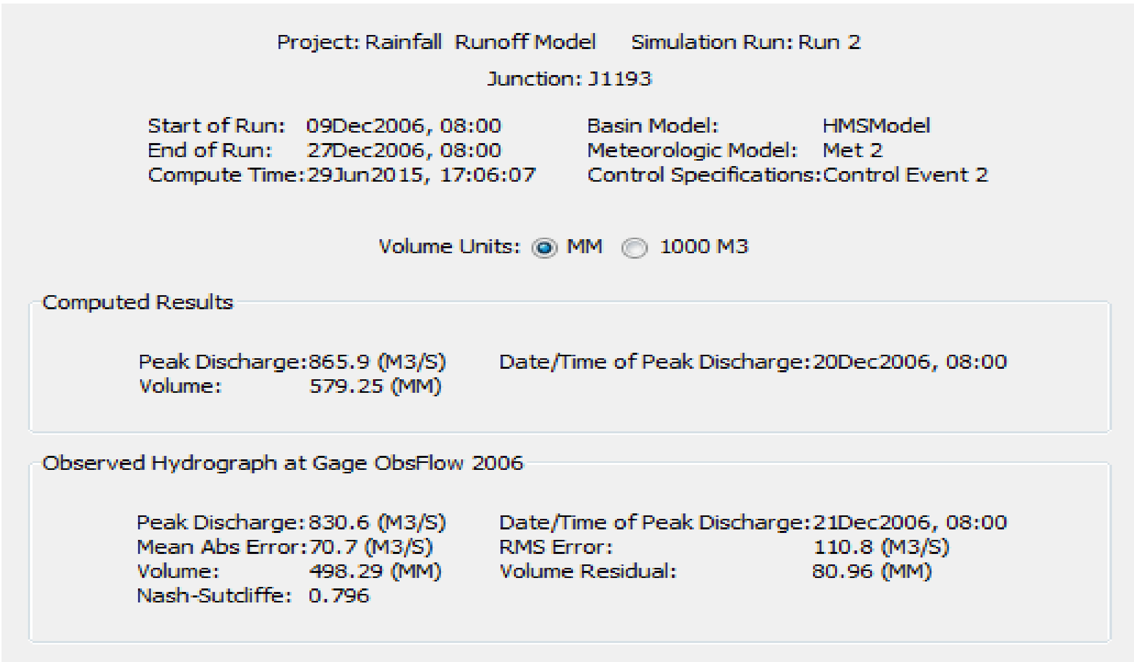


Figure 4.13: Summary of result after calibration for event on December 2006 with 0.2 initial abstraction ratio

Project: Rainfall Runoff Model Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00 Basin Model: HMSModel
End of Run: 27Dec2006, 08:00 Meteorologic Model: Met 2
Compute Time: 29Jun2015, 17:06:07 Control Specifications: Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	11.9	11.7
13Dec2006	08:00	4.0	8.2	13.8	3.1	29.2	11.3
14Dec2006	08:00	3.6	8.0	5.7	1.1	18.3	11.3
15Dec2006	08:00	15.5	13.0	223.3	58.9	310.7	12.6
16Dec2006	08:00	11.5	11.2	177.0	42.9	242.6	118.3
17Dec2006	08:00	15.6	12.7	236.0	61.2	325.4	109.6
18Dec2006	08:00	22.8	15.3	367.8	96.8	502.6	285.1
19Dec2006	08:00	16.0	12.7	266.3	66.1	361.0	378.0
20Dec2006	08:00	38.2	21.0	635.2	171.5	865.9	803.9
21Dec2006	08:00	32.3	18.8	584.0	149.2	784.4	830.6
22Dec2006	08:00	11.6	11.0	215.1	47.9	285.6	330.9
23Dec2006	08:00	5.1	8.5	52.5	10.5	76.6	204.7
24Dec2006	08:00	3.7	8.0	9.8	1.8	23.2	102.7
25Dec2006	08:00	3.5	7.9	2.7	0.6	14.7	71.5
26Dec2006	08:00	4.9	8.5	25.5	7.1	45.9	59.1
27Dec2006	08:00	4.5	8.3	22.0	5.6	40.4	53.5

Figure 4.14: Time series table for event on December 2006 with 0.2 initial abstraction ratio

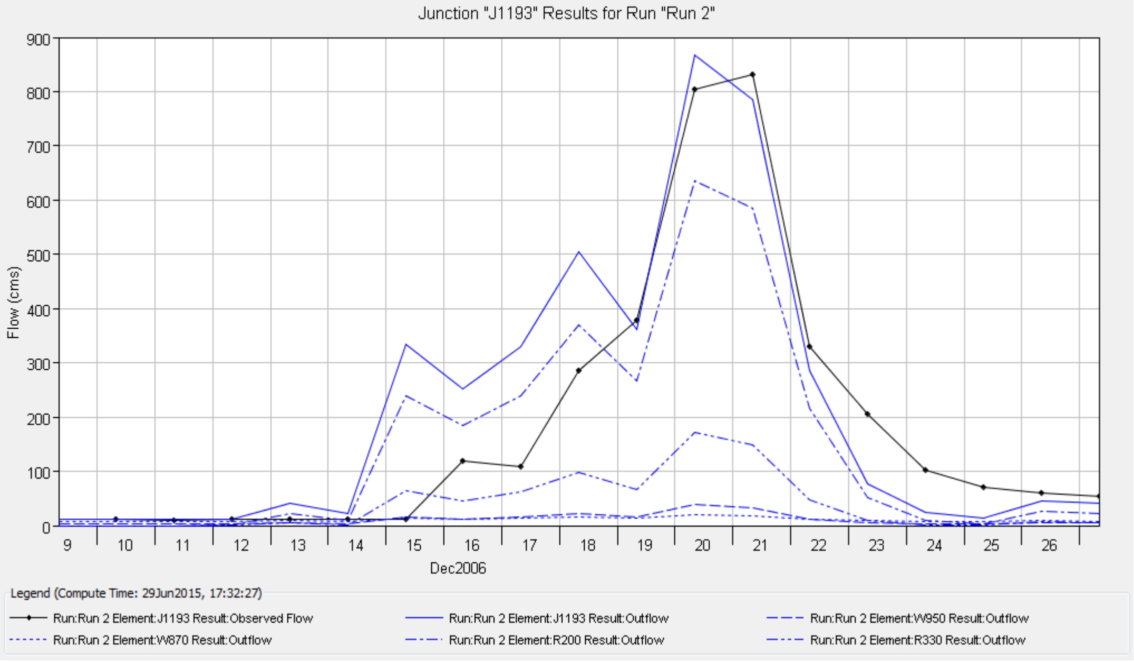


Figure 4.15: Hydrograph after calibration for event on December 2006 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model Simulation Run: Run 2

Junction: J1193

Start of Run: 09Dec2006, 08:00 Basin Model: HMSModel
End of Run: 27Dec2006, 08:00 Meteorologic Model: Met 2
Compute Time: 29Jun2015, 17:32:27 Control Specifications: Control Event 2

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 866.9 (M3/S) Date/Time of Peak Discharge: 20Dec2006, 08:00
Volume: 588.00 (MM)

Observed Hydrograph at Gage ObsFlow 2006

Peak Discharge: 830.6 (M3/S) Date/Time of Peak Discharge: 21Dec2006, 08:00
Mean Abs Error: 73.7 (M3/S) RMS Error: 115.6 (M3/S)
Volume: 498.29 (MM) Volume Residual: 89.71 (MM)
Nash-Sutcliffe: 0.778

Figure 4.16: Summary of result after calibration for event on December 2006 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00 Basin Model: HMSModel
End of Run: 27Dec2006, 08:00 Meteorologic Model: Met 2
Compute Time: 29Jun2015, 17:32:27 Control Specifications: Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	11.9	11.7
13Dec2006	08:00	4.6	8.4	22.8	5.6	41.4	11.3
14Dec2006	08:00	3.7	8.1	9.5	1.9	23.1	11.3
15Dec2006	08:00	16.6	13.3	239.6	64.1	333.6	12.6
16Dec2006	08:00	11.9	11.3	184.7	45.0	252.9	118.3
17Dec2006	08:00	15.8	12.7	239.3	62.1	329.8	109.6
18Dec2006	08:00	22.9	15.3	369.5	97.3	505.1	285.1
19Dec2006	08:00	16.0	12.7	267.0	66.3	362.0	378.0
20Dec2006	08:00	38.3	21.0	635.8	171.7	866.9	803.9
21Dec2006	08:00	32.4	18.8	584.4	149.3	784.9	830.6
22Dec2006	08:00	11.6	11.0	215.2	47.9	285.8	330.9
23Dec2006	08:00	5.1	8.5	52.5	10.5	76.6	204.7
24Dec2006	08:00	3.7	8.0	9.8	1.8	23.2	102.7
25Dec2006	08:00	3.5	7.9	2.7	0.6	14.7	71.5
26Dec2006	08:00	4.9	8.5	25.5	7.1	45.9	59.1
27Dec2006	08:00	4.5	8.3	22.0	5.6	40.4	53.5

Figure 4.17: Time series table for event on December 2006 with 0.05 initial abstraction ratio

Based on the result obtained after model calibration based on the antecedent moisture condition for event in December 2006, it still show that the value of initial abstraction ratio of 0.2 produce a significantly more accurate result compare to the 0.05 ratio based of the Nash Sutcliffe Efficiency calculate by the HEC-HMS. For the use of initial abstraction ratio of 0.2 which is the results shown in Figure 4.12, 4,13 and 4,14 , the efficiency of the simulated result over an observed discharge is 0.796 with a peak discharge of 865.9 m^3/s occuring in 20 December 2006. The observed peak discharge is 830.6 m^3/s which is occuring in 21 December 2006. While for the use of initial abstraction ratio of 0.05 which is the results is shown in Figure 4.15, 4.16 and 4.17, the efficiency of the simulated result over an observed discharge is 0.778 with a peak discharge of 866.9 m^3/s which occuring in 20 December 2006 which is different compare to the observed peak which is occuring in 21 December 2006.

The use of initial abstraction ratio of 0.2 significanly produce a high efficincy result compare to the use of ratio of 0.05 but time to peak of both result is the same but different time to peak when comparing to the observed peak discharge. Based on the obtained result, it show that for the event on December 2006, the peak value of the simulated discharge is overestimated the actual dicharge and the time to peak also the same with the uncalibrated result which is on 20 December 2006 which is different that the actual time to peak of the actual discharge. The efficiency of the model also decrease from 0.909 to 0.796 for the 0.2 intial abstraction ratio and decrease from 0.882 to 0.778 for the 0.05 initial abstraction ratio. Based on the result obtained, it shows that the calibration of curve number based on the antercedent moisture condition is not appicable for event on December 2006. Eventhough the model based on the normal condition underestimated the peak discharge during the event, but it produce higher efficeincy value compare to the calibrated model based on the moisture condition. The others error for the model based on the event is the time to peak of the simulated result. Time to peak of the simulated event is not the same with actual time to peak. This indicates that the model is need to be calibrated based on different parameter such as the lag time in order to get the same time to peak.

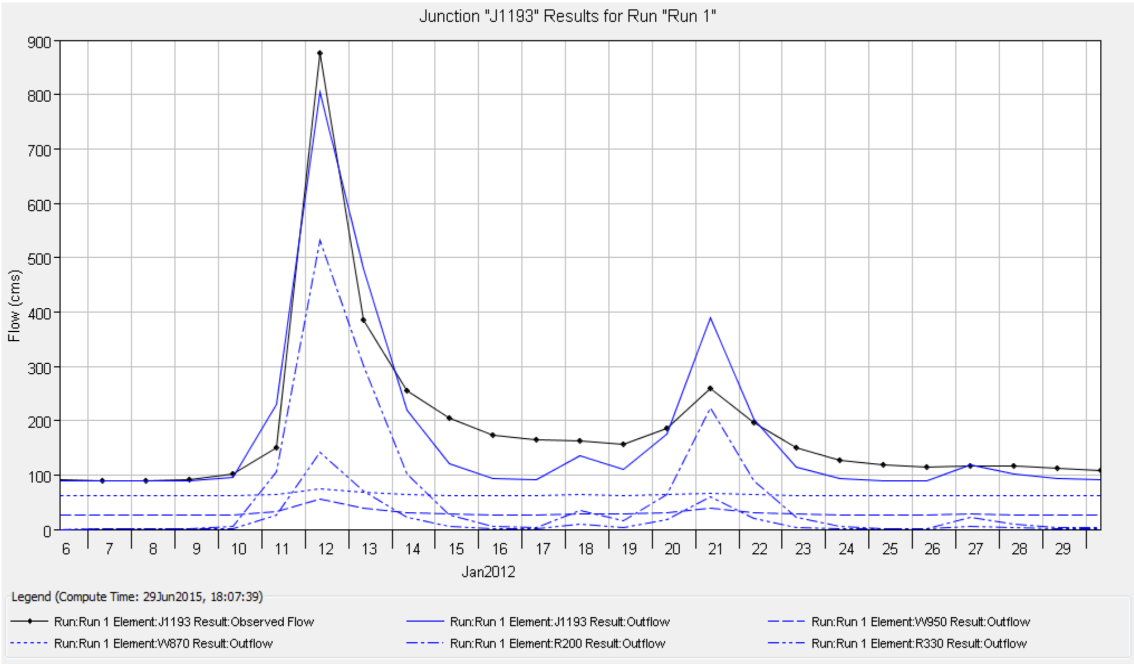


Figure 4.18: Hydrograph after calibration for event on January 2012 with 0.2 initial abstraction ratio


Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 18:07:39   Control Specifications: Control Event 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 803.6 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Volume: 617.02 (MM)

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge: 876.1 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Mean Abs Error: 37.0 (M3/S)   RMS Error: 51.2 (M3/S)
Volume: 659.09 (MM)   Volume Residual: -42.07 (MM)
Nash-Sutcliffe: 0.892

Figure 4.19: Summary of result after calibration for event on January 2012 with 0.2 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1
Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 18:07:39   Control Specifications: Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.2	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	26.9	62.4	4.3	1.1	94.6	101.1
11Jan2012	08:00	32.2	64.8	106.5	26.9	230.5	150.6
12Jan2012	08:00	55.9	73.8	531.4	142.5	803.6	876.1
13Jan2012	08:00	39.8	67.4	301.4	71.3	479.9	385.2
14Jan2012	08:00	30.5	63.8	102.3	22.2	218.7	255.8
15Jan2012	08:00	27.5	62.6	25.2	5.0	120.4	204.8
16Jan2012	08:00	26.8	62.3	4.3	0.7	94.1	173.4
17Jan2012	08:00	26.8	62.3	2.1	0.5	91.8	164.3
18Jan2012	08:00	28.7	63.0	34.4	9.5	135.6	162.1
19Jan2012	08:00	27.3	62.5	15.8	3.6	109.3	156.2
20Jan2012	08:00	30.3	63.7	63.6	17.4	174.9	185.1
21Jan2012	08:00	39.1	67.0	223.3	60.7	390.1	258.5
22Jan2012	08:00	30.1	63.6	88.5	19.8	201.9	195.4
23Jan2012	08:00	27.4	62.6	21.2	4.2	115.3	149.5
24Jan2012	08:00	26.8	62.3	4.2	0.8	94.2	127.8
25Jan2012	08:00	26.7	62.3	0.4	0.0	89.4	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.9	62.8	21.2	5.9	117.7	116.5
28Jan2012	08:00	27.1	62.5	10.4	2.4	102.5	116.9
29Jan2012	08:00	26.8	62.3	2.8	0.6	92.5	111.3
30Jan2012	08:00	26.8	62.3	2.2	0.6	92.0	107.8

Figure 4.20: Time series table for event on January 2012 with 0.2 initial abstraction ratio

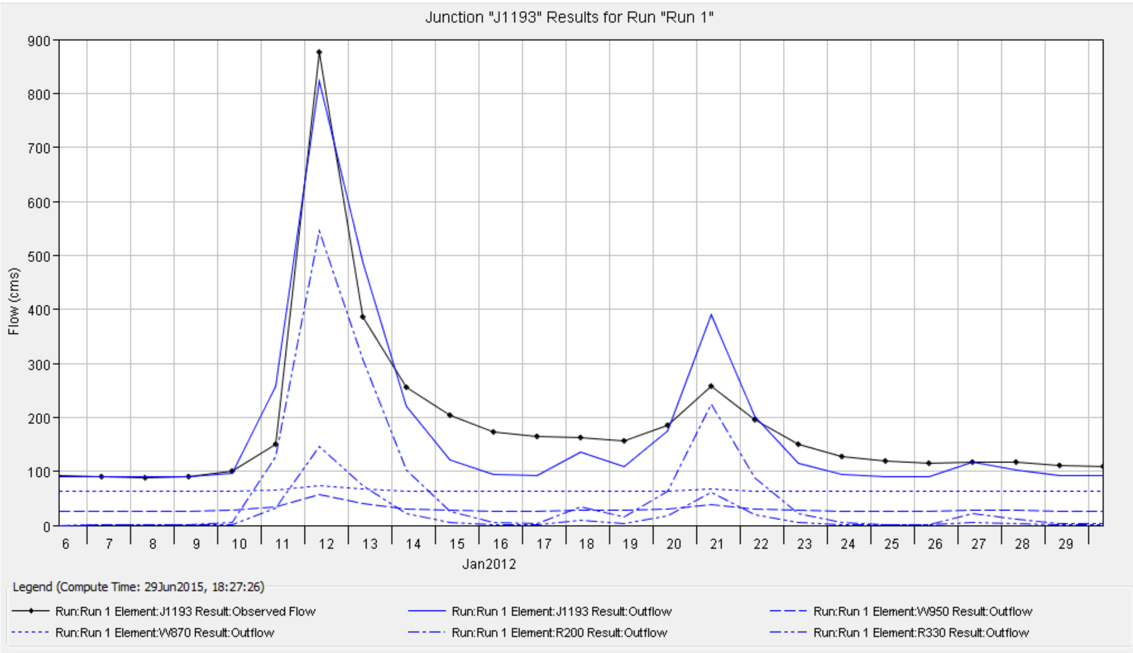


Figure 4.21: Hydrograph after calibration for event on January 2012 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 18:27:26   Control Specifications: Control Event 1

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge: 823.3 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Volume: 625.63 (MM)

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge: 876.1 (M3/S)   Date/Time of Peak Discharge: 12Jan2012, 08:00
Mean Abs Error: 37.4 (M3/S)   RMS Error: 52.7 (M3/S)
Volume: 659.09 (MM)   Volume Residual: -33.46 (MM)
Nash-Sutcliffe: 0.886

Figure 4.22: Summary of result after calibration for event on January 2012 with 0.05 initial abstraction ratio

Project: Rainfall Runoff Model   Simulation Run: Run 1
Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time: 29Jun2015, 18:27:26   Control Specifications: Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.2	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	27.0	62.4	5.8	1.4	96.6	101.1
11Jan2012	08:00	33.5	65.2	126.4	33.0	258.1	150.6
12Jan2012	08:00	56.7	74.0	545.9	146.7	823.3	876.1
13Jan2012	08:00	40.0	67.4	306.3	72.6	486.3	385.2
14Jan2012	08:00	30.6	63.8	103.4	22.5	220.3	255.8
15Jan2012	08:00	27.5	62.6	25.4	5.1	120.6	204.8
16Jan2012	08:00	26.8	62.3	4.3	0.7	94.1	173.4
17Jan2012	08:00	26.8	62.3	2.1	0.5	91.8	164.3
18Jan2012	08:00	28.7	63.0	34.5	9.5	135.7	162.1
19Jan2012	08:00	27.3	62.5	15.8	3.6	109.4	156.2
20Jan2012	08:00	30.3	63.7	63.8	17.4	175.1	185.1
21Jan2012	08:00	39.1	67.0	223.6	60.8	390.6	258.5
22Jan2012	08:00	30.1	63.6	88.6	19.8	202.1	195.4
23Jan2012	08:00	27.4	62.6	21.2	4.2	115.3	149.5
24Jan2012	08:00	26.8	62.3	4.2	0.8	94.2	127.8
25Jan2012	08:00	26.7	62.3	0.4	0.0	89.4	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.9	62.8	21.2	5.9	117.8	116.5
28Jan2012	08:00	27.1	62.5	10.5	2.4	102.5	116.9
29Jan2012	08:00	26.8	62.3	2.8	0.6	92.5	111.3
30Jan2012	08:00	26.8	62.3	2.2	0.6	92.0	107.8

Figure 4.23: Time series table for event on January 2012 with 0.05 initial abstraction ratio

Based on the result obtained after model calibration based on the antecedent moisture condition for event in January 2012, it still show that the value of initial abstraction ratio of 0.2 produce a significantly more accurate result compare to the 0.05 ratio based of the Nash Sutcliffe Efficiency calculate by the HEC-HMS but is understimate the actual peak discharge more comparing to the use of initial abstraction ratio of 0.05. For the use of initial abstraction ratio of 0.2 which is the results shown in Figure 4.18, 4.19 and 4.20 , the efficiency of the simulated result over an observed discharge is 0.892 with a peak discharge of 803.6 m^3/s occuring in 12 January 2012. The observed peak discharge is 876.1 m^3/s which is also occuring in 12 January 2012. While for the use of initial abstraction ratio of 0.05 which is the results is shown in Figure 4.21, 4.22 and 4.23, the efficiency of the simulated result over an observed discharge is 0.886 with a peak discharge of 823.3 m^3/s which occuring in 12 January 2012 which is the same as observed peak which is also occuring on 12 January 2012.

The use of initial abstraction ratio of 0.05 significanly produce a high efficincy result compare to the use of ratio of 0.2 for the normal condition of the watershed but after calibrated, the efficiency for both ratio almost have a relatively small differences. Based on the obtained result, it show that for the event on January 2012, the peak value of the simulated discharge is underestimated the actual dicharge before and after the model calibration but after the calibration, the simulated dicharge value is much closer to the actual dicharge. The efficiency of the model also increase from 0.792 to 0.892 for the 0.2 intial abstraction ratio and also increase from 0.843 to 0.886 for the 0.05 initial abstraction ratio. Based on the result obtained, it shows that the calibration of curve number based on the antercedent moisture condition is appicable for event on January 2012. The calibrated model almost have the same efficiency value with the original model with the use of 0.2 initial abstraction ratio. The calibrated model shows significant increase of efficiency when compare to the original model for the use of initial abstraction ratio of 0.05. The calibrated model for event on January 2012 is more accurate that the model with normal condition and the use of initial abstraction of 0.05 significantly increase the discharge volume which almost closer to the actual discharge value.

The obtained result based on Figure 4.0 until 4.23 is based on the calculation of the Lag Time for the routing method using SCS Lag Time formula. As a method comparison, the Lag Time is calculated again using the Kirpich Equation based on the new computed lag time, the performance of the method can be access by comparing the result obtained. The calculation of Lag Time using Kirpich Equation is shown in Table 4.8 and the result will be comparing with the original model for December 2006 event and calibrated model of January 2012 event since that the based on the early result, the model perform more accurate based that condition.

Reach	Hydraulic Length, L (m)	Elevation Up	Elevation Down	Slope (m)	K	L^0.77	1/(S^0.385)	Lag Time (min)
R30	2504.4122	176	69	107	0.0195	414.0030	0.1959	1.582
R50	6053.4719	220	45	175	0.0195	816.8522	0.2309	3.679
R70	8793.2824	202	25	177	0.0195	1088.9208	0.2896	6.149
R120	4516.6228	122	10	112	0.0195	651.9385	0.4121	5.239
R130	10541.0280	166	10	156	0.0195	1252.0448	0.4121	10.061
R170	13829.8131	103	22	81	0.0195	1543.2225	0.3042	9.154
R180	12568.6857	555	39	516	0.0195	1433.6832	0.2440	6.822
R190	6691.9466	509	74	435	0.0195	882.4201	0.1907	3.281
R200	5706.0740	174	11	163	0.0195	780.5124	0.3972	6.046
R210	10334.8846	102	8	94	0.0195	1233.1484	0.4491	10.798
R260	304.9306	4	5	-1	0.0195	81.8153	0.5381	0.859
R270	338.8291	9	5	4	0.0195	88.7330	0.5381	0.931
R290	10858.7171	42	8	34	0.0195	1281.0010	0.4491	11.217
R300	9826.9065	45	6	39	0.0195	1186.2083	0.5017	11.604
R310	16275.2624	498	8	490	0.0195	1749.3494	0.4491	15.319
R330	13928.7561	162	11	151	0.0195	1551.7169	0.3972	12.020
R340	9077.9801	70	6	64	0.0195	1115.9679	0.5017	10.917
R350	2704.3639	61	6	55	0.0195	439.2281	0.5017	4.297
R380	4299.1588	78	26	52	0.0195	627.6323	0.2853	3.491
R390	24866.3258	85	31	54	0.0195	2424.4931	0.2666	12.603
R420	2692.5117	132	12	120	0.0195	437.7452	0.3842	3.279
R440	17015.6206	52	12	40	0.0195	1810.3094	0.3842	13.561
R470	13828.9061	184	8	176	0.0195	1543.1446	0.4491	13.513
R480	1902.0247	43	13	30	0.0195	334.9627	0.3725	2.433
R510	15.4014	23	13	10	0.0195	8.2115	0.3725	0.060
R520	16065.1162	38	23	15	0.0195	1731.9310	0.2990	10.100
R530	4992.0624	19	21	-2	0.0195	704.1669	0.3097	4.253
R540	8526.8155	56	33	23	0.0195	1063.4226	0.2602	5.397
R570	26562.8486	108	7	101	0.0195	2550.8885	0.4728	23.516
R600	8433.1254	232	16	216	0.0195	1054.4141	0.3439	7.071
R620	19226.1247	113	19	94	0.0195	1988.8254	0.3219	12.483

Table 4.8: Calculated Lag Time based on Kirpich Equation

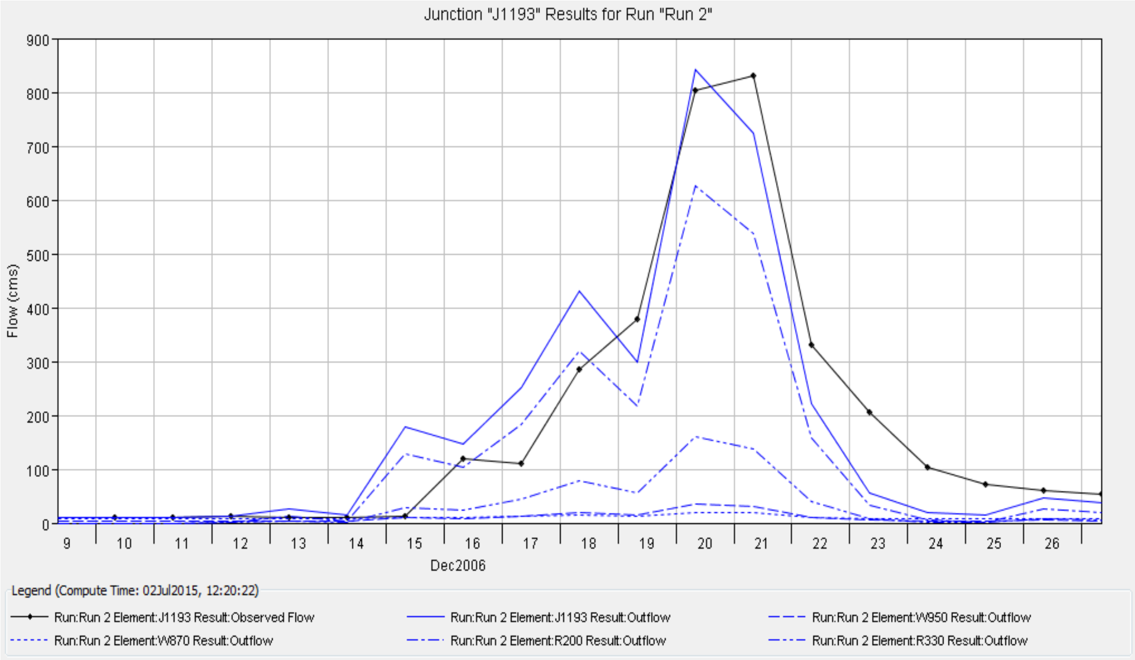
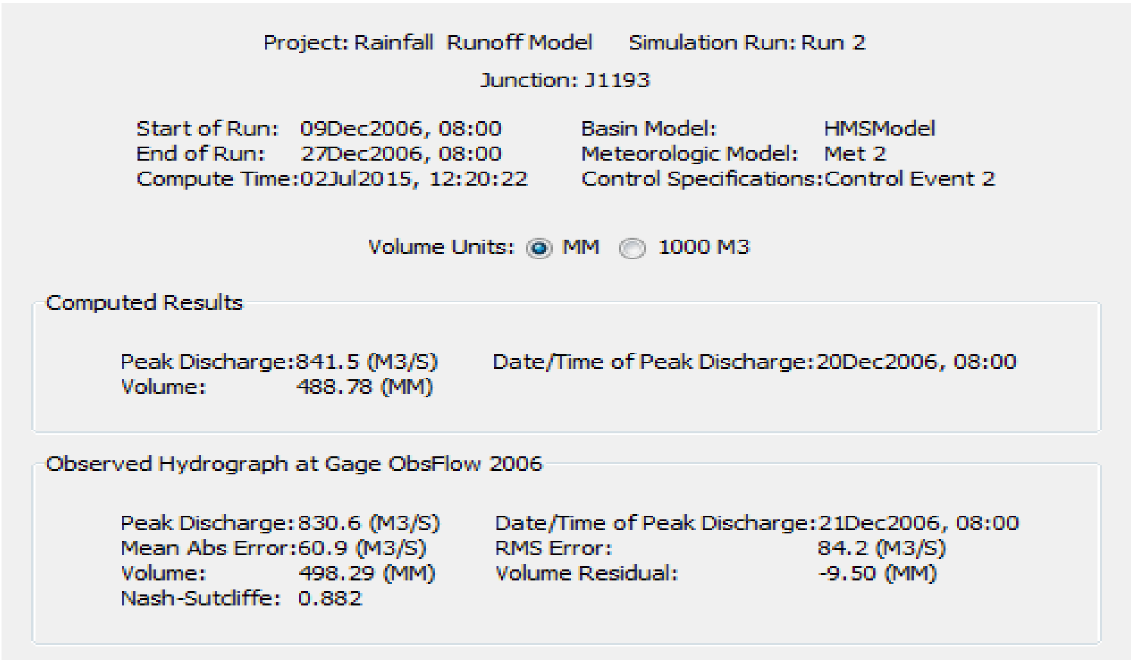


Figure 4.24: Hydrograph for event on December 2006 before calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time


Project: Rainfall Runoff Model Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00 Basin Model: HMSModel
End of Run: 27Dec2006, 08:00 Meteorologic Model: Met 2
Compute Time: 02Jul2015, 12:20:22 Control Specifications: Control Event 2

Volume Units: MM 1000 M3

Computed Results

Peak Discharge: 841.5 (M3/S) Date/Time of Peak Discharge: 20Dec2006, 08:00
Volume: 488.78 (MM)

Observed Hydrograph at Gage ObsFlow 2006

Peak Discharge: 830.6 (M3/S) Date/Time of Peak Discharge: 21Dec2006, 08:00
Mean Abs Error: 60.9 (M3/S) RMS Error: 84.2 (M3/S)
Volume: 498.29 (MM) Volume Residual: -9.50 (MM)
Nash-Sutcliffe: 0.882

Figure 4.25: Summary of result for event on December 2006 before calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00
End of Run: 27Dec2006, 08:00
Compute Time:02Jul2015, 12:20:22

Basin Model: HMSModel
Meteorologic Model: Met 2
Control Specifications:Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	12.0	11.7
13Dec2006	08:00	3.9	8.1	11.6	2.7	26.3	11.3
14Dec2006	08:00	3.5	8.0	3.4	0.8	15.7	11.3
15Dec2006	08:00	9.2	10.8	129.4	29.4	178.8	12.6
16Dec2006	08:00	8.2	10.1	104.5	24.6	147.4	118.3
17Dec2006	08:00	12.2	11.7	182.9	44.7	251.5	109.6
18Dec2006	08:00	19.0	14.3	318.7	79.5	431.6	285.1
19Dec2006	08:00	14.0	12.2	217.7	54.6	298.5	378.0
20Dec2006	08:00	34.8	20.2	626.9	159.6	841.5	803.9
21Dec2006	08:00	30.2	18.3	538.3	137.3	724.2	830.6
22Dec2006	08:00	11.1	10.9	158.5	40.2	220.6	330.9
23Dec2006	08:00	5.0	8.5	33.1	8.4	54.9	204.7
24Dec2006	08:00	3.6	8.0	5.4	1.3	18.4	102.7
25Dec2006	08:00	3.5	7.9	2.0	0.5	14.0	71.5
26Dec2006	08:00	4.8	8.4	27.3	7.0	47.5	59.1
27Dec2006	08:00	4.4	8.3	20.4	5.2	38.4	53.5

Figure 4.26: Time series table for event on December 2006 before calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time

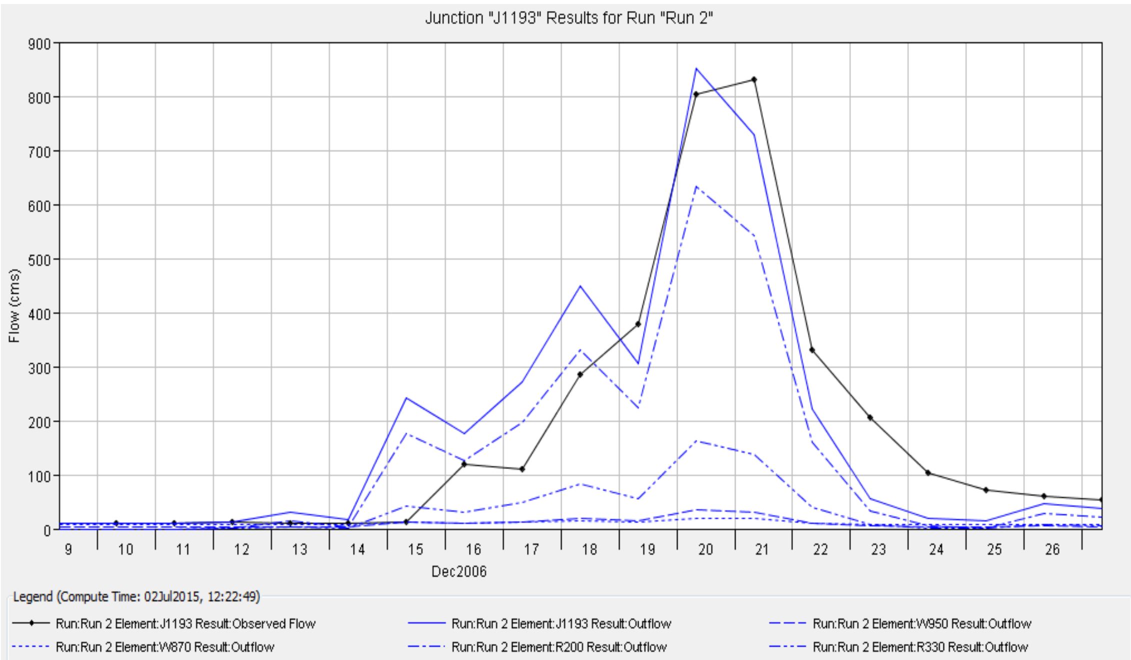


Figure 4.27: Hydrograph for event on December 2006 before calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 2

Junction: J1193

Start of Run: 09Dec2006, 08:00   Basin Model: HMSModel
End of Run: 27Dec2006, 08:00   Meteorologic Model: Met 2
Compute Time: 02Jul2015, 12:22:49   Control Specifications: Control Event 2

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge: 851.3 (M3/S)   Date/Time of Peak Discharge: 20Dec2006, 08:00
Volume: 511.87 (MM)

Observed Hydrograph at Gage ObsFlow 2006

Peak Discharge: 830.6 (M3/S)   Date/Time of Peak Discharge: 21Dec2006, 08:00
Mean Abs Error: 67.6 (M3/S)   RMS Error: 95.1 (M3/S)
Volume: 498.29 (MM)   Volume Residual: 13.58 (MM)
Nash-Sutcliffe: 0.850

Figure 4.28: Summary of result for event on December 2006 before calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 2
Junction: J1193

Start of Run: 09Dec2006, 08:00   Basin Model: HMSModel
End of Run: 27Dec2006, 08:00   Meteorologic Model: Met 2
Compute Time: 02Jul2015, 12:22:49   Control Specifications: Control Event 2

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
09Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	11.3
10Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.9
11Dec2006	08:00	3.4	7.9	0.0	0.0	11.3	10.5
12Dec2006	08:00	3.4	7.9	0.5	0.1	12.0	11.7
13Dec2006	08:00	4.0	8.2	14.5	3.3	30.0	11.3
14Dec2006	08:00	3.6	8.0	4.2	0.9	16.8	11.3
15Dec2006	08:00	11.8	11.6	176.5	42.5	242.4	12.6
16Dec2006	08:00	9.3	10.5	125.3	30.5	175.6	118.3
17Dec2006	08:00	13.0	11.9	197.3	49.0	271.3	109.6
18Dec2006	08:00	19.7	14.5	330.7	83.2	448.1	285.1
19Dec2006	08:00	14.3	12.3	223.1	56.3	306.0	378.0
20Dec2006	08:00	35.3	20.3	633.9	161.8	851.3	803.9
21Dec2006	08:00	30.5	18.3	542.1	138.5	729.4	830.6
22Dec2006	08:00	11.1	10.9	159.5	40.5	221.9	330.9
23Dec2006	08:00	5.0	8.5	33.3	8.4	55.2	204.7
24Dec2006	08:00	3.6	8.0	5.4	1.4	18.4	102.7
25Dec2006	08:00	3.5	7.9	2.1	0.5	14.0	71.5
26Dec2006	08:00	4.8	8.4	27.4	7.0	47.6	59.1
27Dec2006	08:00	4.4	8.3	20.5	5.3	38.5	53.5

Figure 4.29: Time series table for event on December 2006 before calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

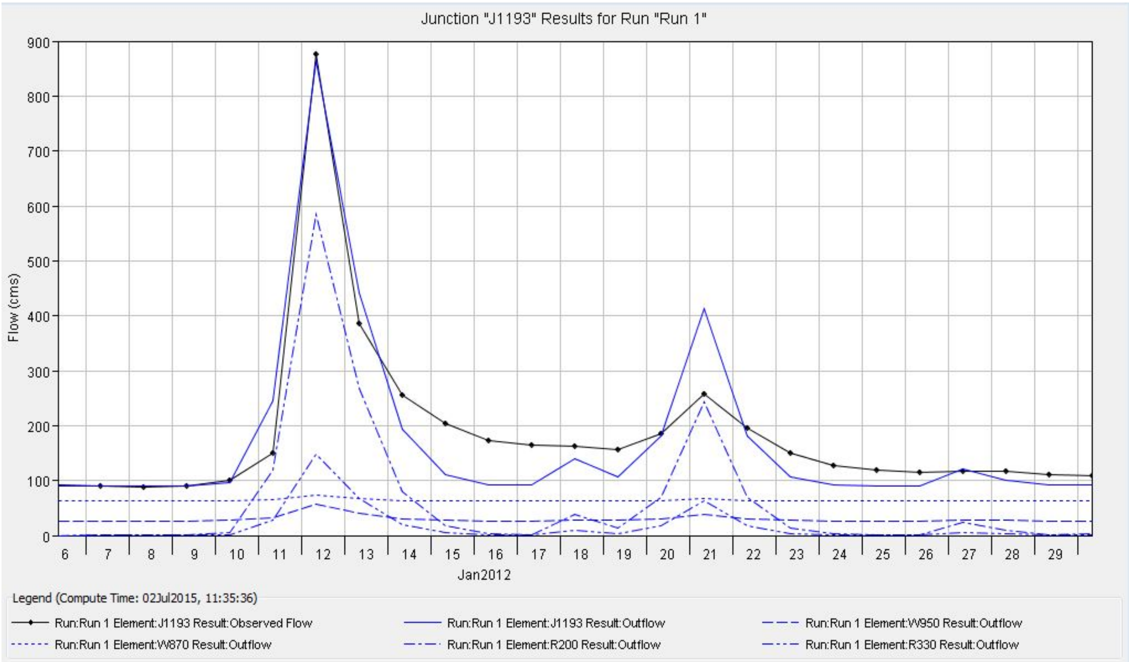


Figure 4.30: Hydrograph for event on January 2012 after calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run:	06Jan2012, 08:00	Basin Model:	HMSModel
End of Run:	30Jan2012, 08:00	Meteorologic Model:	Met 1
Compute Time:	02Jul2015, 11:35:36	Control Specifications:	Control Event 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge:	863.1 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Volume:	617.06 (MM)		

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge:	876.1 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Mean Abs Error:	36.6 (M3/S)	RMS Error:	52.6 (M3/S)
Volume:	659.09 (MM)	Volume Residual:	-42.02 (MM)
Nash-Sutcliffe:	0.887		

Figure 4.31: Summary of result for event on January 2012 after calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 1
Junction: J1193

Start of Run: 06Jan2012, 08:00   Basin Model: HMSModel
End of Run: 30Jan2012, 08:00   Meteorologic Model: Met 1
Compute Time:02Jul2015, 12:25:40   Control Specifications:Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.3	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	26.9	62.4	4.8	1.1	95.2	101.1
11Jan2012	08:00	32.2	64.8	119.7	28.2	244.9	150.6
12Jan2012	08:00	55.9	73.8	585.5	148.0	863.1	876.1
13Jan2012	08:00	39.8	67.4	267.4	67.6	442.2	385.2
14Jan2012	08:00	30.5	63.8	79.0	20.0	193.3	255.8
15Jan2012	08:00	27.5	62.6	17.1	4.3	111.5	204.8
16Jan2012	08:00	26.8	62.3	2.2	0.6	91.9	173.4
17Jan2012	08:00	26.8	62.3	2.0	0.5	91.7	164.3
18Jan2012	08:00	28.7	63.0	38.6	9.9	140.2	162.1
19Jan2012	08:00	27.3	62.5	13.1	3.3	106.3	156.2
20Jan2012	08:00	30.3	63.7	70.0	18.0	182.0	185.1
21Jan2012	08:00	39.1	67.0	243.5	62.8	412.4	258.5
22Jan2012	08:00	30.1	63.6	69.4	17.7	180.8	195.4
23Jan2012	08:00	27.4	62.6	13.9	3.5	107.3	149.5
24Jan2012	08:00	26.8	62.3	2.6	0.7	92.5	127.8
25Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.9	62.8	23.9	6.2	120.7	116.5
28Jan2012	08:00	27.1	62.5	8.8	2.3	100.7	116.9
29Jan2012	08:00	26.8	62.3	1.9	0.5	91.6	111.3
30Jan2012	08:00	26.8	62.3	2.2	0.6	92.0	107.8

Figure 4.32: Time series table for event on January 2012 after calibration with 0.2 initial abstraction ratio based on Kirpich Lag Time

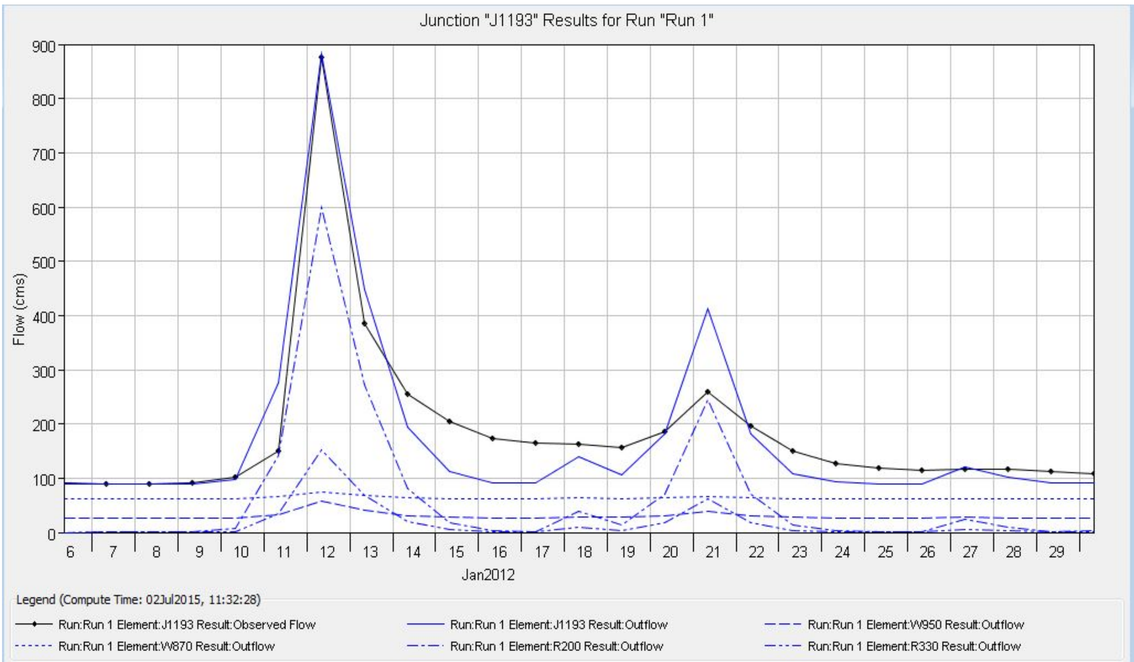


Figure 4.33: Hydrograph for event on January 2012 after calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run:	06Jan2012, 08:00	Basin Model:	HMSModel
End of Run:	30Jan2012, 08:00	Meteorologic Model:	Met 1
Compute Time:	02Jul2015, 11:32:28	Control Specifications:	Control Event 1

Volume Units: (•) MM ( ) 1000 M3

Computed Results

Peak Discharge:	881.9 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Volume:	625.67 (MM)		

Observed Hydrograph at Gage ObsFlow 2012

Peak Discharge:	876.1 (M3/S)	Date/Time of Peak Discharge:	12Jan2012, 08:00
Mean Abs Error:	37.6 (M3/S)	RMS Error:	55.2 (M3/S)
Volume:	659.09 (MM)	Volume Residual:	-33.42 (MM)
Nash-Sutcliffe:	0.875		

Figure 4.34: Summary of result for event on January 2012 after calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

Project: Rainfall Runoff Model   Simulation Run: Run 1

Junction: J1193

Start of Run:	06Jan2012, 08:00	Basin Model:	HMSModel
End of Run:	30Jan2012, 08:00	Meteorologic Model:	Met 1
Compute Time:	02Jul2015, 11:32:28	Control Specifications:	Control Event 1

Date	Time	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Inflow from... (M3/S)	Outflow (M3/S)	Obs Flow (M3/S)
06Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	91.6
07Jan2012	08:00	26.7	62.3	0.3	0.1	89.3	89.4
08Jan2012	08:00	26.7	62.3	0.1	0.0	89.1	88.3
09Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	90.4
10Jan2012	08:00	27.0	62.4	6.6	1.5	97.4	101.1
11Jan2012	08:00	33.5	65.2	142.0	34.5	275.2	150.6
12Jan2012	08:00	56.7	74.0	599.0	152.1	881.9	876.1
13Jan2012	08:00	40.0	67.4	271.1	68.7	447.3	385.2
14Jan2012	08:00	30.6	63.8	79.8	20.2	194.4	255.8
15Jan2012	08:00	27.5	62.6	17.2	4.3	111.7	204.8
16Jan2012	08:00	26.8	62.3	2.2	0.6	91.9	173.4
17Jan2012	08:00	26.8	62.3	2.0	0.5	91.7	164.3
18Jan2012	08:00	28.7	63.0	38.7	10.0	140.4	162.1
19Jan2012	08:00	27.3	62.5	13.1	3.3	106.3	156.2
20Jan2012	08:00	30.3	63.7	70.2	18.1	182.2	185.1
21Jan2012	08:00	39.1	67.0	243.9	62.9	412.9	258.5
22Jan2012	08:00	30.1	63.6	69.5	17.7	180.9	195.4
23Jan2012	08:00	27.4	62.6	13.9	3.5	107.4	149.5
24Jan2012	08:00	26.8	62.3	2.6	0.7	92.5	127.8
25Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	118.0
26Jan2012	08:00	26.7	62.3	0.0	0.0	89.0	114.3
27Jan2012	08:00	27.9	62.8	23.9	6.2	120.8	116.5
28Jan2012	08:00	27.1	62.5	8.9	2.3	100.7	116.9
29Jan2012	08:00	26.8	62.3	1.9	0.5	91.6	111.3
30Jan2012	08:00	26.8	62.3	2.2	0.6	92.0	107.8

Figure 4.35: Time series table for event on January 2006 after calibration with 0.05 initial abstraction ratio based on Kirpich Lag Time

By comparing the result obtained after using both equation for SCS Lag Time and Kirpich Lag Time Equation, the result obtained did not show any significant changes on the efficiency of the model but increase in the accuracy of predicting the peak discharge. Based on event on December 2006 by using SCS Lag Time and without calibration, the peak discharge for initial abstraction ratio of 0.2 is 790 m^3/s and while using Kirpich Lag Time Equation, the peak discharge is 841.5m^3/s. By using the Kirpich Equation, the prediction of peak discharge is overestimated the actual peak discharge, different with the used of SCS Lag Time equation which is it underestimated the prediction. Both application of SCS Lag Time and Kirpich gives a quite good efficiency which are 0.909 and 0.882 respectively. By using the value on initial abstraction ratio of 0.05 the obtained result is almost similar for the used of ratio of 0.2 which for the SCS Lag Time, the predicted peak discharge is 799.9 m^3/s while by using the Kirpich Lag Time, the predicted peak discharge is 851.3 with efficiency of 0.882 and 0.850 respectively. Based on the result, both value of initial abstraction ratio and lag time equation did not gives significant changes in the efficiency of the model but gives slightly changes to the prediction of peak discharge.

While for event on January 2012, the use of Kirpich Equation gives a prediction of 863.1 m3/s peak discharge in which it predict only 803.6 m^3/s by using the SCS Lag Time for the use of initial abstraction ratio of 0.2. The efficiency generate by both method is 0.887 and 0.892 respectively, in which there is a slight decrease on the efficiency on the use of Kirpich Equation. By applying the initial abstraction ratio of 0.05, the use of Kirpich Equation seem to overestimated the prediction of peak discharge compare to the use of SCS Lag Time. By using the Kirpich Equation, the predicted peak discharge is 881 m^3/s and by using SCS Lag Time, the predicted peak discharge is 823.3 m^3/s, where the actual peak discharge is 876.1 m^3/s.

In comparison, by applying both equations for the routing method, the Kirpich Equation seems to give more accurate result on the prediction of the peak discharge. The SCS Lag Time tend underestimate the prediction while Kirpich Equation tend to overestimate the prediction but the Kirpich method seem to give a closer value of the simulated peak discharge with the actual peak discharge without affecting it efficiency.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

The efficiency of the model in the simulation run is measure in the HEC-HMS based on the Nash-Sutcliffe Efficiency (NSE) where the calculation is done based on simulated result and the actual data. The computation of simulation run is done based on 2 selected events which is the first event is on December 2006 and the second event is on January 2012.

Based on the result obtained based on the simulation of two events which is on December 2006 and January 2012, the model efficiency based on event December 2006 is higher without calibration based on the antecedent moisture condition and it high for event on 2012 after the model is calibrated. By comparing the 5 days antecedent moisture condition, on event 2006, the recorded rainfall depth is 7.5 mm while for event on January 2012, the recorded rainfall depth is 52 mm. Prior to the condition, it can be conclude that the model for event on December 2006 did not has to be calibrated based on the factor of antecedent moisture condition since the previous rainfall depth is low. Different with the model for event on January 2012, the model need to be calibrated based on the antecedent moisture condition due to the high previous rainfall depth which causes the soil to be saturated with water, thus increase in the runoff volume.

In comparison with the modification made by changing the ratio for the initial abstraction ratio, the use of initial abstraction ratio of 0.2 and 0.05 did not gives much different on the efficiency of the model but slightly give much different on the value of discharge predicted. By using the initial abstraction ratio of 0.05, the result obtained shows a closer prediction of peak discharge to the actual peak discharge compare to the use of initial abstraction ratio of 0.2. The use of initial abstraction 0.2 have high tendency to underestimate the peak discharge while for ratio of 0.05, it tend to overestimate the prediction of peak discharge.

While, in comparison with the method use for the routing method based on the original model for event on December 2006 with calibrated model for event on January 2012, the use of Kirpich Equation seem to overestimate the prediction for the event on December 2006 for both application of initial abstraction ratio. For event on January 2012, the Kirpich method underestimated the prediction while using the abstraction ratio of 0.2 but overestimate the prediction in the use of 0.05 initial abstraction ratios. By using the SCS Lag Time, the application of the equation in the model shows that the model is underestimated all the prediction of the peak flood for event on December 2006 and January 2012. By using both equations in the model, the model efficiency is seemed to be not affected because it only shows slightly small changes on the efficiency.

Based on the first objective of the researched, which is to develop the rainfall-runoff relationship using hydrological model and GIS in Kuantan watershed, it can be conclude that the relationship between rainfalls with runoff is basically affecting by various factor inside the watershed. The most common factor is the land use, hydrological soil groups, antecedent moisture condition, the initial abstraction ratio and the lag time. The land use and the hydrological soil groups are important features to generate curve number maps. Curve number is one of the important features in generation of runoff in the watershed. The antecedent moisture condition is the earlier condition of the soil in the watershed before the event which the value of the runoff will be increase as the saturation of water in the soil is higher. Initial abstraction is the amount of precipitation that is estimate to infiltrate into the soil. Low curve number value will generates high infiltration rate. Based on the result, the use of different ratio for the initial abstraction give a significant different value in the result obtained.

The next objective is to assess the performance of HEC-HMS model in runoff prediction in the Kuantan watershed. Based on the result obtain from both original and calibrated model, the HEC-HMS is preforming well in predicting runoff in the study area. The performance of the HEC-HMS is basically influenced by the input parameter of the model in the HEC-HMS. Generally, the HEC-HMS will increase its performance in predicting runoff based the define parameter such as the lag time and curve number of the watershed. To increase the performance of the HEC-HMS, the method used and calculate data must relatively closer to the actual condition of the watershed. During the creation of the model for the watershed using ArcMap, the process need to be done precisely in order to define correctly the parameter needed in the HEC-HMS. The method to calculate the model parameter also can affect the result as in the study; the use of two different equations for the routing method shows a different in the result generated.

The final objective is to evaluate the accuracy of modified SCS-CN in tropical area. Kuantan watershed is located in the tropical area, which consists of two major seasons which is wet and dry session. In the researched the method use to modify the curve number is by changing the value of the initial abstraction ratio of the initial abstraction which is related to the curve number. The modification also been carried out by taking consideration of the antecedent moisture condition in the watershed. Based on the research, the accuracy of the method is evaluated using the Nash-Sutcliffe Efficiency (NSE). The efficiency value obtained is range in 0.7 to 0.9 for model before and after calibration, indicates that the application of the modified SCS-CN is applicable in the runoff prediction in the tropical area. In term of time to peak and peak discharge, simulation on event on December 2006 is underestimated the peak discharge with different time to peak when compare to the actual time to peak while after calibration, the model overestimated the peak discharge also along with different time to peak than actual value. For event on January 2012, the simulation result after and before calibration gives the same time to peak with the actual value but both underestimated the peak discharge. The simulated peak discharge for event on January 2012 is closed to the actual peak discharge after the model calibration is carried out.

For the recommendation to the researched, the result can be improve by creating the model with a more higher resolution of digital elevation model (DEM). Higher resolution DEM has a better generation of the parameter in the watershed which can parameterized the watershed more accurately. The curve number of the watershed also can be improved by studying the current condition of the soil based on the land use since that it can change fast due to development.The parameter of slope in the watershed also need to be define more precisely since that the slope is the importance parameter for the movement of the water in the watershed. The next suggestion is by using other method or software used to delineated define the parammeter in the watershed such as ILWIS and QGIS and apply different method used in the HEC-HMS for flood routing, loss method and transform method. The calibration of the model also can be made by using other method of transforming the curve number based on the antecedent moisture condition and use different method such as using the existing developed equation for the conversion of the curve number. The calibration procedure also can be varies by performing the adjusted slope method or redefine the actual lag time and the timee of concentration of the watershed to be apply in the model. Beside that, the model can be verify and validate using more event to really understand and accessing the performance of the model in the runoff prediction. The equation use for the calculation of parameter for the watershed such as lag time and time of concentration also can be varies since that there a few different equation in which the generated value may also varies and some of the value may not be suitable to be used in the model. In addition, based on the calculation for Lag Time of routing method, the use of equation such as SCS Lag Time and Kirpich Equation also can be choose based on the method that easy to be used and have the value needed in the eqaution is readily available.

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APPENDIX A

Manual to Determine the Curve Number (Source: Technical Release 55 (TR55): Urban Hydrology for Small Watersheds, Second Ed., June 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S

2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. 3/	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 4/	48	65	73
Woods—grass combination (orchard or tree farm). 5/	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. 6/	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 4/	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 ***Poor:*** <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 ***Poor:*** <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 ***Poor:*** Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1 Average runoff condition, and I_a, = 0.2S. For range in humid regions, use table 2-2c.

2 Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.

3 Curve numbers for group A have been developed only for desert shrub.