DEVELOPMENT OF THE RAINFALL RUNOFF RELATIONSHIP FOR KECAU RIVER BY USING HEC-HMS AND IT'S APPLICATION TO TANUM RIVER

NUR SHAFIKAL BINTI ZAKARIA

Report submitted in partial fulfillment of the requirements
for the award of degree of
Bachelor of Engineering (Hons) of Civil Engineering

Faculty of Civil Engineering & Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2015

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name : **NUR SHAFIKAL BINTI ZAKARIA**

Date of birth : **10 MARCH 1992**

Title : **DEVELOPMENT OF THE RAINFALL-RUNOFF RELATIONSHIP FOR KECAU RIVER BY USING HEC-HMS AND IT'S APPLICATION TO TANUM RIVER**

Academic Session : **2014/2015**

I declare that this thesis is classified as :

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)*

☑ **OPEN ACCESS** I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of University Malaysia Pahang
2. The Library of University Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified By:

______________________________	______________________________
(Student's Signature)	(Signature of Supervisor)
920310-11-5578	DR BAMBANG WINARTA
Date :	Date :

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project is satisfactory in terms of scope and quality for the award of Bachelor of Civil Engineering (Hons).

Signature	:	
Name of Supervisor	:	DR. BAMBANG WINARTA
Position	:	LECTURER
Date	:	

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:	
Name	:	NUR SHAFIKAL BINTI ZAKARIA
ID Number	:	AA11185
Date	:	

Dedicated to Allah S.W.T.

My beloved father and mother,
Zakaria Long & Roslina Ibrahim

My beloved siblings,
Muhammad Syazwan, Muhammad Syahiran,
Muhammad Syafiq, Muhammad Syakir Aiman.

My beloved lecturers and friends.

For their endless support and encouragement
throughout my years as a student.

ACKNOWLEDGEMENTS

Alhamdulillah, praise to Almighty Allah, with His blessing and whom without Him, none of this can be achieved.

First and foremost, thousands of thank and deep appreciation towards my supervisor Dr Bambang Winarta for all his help, encouragement, critics, guidance and friendship. I'm very thankful to University Malaysia Pahang (UMP) for providing good facilities in the campus and faculty in order to finish my thesis. My sincere appreciation also goes to all lecturers in UMP for endless support and guides me in Hydrology.

I also would like to acknowledge my family, especially my parent for their undying support and love that they give to me. Thousand thanks also to my entire classmate especially girl, roommate and special friend that helping me in completing this project.

Lastly, to all parties that have contributed, support and help me especially Jabatan Pengairan dan Saliran (JPS) and Jabatan Ukur dan Pemetaan (JUPEM) either directly or indirectly in completion of this project. Thank you so much.

ABSRACT

This study is about flood estimation model for Kecau River and Tanum River in Lipis, Pahang by using Hydrological Modeling System (HEC-HMS). HEC-HMS is tool for analyzing and simulating rainfall and runoff process. HEC-HMS version 4.0 is used in this study to simulate stream flow for Kecau River basin and applied to Tanum River basin since both river have same characteristic. Rainfall and stream flow data that used in this study is from 1999 until 2014. Result of simulation can be generated in summary table, hydrograph and time series table. Correlation coefficient, R^2 is used to measure the performance of the modeling. A model with the R^2 value is nearly to 1.0 is considered as good and satisfactory. During simulation, value of R^2 for station Kg Dusun, Pahang (4320401) in May 1999 is 0.4158 and in January 2010 is 0.8143. The simulated model were fit with the onserved data and show that HEC-HMS are suitable model to predict the stream flow in Tanum River.

ABSTRAK

Kajian ini berkaitan dengan pemodelan anggaran banjir di Sungai Kecau dan Sungai Tanum yang terletak di Lipis, Pahang dengan menggunakan HEC-HMS (Hydrological Modelling System). HEC-HMS adalah alatan penting yang digunakan untuk menganalisa dan membuat simulasi hujan dan proses larian hujan. HEC-HMS versi 4.0 telah digunakan dalam kajian ini untuk membuat aplikasi pergerakan air untuk kawasan tadahan Sungai Kecau dan membuat kalibrasi untuk kawasan tadahan Sungai Tanum memandangkan kedua-dua sungai mempunyai kriteria yang sama. Data hujan dan pergerakan airyang digunakan di dalam kajian ini diambil dari tahun 1999 hingga tahun 2014. Keputusan simulasi ini boleh dilihat di dalam jadual ringkasan, hidrograf dan jadual siri masa. Pekali kolerasi, R^2 digunakan untuk mengukur prestasi pemodelan ini. Pemodelan dengan pekali kolerasi yang menghampiri 1.0 adalah dianggap tepat dan memuaskan. Semasa proses simulasi, nilai R^2 untuk stesen Kg Dusun, Pahang (4320401) untuk May 1999 ialah 0.4158 dan untuk January 2010 ialah 0.8143. Simulasi pemodelan adalah tepat dengan data yang diperhatikan dan ianya menunjukkan bahawa HEC-HMS adalah pemodelan yang sesuai digunakan untuk meramal aliran sungai di Sungai Tanum.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

LIST OF SYMBOLS

q_t	Discharge at time
q_o	Discharge at time, t=0
K	Fitting coefficient
Q	Calculated flowrate
A	Area of catchment involve
I	Design rainfall intensity
C	Runoff coefficient
t_r	Effective rainfall duration
q_p	Peak direct runoff rate
t_1	Basin lag time
q_{pR}	peak discharge per unit of watershed area
t_{1R}	basin lag
t_b	Base time
A_1	Basin area
C	Conversion constant
Cp	UH peaking coefficient.
S	Potential storage
CN	Curve number
Tc	Time of concentration
L	Lag
a_x	Incremental of watershed area
Q_x	Runoff from area

T_{tx}	Travel time
A_2	Total area of the watershed above the references point
Q_a	Total runoff

LIST OF ABBREVIATIONS

HEC-HMS	Hydologic Engineering Center Hydrologic Modelling System
JPS	Jabatan Pengairan dan Saliran
UH	Unit Hydrograph
SCS	Soil Conservation Service
JUPEM	Jabatan Ukur dan Pemetaan

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Water is an important natural resource for all creatures on this earth. Humans, animals and plants need water in their daily life. Without water, living thing can not only survive, but also the development and the industry could not operate. This is because, water play a big part in the growth of the community as a permanent water supply system is a prerequisite to building a permanent community. Unlike other raw materials, there are no materials that can replace the water because it cannot be created or replaced. There are a few natural water sources such as rivers, ground water, dew, snow and rain. However, too rapid technological advances today allow re-use of rain water in an effort to alleviate the shortage of clean water supply and water pollution issues.

Hydrologic cycle is a conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and the hydrosphere Water on our planet can be stored in any one of the following major reservoirs: atmosphere, oceans, lakes, rivers, soils, glaciers, snowfields, and groundwater. Water moves from one reservoir to another by way of processes like evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, and groundwater flow.

Basically, river flooding occurs because of the incidences of the heavy rainfall and the resultant large concentration of runoff, which can exceed the capacity of the river. Commonly, the major problem in Malaysia due to hydrological problem is flooding. Due to the flooding problem, there are many software have been created to analyze and stimulate rainfall and runoff process. In this research, Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) is used to stimulate rainfall-runoff model. The relationship between rainfall and runoff by producing hydrograph can be obtained by using this software.

Since Kecau River is near to Tanum River, the watershed characteristic is almost similar. So, calibrated hydrological model of Kecau River will be used to predict stream flow for Tanum River.

1.2 PROBLEM STATEMENT

Flooding is one of the regular natural disaster due to this factor and flooding is becoming a common phenomenon in Malaysia. Basically, river flooding occurs because of the incidence of the heavy rainfall and the resultant large concentration of runoff, which can exceed th capacity of the river. The rivers that contribute flood problem in Pahang are Kecau River and Tanum River.

Kecau River and Tanum River are stream in the region of Pahang, the country of Malaysia. Flooding risk at Kecau River is extremely high and medium at Tanum River. Modeling system (HEC-HMS) is designed to analyze the rainfall-runoff at these both rivers.

1.3 OBJECTIVES

The objectives of this study are:

i. To develop rainfall-runoff model for Kecau River
ii. To apply Clark Unit Hydrograph method for determining the rainfall-runoff relationship in Kecau River and Tanum River
iii. To apply a calibrated rainfall-runoff of Kecau River to Tanum River (un-gauge stream flow)

1.4 SCOPE OF STUDY

The study was carried out on two catchment area. The catchment used in this study are Kecau River and Tanum River in Pahang, Malaysia. Kecau River have 61.5km long with average elevation 76m above sea level while Tanum River have 12.5km long with average elevation 91m above sea level. The hydrology data are analyzed by using HEC-HMS that obtain from rainfall data and flow rate from the runoff. By analyzed this data using HEC-HMS, we can predict the discharge and determine the rainfall-runoff relationship for Kecau River and Tanum River in certain period of time.

In addition, this study includes data collection work. Specific required data needs from these rivers. For data collection I need to do site visit to Jabatan Pengairan dan Saliran (JPS) at Ampang. The second part deal with data analyzing which is analyze the data by comparing the rainfall-runoff for these two rivers.

1.5 SIGNIFICANCE OF STUDY

From this research, the rainfall-runoff relationship can be obtained from using Hydrologic Modeling System (HEC-HMS). It is important to do this research because the data from this research is effective to use in order to solve and prevent flood in the catchment area with or without gauge.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROLOGY

Hydrology is a fascinating discipline of knowledge. It is concerned with water on, under and above the land surface. Scientific and engineering hydrology covers a broad field of interdisciplinary subjects that may be approached from various perspectives, including those of the geologist, chemists, civil engineers, environmental engineers, as well as hydrologists. U.S National Research Council had interpreted hydrology is the science that treats the water of the Earth their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with the environment including the relation to living things. The domain of hydrology embraces the full life history of water on earth.

2.1.1 Hydrologic Cycle

Water does not remain locked up in the ocean, icecaps, groundwater system or the atmosphere. Instead, water is continually moving from one reservoir to another. This movement of water is called hydrologic cycle. This phenomenon has even been noticed in the early days of mankind.

The main link in the water cycle in nature is exchange between the oceans and land, which includes not only quantitative renewal, but qualitative restoration as well. All types of nature waters are renewed annually, but the rates of renewal differ sharply. As for general description for hydrologic cycle, it is the continuous, unsteady circulation of the water resources from the atmosphere to under the land surface by various processes, back to atmosphere (Walesh, 1989). It consist of various unsteady processes occurring either in the atmosphere or beneath the earth's surfaces and illustrated by **Figure 2.1** below.

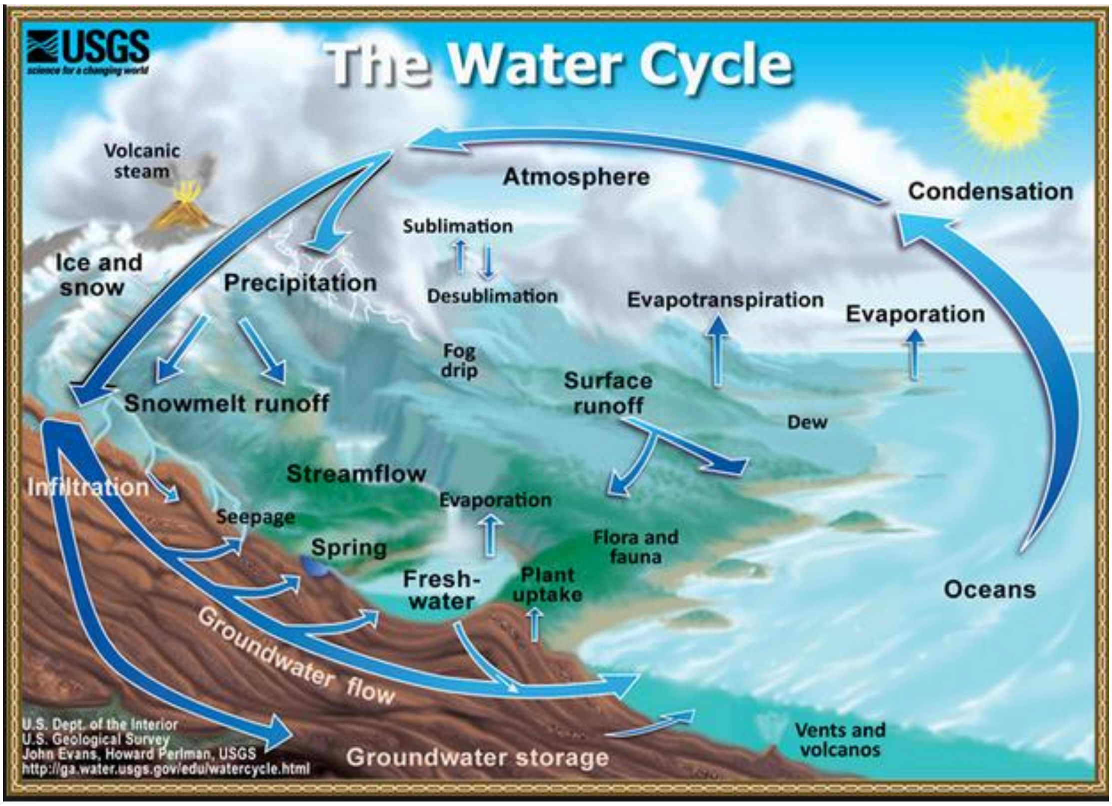

Figure 2.1: Hydrologic cycle

Source: USGS water science school

The hydrological processes involved in the cycle. Energy from the sun results in evaporation of water from ocean and land surfaces and also causes differential heating and resultant movement of air masses. Water vapor is transported with the air masses and under the right conditions becomes precipitation. Evaporation from oceans is primary source of atmospheric vapor for precipitation, but evaporation from soil, stream, lakes, and transpiration from vegetation also contribute. Precipitation runoff from the land becomes streamflow. Soil moisture replenishment, groundwater storage and subsurfaces flow occur as a result of water infiltrating into the ground while stream and groundwater flow convey water back to the oceans. Overall, the hydrologic processes by which water moves through the hydrologic cycle includes atmospheric movement of air masses, precipitation, evaporation, transpiration, infiltration, percolation, groundwater flow, surfaces runoff and streamflow.

2.1.2 Hydrological Characteristics

Hydrological characteristic refer to rainfall distribution, runoff distribution and peak discharge at a particular location along the course of river or stream (Sudmeyer, R.A., 2004). One of the important graph to determine hydrological characteristic of the river or stream is hydrograph. Annual hydrograph can predict the changes in the flow of water over the year at a certain location (RAMP, 2007). It shows all variations of the flow and periods of high and low flows while hydrometric data refer to data collection of that flow.

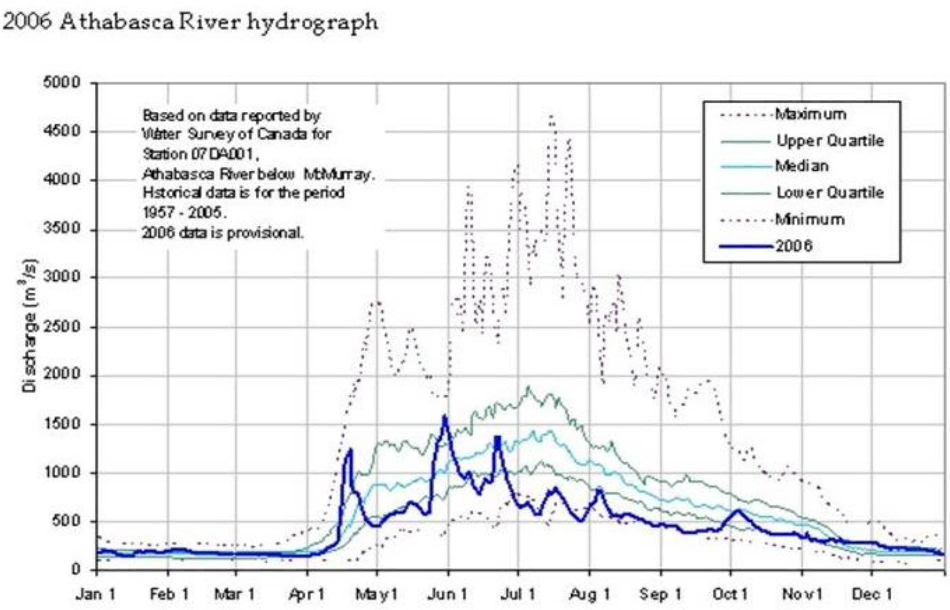

Figure 2.2: Example of a hydrograph for Athabasca River

Source: RAMP, 2007

There are three important parts of hydrograph which are crest segment (peak flow), rising limb and falling limb (recession curve). These parts are measured at a specific point in certain river and typically time variation (Strandhagen et al., 2006). Rising limb represents the increasing of stream flow rate while peak flow shows the maximum flow rate that occur and falling limb is where the stream flow rate is decreasing.

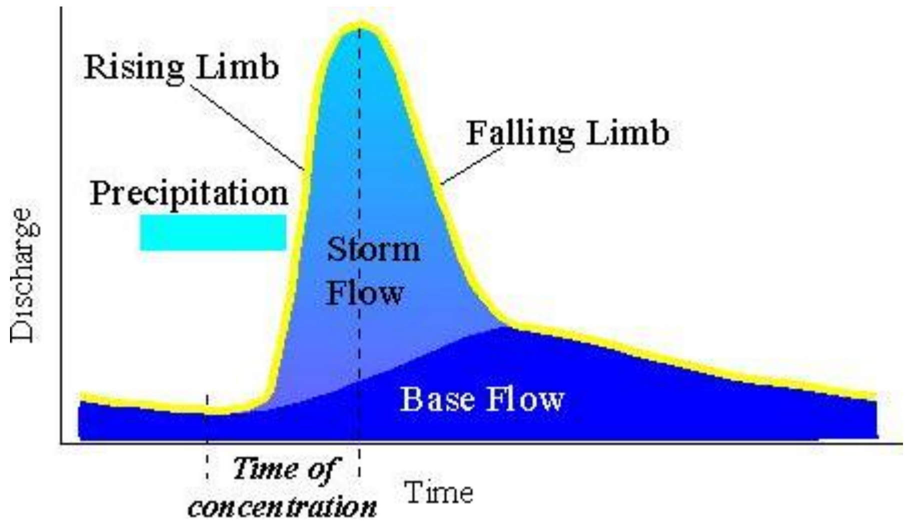

Figure 2.3: Charecteristic of hydrograph

Source: NRCCA study resources

Some of the hydrological indicators used in hydrological characteristic include discharge, maximum flow, minimum flow and median flow. Overall, hydrological characteristic deals with quantitative aspect of the hydrological cycle as well as particular space-time variation of hydrological elements

2.2 RAINFALL AND RUNOFF

Rainfall is known as the main contributor to the generation of surface runoff. Therefore there is a significant and unique relationship between rainfall and surface runoff. By basic principle of hydrologic cycle, when rain falls, the first drops of water are intercepted by the leaves and stems of the vegetation. This is usually referred to as interception storage. Once they reach the ground sirfaces, the water will infiltrate through the soil until it reaches a stages where the rate of rainfall intensity exceeds the infiltration capacity of the soil. The infiltration capacity of soil may vary depending on the soil texture and structure. For instant, soil composed of a high percentage of sand allows water to infiltrate through it quite rapidly because it has large, well connected pore spaces. Soils dominated by clay have low infiltration rates due to their smaller sized pore spaces. However , there is actually less total pore space in a unit volume of coarse, sandy soil than that of soil composed mostly of clay. As a result, sandy soils fill rapidly and commonly generate runoff sooner than clay soils

Apart from rainfall characteristics such as intensity, duration, and distribution, there are other specific factors which have a direct bearing on the occurrence and volume of runoff. The most common factor is the soil type. Due to the variation of runoff production, different studies have been conducted according to particular soil condition. For example, runoff production in blanket peat covered catchment would be rather different than urban area catchment. Blanket peat catchments exhibits flashy regimes, but little is known about the exact nature of runoff production processes within such catchment. In the past, many believed that blanket peatlands were able to attenuate floods and to sustain baseflow in streams and rivers during periods of low precipitation. However, recent studies have demonstrated that intact and degraded blanket peats are indeed extremely productive of runoff and have flashy regimes with little base flow contribution Price. The runoff generation in the area is also associated with the peat soil layering as the deeper layers may be an important overall contributor to runoff .

Another factor that can affect the runoff production is vegetation. An area which is densely covered with vegetation produces less runoff than bare ground while the amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. Vegetation has significant effect on the infiltration capacity of the soil. A dense vegetation cover shields the soil from the intense raindrop impact which eventually will cause a breakdown of the soil aggregates as well as soil dispersion with the consequence of driving fine soil particles into the upper soil pores. This results in clogging of the pores, formation of a thin biut dense and compacted layer at the surface which highly reduces the infiltration capacity. This particular effect is often referred as to capping, crusting or sealing. In addition, the roots system as well as organic matter in the soil increases the soil porosity thus allowing more water to infiltrate.

Slope and catchment size also influence the generation of surface runoff. Steep slope in the headwaters drainage basins tend to generate more runoff than the lowland areas. Overall mountain areas tend to receive more precipitation because they force air to be lifted and cooled. On gentle slopes, water may temporarily pond and later infiltrate, but in mountainsides, water tends to move downward more rapidly. Size of catchment may have an effect to the runoff generation in terms of the runoff efficiency (volume of runoff per unit area). The larger the size of catchment, the larger is the time of concentration and the smaller the runoff efficiency.

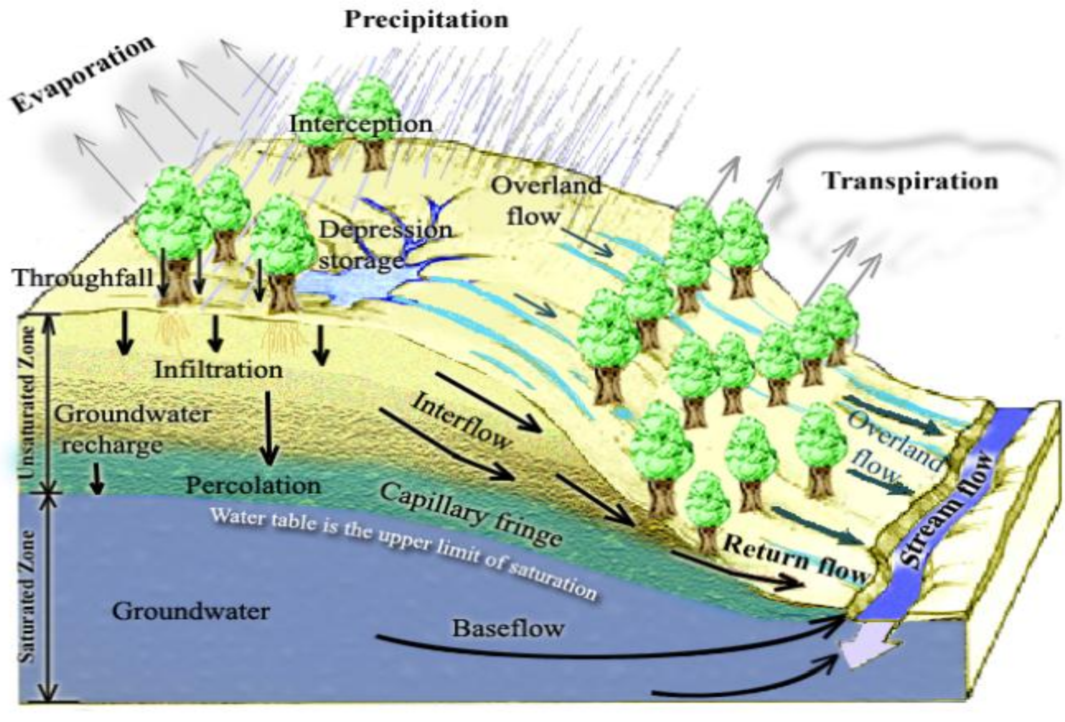

Figure 2.4: Physical processes involve in runoff generation

Source: Hydroviz.org

2.3 PHYSICAL CHARACTERISTIC OF BASIN

2.3.1 Land Use

Various types of physical characteristic of basin give major impact on quality and volume water flow through river and oceans. Land use can be defined as an activity done on the ground or a structure above ground. Land use change is the main cause of human affected on the hydrological system on regional, local and global scale. (B. Bhaduri, 2000). Mostly, it's controlled by increasing of urban area in several scales.

The primary case of land use vary at many scales because of land use by humans. However, the scale of these effects depends on a form of climatic features of the region and land use changes. Negative impacts on human health, loss of wetland habitat and riparian and decreasing of ecological diversity are a few example effect of land use on environmental aspects.

2.3.2 Elevation of the Basin

Elevation of the basin is one of the physical characteristic that affect the time distribution and concentration of discharge from the basin. Elevation of the basin can detect on the topography of the land. There are a few software in hydrological modeling can analysis the network drainage and extraction of the watershed. (N.S. Magesh, K.V. Jitheshlal, N. Chandrasekar and others, 2013).

2.3.3 Slope

Pattern of the watershed drainage depends on the slope of the basin where the surface of every soil is different in each place. It is difficult for rainfall or snow melt to seep into the ground for steep slope while for the shallow and permeable surface, the rainwater become a direct discharge flow. Besides, rate of elevation always change along the main channel and this kind of change can be estimated from the main channel of slope. Hence, more velocity will be generated in the larger slope of basin compared to smaller one.

2.4 RAINFALL AND RUNOFF RELATIONSHIP

2.4.1 Hydrograph separation

Hydrograph separation is a process of separating the major hydrograph components for analysis namely the surface runoff and the baseflow. Surface runoff (rainfall excess) is the water that enters the stream primarily by way overland flow across the ground surface while baseflow is defined as water that enters the streams by way of deep sub-surface flow below the main water table and may include other components such as throughflow and interflow. Several method have been proposed and used for separating the surface runoff and the baseflow but none of them have proven to be more superior as there is no ready basis for distinguishing both components in a stream at any instant. The selection of an appropriate method depends on the type and amount of measured data available, the desired accuracy for the design problem and the effort that the modeler wishes to expend.

Numerous academic explanations have been published in elaborating the separation method. Four types of baseflow separation, which are:

1) Constant-discharge baseflow separation
2) Constant-slope baseflow separation
3) Concave baseflow separation
4) Master depletion curve method

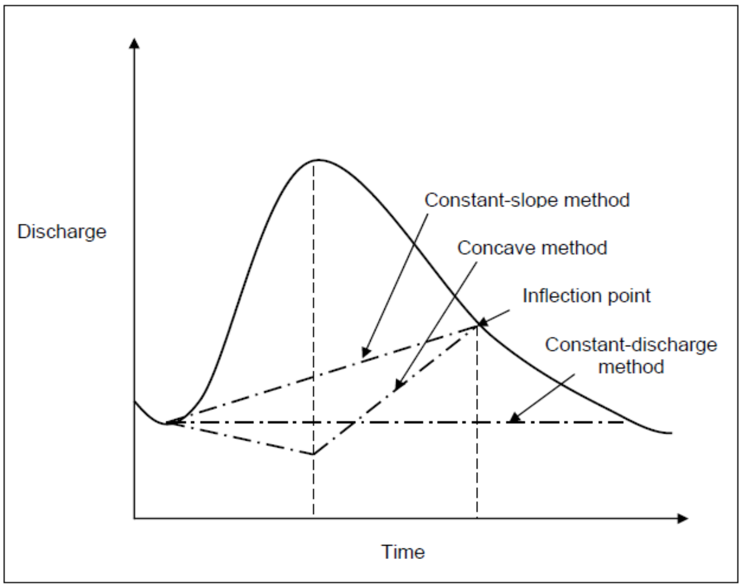

Figure 2.5: Baseflow separation method

Source: McCuen, 1989

The easiest method to use is the constant discharge baseflow method. It is a straight line drawn from lowest discharge rate at the start of the flood runoff and extends at a constant discharge rate until it intersects the recession limb of the hydrograph. The next method is the constant slope method whereby the inflection point is indeed arbitrary but it can be defined by the point in which the hydrograph change from being concave to convex such as the slope being greater than 1 to the slope being less than 1. Simply stated, it is the line drawn from lowest discharge rate directly to the inflection point of the hydrograph.

The third method is called the concave baseflow separation. The baseflow is assumed to decrease until the time of the peak discharge of the storm hydrograph. From the point, the separation line is straight between that point and the inflection point on the recession as shown in the figure above. Finally is the master depletion curve method which uses semi-logarithmic plots on the recession curves. A mathematical function form which fits the data is applied to construct the curve.

$$q_t = q_o e^{-Kt} \qquad (2.1)$$

Where :

q_t	=	discharge at time, t
q_o	=	discharge at time t = 0
K	=	fitting coefficient

2.5 METHOD OF ANALYSIS RAINFALL AND RUNOFF DATA

2.5.1 Peak Discharge Method

Peak Discharge Method cam be used to analyze the data of rainfall and runoff and this method also can determine the peak discharge for the watershed, the number of curves, time of concentration and depth and volume of runoff and the area of watershed. This method only effective for watershed which the area more than 2000 acres in size.

Peak Discharge Method is one of the best methods to solve the flooding problem through hydrograph as the hydrograph can be used as flood prediction. Peak Discharge Method also known as Slope Area Method. Total volume of runoff is computed from the uniform flow equation.

2.5.2 Rational Method

Rational method is well known as one of the basic approach to compute stormwater flows from rainfall by relating peak runoff to rainfall intensity through aproportionally factor. When the first flow rate or discharge formula was established, the rainfall intensities were not considered as a significant factor. Only by 1945, the rainfall intensities were recognized as an important proportion to be included in the following formula

$$Q = C\,.I\,.A \qquad (2.2)$$

Where :

Q	=	calculated flowrate (m^3/s)
A	=	area of catchment involve (ha)
I	=	design rainfall intensity (mm/h)
C	=	runoff coefficient

2.5.3 Unit Hydrograph Method

2.5.3.1 Synthetic Unit Hydrograph

Synthetic Unit Hydrograph can be defined as the parametric UH with the characteristic of the watershed. Unit Hydrograph can be develop from the condition and date of the watershed. For example, all synthetic unit hydrograph model is related to peak UH of drainage area to watershed hydrograph. Unit Hydrograph can be called as synthetic when total time base of UH is same with time of UH peak. Hence, rainfall and runoff data is very important in deriving a unit hydrogrph. There are 3 categories of Synthetic Unit Hydrograph which is Snyder's UH (based on characteristics of UH), SCS UH (relate to dimensionless of UH) and Clark's UH which is related to quasi-conceptual of watershed storage.

2.5.3.2 Snyder's UH Method

U.S. Army Corp of Engineer said the synthetic unit hydrograph of Snyder (1938) is based on relationships found between three characteristics of a standard unit hydrograph and descriptors of basin morphology. The hydrograph characteristics are the effective rainfall duration (t_r), the peak direct runoff rate (q_p), and the basin lag time (t_1). From these relationship, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated which is the peak discharge per unit of watershed area (q_{pR}), the basin lag(t_{1R}), the base time(t_b) and the width(W) of the hydrograph at 50 and 75 percent of the peak discharge.

Standard unit hydrograph is associated with specific effective rainfall duration (t_r) defined by the following relationship with basin lag (t_1),

$$T_1 = 5.5\, t_r \tag{2.3}$$

For the standard unit hydrograph, the peak discharge, Q_p defined by the relationship with basin lag, t_1

$$Q = C\, Cp\, A / t_1 \tag{2.4}$$

Where :

A = basin area (km^2)

C = conversion constant (2.75 for SI)

Cp = UH peaking coefficient.

2.5.3.3 Soil Conservation Service (SCS)

In 1972 the U.S Soil Conservation Service suggested an empirical model for rainfall abstractions which is based on the potential for the soil to absorb a certain amount of moisture. On the basis of field observations, the potential storage S (millimeters or inches) was related to a curve number (CN) which is a characteristic of the soil type, land use and the initial degree of saturation known as the antecedent moisture condition.

$$S = (25400/CN) - 254 \quad (2.5)$$

Typical values for the SCS Curve Number (CN) as a function of soil type, land use and degree of saturation can be found in most texts on hydrology

Values of CN estimated in this way are intended to be applied to the total catchment assuming other parameter to be the same for both pervious and impervious areas. Many programs compute the runoff from pervious and impervious fractions separately and then add the two hydrographs.

2.5.3.4 Clark's UH Method

Clark's Unit Hydrograph differ from the other synthetic UH method because it is an instantaneous unit hydrograph which is has no duration. Clark defined the runoff is related to uniformly generate excess precipitation. So, Clark's UH has two processes in the transformation of excess precipitation to runoff which is translation and attenuation. Translation is a condition where excess precipitation moves from original drainage to the watershed outlet while attenuation is a condition where the magnitude of discharge is reduced and stored in the watershed.

Parameters used in this method are related to muskingum hydrograph routing. Clark states that valley storage and flood routing is at great length. So, Clark used this technique to determine the number of gauge basin.

Lastly, basin storage is the main factor in the formation of attenuation of hydrograph. The parameter used to calculate attenuation imposed by storage of basin storage coefficient (R) and time of concentration (T_c).

2.6 PARAMETER OF ANALYSIS RAINFALL AND RUNOFF DATA

2.6.1 Time of Concentration, T_c and storage, R

Equations relating Tc, R and catchment characteristics are required to estimate Tc and R for ungauged catchments. A multiple linear regression program was used to determine the mathematical relationships of Tc and R with catchment characteristics such as area, slope and length of mainstream for the 43 catchments of Peninsular Malaysia. Generally, Tc and R are correlated to catchment size, slope and main stream length, and slope and main stream length only, it was found that overall Tc and R correlate better with catchment size, stream slope, and main stream length.

For simplicity and consistency, equations relating Tc and R and catchment area, stream slope, and main stream length are used to estimate Tc and R for this procedure. Results are:

$$Tc = 2.32\, A^{-0.1188}\, L^{0.9573}\, S^{-0.5074} \qquad (2.6)$$

$$R^2 = 0.7883$$

$$SE = 0.2116$$

Where :

A = catchment area (km^2)

L = main stream length (km)

S = weighted slope of main stream (m/km)

The catchments were subdivided into east and West Coast catchments and the same multiple linear correlations carried out to derive Tc and R on a regional basis, it was found that no better correlations can be obtained. Attempts to obtain better correlations by further dividing the catchments into smaller regional groups for regression analysis are not successful.

2.6.2 Lag

Lag is the delay between the time runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. Conceptually, lag may be thought of as a weighted time of concentration where, if for a given storm, the watershed is divided into bands of area, the travel times from the centroids of the areas to the main watershed outlet may be represented by the following relationship:

$$L = \sum(a_x Q_x T_{tx}) / A Q_a \tag{2.7}$$

Where :

L	=	lag (h)
A_x	=	incremental of watershed area (mi2)
Q_x	=	runoff from area a_x (in)
T_{tx}	=	travel time from the centroid of a_x to the references point (h)
A	=	total area of the watershed above the references point (mi2)
Q_x	=	total runoff (in)

2.6.3 Design Baseflow

A baseflow is required to derive the total design hydrograph. It is difficult to predict the statistical characteristics of baseflow prior to a major flood. For this study, baseflows of the recorded hydrographs for the catchments before the occurrence of the floods were averaged and plotted. Baseflows were taken for rather dry and moderate wet antecedent catchment conditions. A best fit equation was derived for general use. The equation is:

$$Q_B = 0.11\, A^{0.85889} \tag{2.8}$$

Where :

Q_B	=	Baseflow (m^3/s)
A	=	Catchment area (km^2)

2.6.4 Relationship Between Lag and Time of Concentration

Various researchers found that for average natural watershed conditions and an approximately uniform distribution of runoff:

$$L = 0.6\ T_c \tag{2.9}$$

Where :

L	=	Lag, h
T_c	=	Time of Concentration, h

2.7 HEC-HMS

2.7.1 Introduction

The Hydrological Modeling System (HEC-HMS) is a software and tool for use in analyzing, planning and stimulating the process of rainfall and runoff. It is a new program of hydrologicam modeling from Hydrologic Engineering Center's (HEC) to stimulate the hydrological process of the watershed system (M.L Ramli and S. Harun, 2009). The major problem in Malaysia due to hydrological problem is flooding. Thus, HEC-HMS is effective to use in wide geographical areas like Malaysia to prevent and solve problem.

Hydrological modeling reveals how precipitation responds to natural watershed runoff. For example, the peak discharge, quantity of runoff and detention. (X. Chu and A. Steinman, 2009)

2.7.2 Parameter Estimation

Generally, in order to verify and calibrate the HEC-HMS hydrologic model, there are four types of precipitation event have been choosen. All of the events are organized and separated into two main sections which is continuous hydrologic model and HEC-HMS event model. (J. M. Canderlik and S. P. Simonovic, 2004). In the continuous HEC-HMS model, calibrated parameter is selected to analyze surface runoff from basin such as Soil Moisture Accounting Method and Soil Conversation Service runoff curve number method. . (X. Chu and A. Steinman, 2009)

Besides, the other parameters have been used as HEC-HMS hydrologic model estimation are structure of model, analysis of sensitivity, result obtained and calibration and verification procedures.

2.7.3 HEC-HMS Simulation method

The HEC-HMS simulation methods, which are summarized in **Table 2.1** represent:

- Watershed precipitation and evaporation. These describe the spatial and temporal distribution of rainfall on and evaporation from watershed.
- Runoff volume. These address questions about the volume of precipitation that falls on the watershed.
- Direct runoff, including overland flow and interflow. These methods describe what happen as water that has not infiltrated or been stored on the watershed moves over or just beneath the watershed surface.
- Baseflow. These simulate the slow subsurface drainage of water from a hydrologic system into the watershed’s channels.
- Channel flow. These so called routing methods simulated one-dimensional open channel flow, thus predicting time series of downstream flow, stage, or velocity, given upstream hydrographs.

The HEC-HMS methods are described in greater details in the HEC-HMS Technical Reference Manual (USACE, 2000). That manual presents the concept of each method and the relevant equations that are included. It discusses solution of the equations and it addresses configuration and calibration of each method.

Table 2.1: Summary of simulation methods include in HEC-HMS

Category	**Methods**
Precipitation	User-specified hyetograph
	User-specified gage weighting
	Inverse-distance-squared gage weighing
	Gridded precipitation
	Frequency-based hypothetical storms
	Standard Project Storm (SPS) for eastern U.S.
	Soil Conversation Services (SCS) hypothetical storm
Evapotranspiration	Monthly average
	Priestly-taylor
	Gridded priestly-taylor
Snowmelt	Temperature index
	Gridded temperature index
Runoff volume	Initial and constant
	SCS curve number (CN)
	Gridded SCS CN
	Green and Ampt
	Exponential
	Smith Parlange
	Deficit and constant
	Gridded deficit and constant rate
	Soil moisture accounting (SMA)
	Gridded SMA
Direct runoff	User-specified unit hydrograph (UH)
	Clark's UH
	Snyder's UH

	SCS UH
	ModClark
	Kinematic wave
	User-specified s-graph
Baseflow	Constant monthly
	Exponential recession
	Linear reservoir
	Nonlinear boussinesq
Routing	Kinematic wave
	Lag
	Modified puls
	Muskingum
	Muskingum-cunge
Water control structures	Diversion
	Reservoir / detention pond

2.7.4 Model Components

Model components are used to simulate the hydrologic response in a watershed. The primary model components are basin models, meteorologic models, and control specifications. There are also input data components. A simulation calculates the precipitation runoff response in the basin model given input from the meteorologic model. The control specifications define the time period and time step of the simulation run. Input data components, such as time-series data, paired data, and gridded data are often required as parameter or boundary conditions in basin and meteorologic models.

2.7.4.1 Basin Model Components

The basin model represents the physical watershed. The user develops a basin model by adding and connecting hydrologic elements. Hydrologic elements use mathematical models to describe physical processes in the watershed. **Table 2.2** provides a list and description of available hydrologic elements.

Table 2.2: Hydrologic element description

Hydrologic Element	Description
Subbasin	The subbasin element is used to represent the physical watershed. Given precipitation, outflow from the subbasin element is calculated by subtracting precipitation losses, transforming excess precipitation to stream flow at the subbasin outlet and adding baseflow.
Reach	The reach element is used to convey stream flow downstream in the basin model. Inflow into the reach elements can come from one or many upstream hydrologic element. Outflow from the reach is calculated by accounting for translation and attenuation of the inflow hydrograph.
Junction	The junction element is used to combine stream flow from hydrologic element located upstream of the junction element. Inflow into the junction element can come from one or many upstream elements. Outflow is simply calculated by summing all inflows and assuming no storage at the junction.
Source	The source element is used to introduce flow into the basin model. The source element has no inflow. Outflow from the source element is defined by the user.
Sink	The sink element is used to represent the outlet of the physical watershed. Inflow into the sink element can come from one or many upstream hydrologic elements. There is no outflow from the sink element.
Reservoir	The reservoir element is used to model the detention and attenuation of a hydrograph caused by a reservoir or detention pond. Inflow into the reservoir element can come from one or many upstream hydrologic elements. Outflow from the reservoir element can be calculated three ways. The user can enter a storage-outflow, elevation storage-outflow, or elevation area-outflow relationship, or the user can enter en elevation storage or elevation-area relationship and define one or more outlet

	structure, or the user can specify a time-series of outflow.
Diversion	The diversion element is used for modeling stream flow leaving the main channel. Inflow into the diversion element can come from one or many upstream hydrologic elements. Outflow from the diversion element consist of diverted flow and non-diverted flow. Diverted flow is calculated using output from the user. Both diverted and non-diverted flows can be connected to hydrologic elements downstream of the diversion element

In the case of the subbasin element, many mathematical models are available for determining precipitation losses, transforming excess precipitation to stream flow at the subbasin outlet and adding baseflow. **Table 2.3** lists the methods available for subbasin and river reach elements.

Table 2.3: subbasin and reach calculation method

Hydrologic Element	Calculation Type	Method
Subbasin	Canopy	Dynamic canopy
		Simple canopy
		Gridded simple canopy
	Surface	Simple surface
		Gridded simple surface
	Runoff-volume	Deficit and constant rate (DC)
		Exponential
		Green and ampt
		Gridded DC
		Gridded SCS CN
		Gridded green and ampt
		Gridded SMA
		Initial and constant rate
		SCS curve number (CN)
		Smith parlange

		Soil moisture accounting (SMA)
	Direct-runoff	Clark's UH
		Kinematic wave
		ModClark
		SCS UH
		Snyder's UH
		User-specified s-graph
		User-specified unit hydrograph (UH)
	Baseflow	Bounded recession
		Constant monthly
		Linear reservoir
		Nonlinear boussinesq
		Recession
Reach	Routing	Kinematic wave
		Lag
		Modifies puls
		Muskingum
		Muskingum-cunge
		Straddle stagger
	Loss / gain	Constant
		Percolation

2.7.5 HEC-HMS Interface

The HEC-HMS interface consists of a menu bar, tool bar and four main panes. Starting from the upper left pane in **Figure 2.6** and moving counter-clockwise, these panes will be referred to as the Watershed Explorer, the Component Editor, the Mesaage Log and the Desktop.

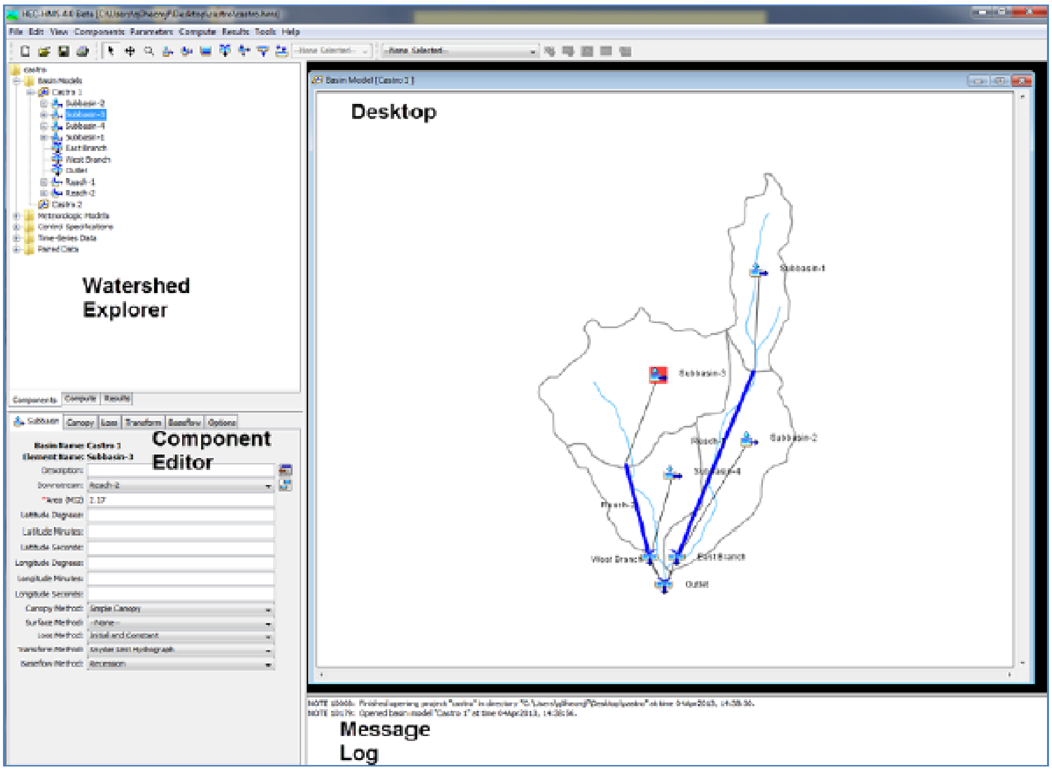

Figure 2.6: HEC-HMS interface

2.7.5.1 Watershed Explorer

The Watershed Explorer was developed to provide quick access to all components in an HEC-HMS project. For example, the user can easily navigate from a basin model to a precipitation gage and then to a meteorologic model without using menu options for opening additional windows. The Watershed Explorer is divided into three parts which is Component, Compute and Result. The arrow in **Figure 2.7** points the "components" tab of the Watershed Explorer. The hierarchal structure of model components, such as basin model, meteorologic model, etc is available from the "components" tab of the Watershed Explorer. The Watershed Explorer organizes model components into individual folders. When a component is selected, the Watershed Explorer expands to show sub-components. For example, when a basin model is selected the Watershed Explorer will expand to show all hydrologic elements in the basin model. Notice in **Figure 2.7** that the basin model is selected and the Watershed Explorer is expanded to show all hydrologic elements in the basin model. The plus/minus sign beside model components and sub-components can be used to expand/collapse the Watershed Explorer. All project simulation run, optimization trials, and analyse are accessed from the "compute" tab of the Watershed Explorer. Model results are available from the "resuls" tab of the Waterhed Explorer. Result from different simulations can be compared in the same graph or table.

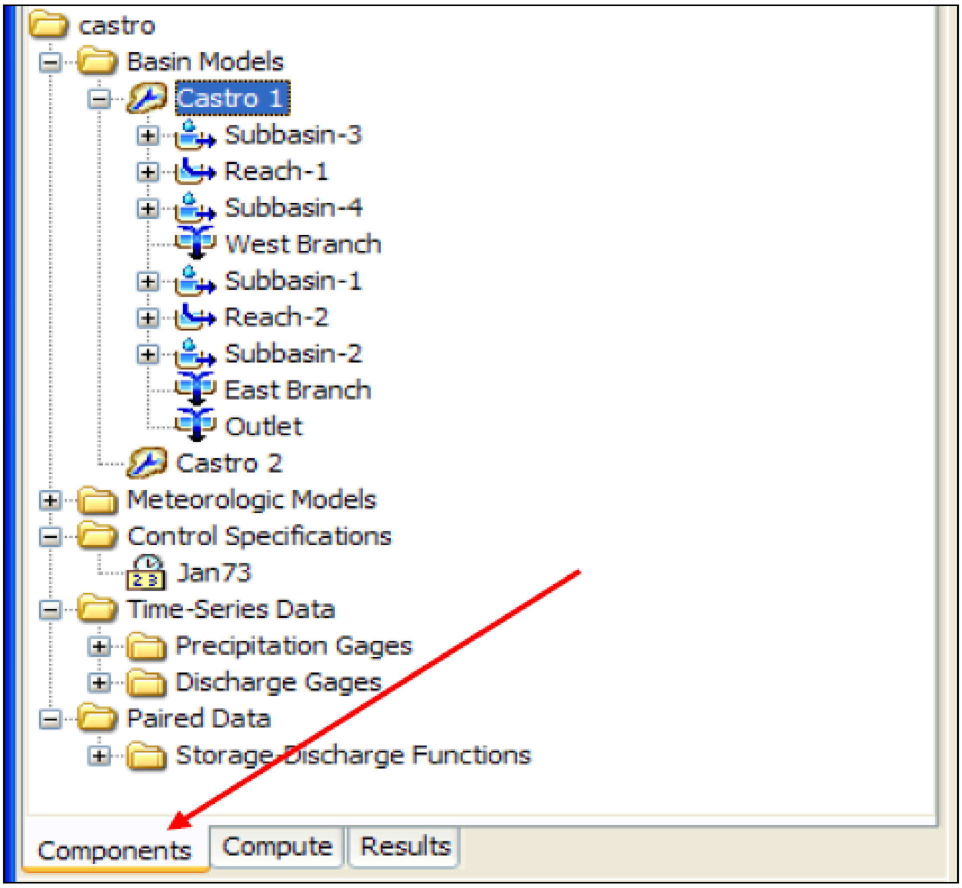

Figure 2.7: Watershed Explorer showing components in the project

2.7.5.2 Component Editor

When a component or sub-component in the Watershed Explorer is active, a specific Component Editor will open. All data that can be specified in the model component is entered in the Component Editor. Any required data will be indicated with a red asterisk. For example, parameter data for the SCS curve number method is entered in the Component Editor for a subbasin element. The component Editor for the basin model in shown in **Figure 2.8.**

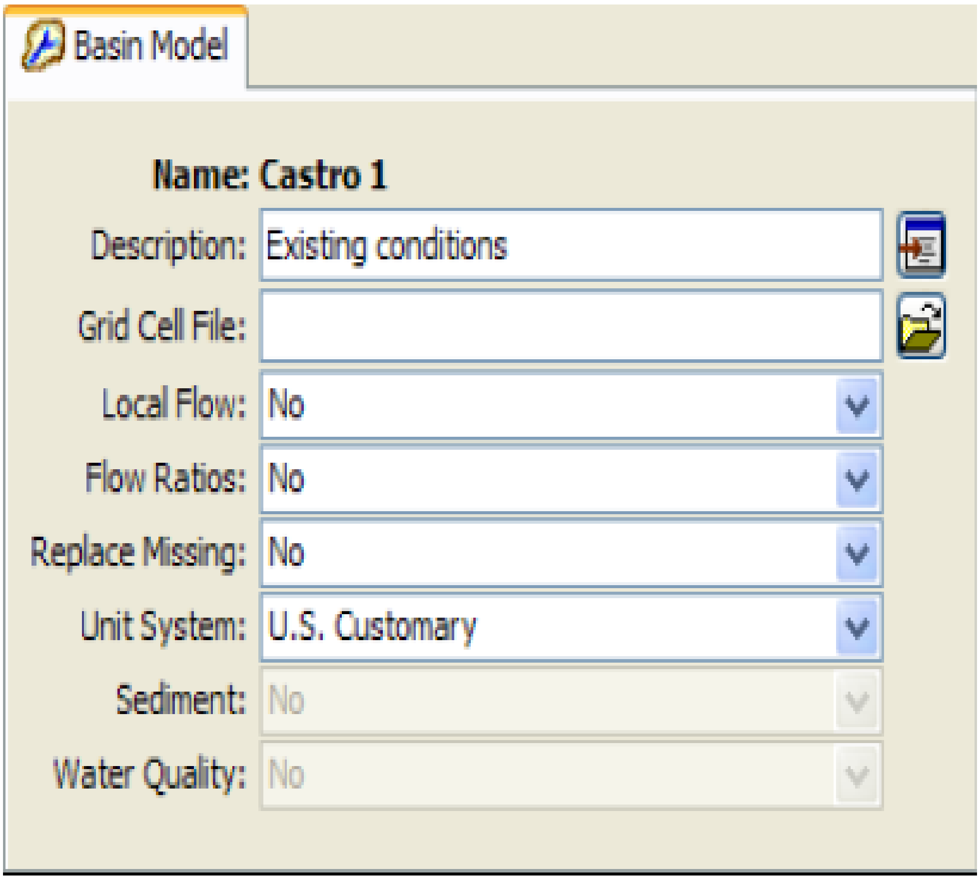

Figure 2.8: Component editor for a basin model

2.7.5.3 Message Log

Notes, warning, and errors are shown in the Message Log as in **Figure 2.9.** These messages are useful for identifying why a simulation run failed or why a requested action, like opening a project, was not completed. A comprehensive list and description of messages will be provided in future documentation.

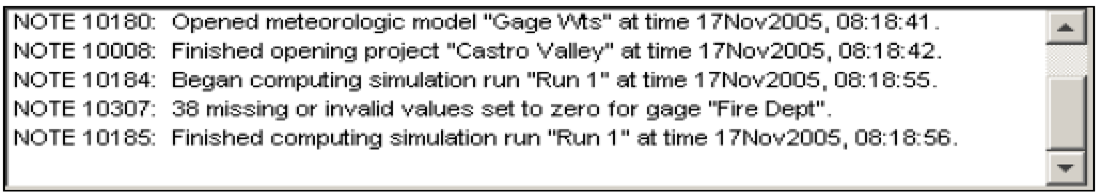

Figure 2.9: Message log

2.7.5.4 Desktop

The Desktop holds a variety of windows including summary tables, time-series tables, graphs, global editors and the basin model map. Results are not confined to the desktop area. A program settings option will allow results to be displayed outside the desktop area. The basin model map is confined to the desktop. The basin model map is used to develop a basin model. Elements (subbasin, river reach, reservoir, etc) are added from the toolbar and connected to represent the physical drainage network of the study area. Background maps can be imported to help visualize the watershed. The basin model map is shown in **Figure 2.10.**

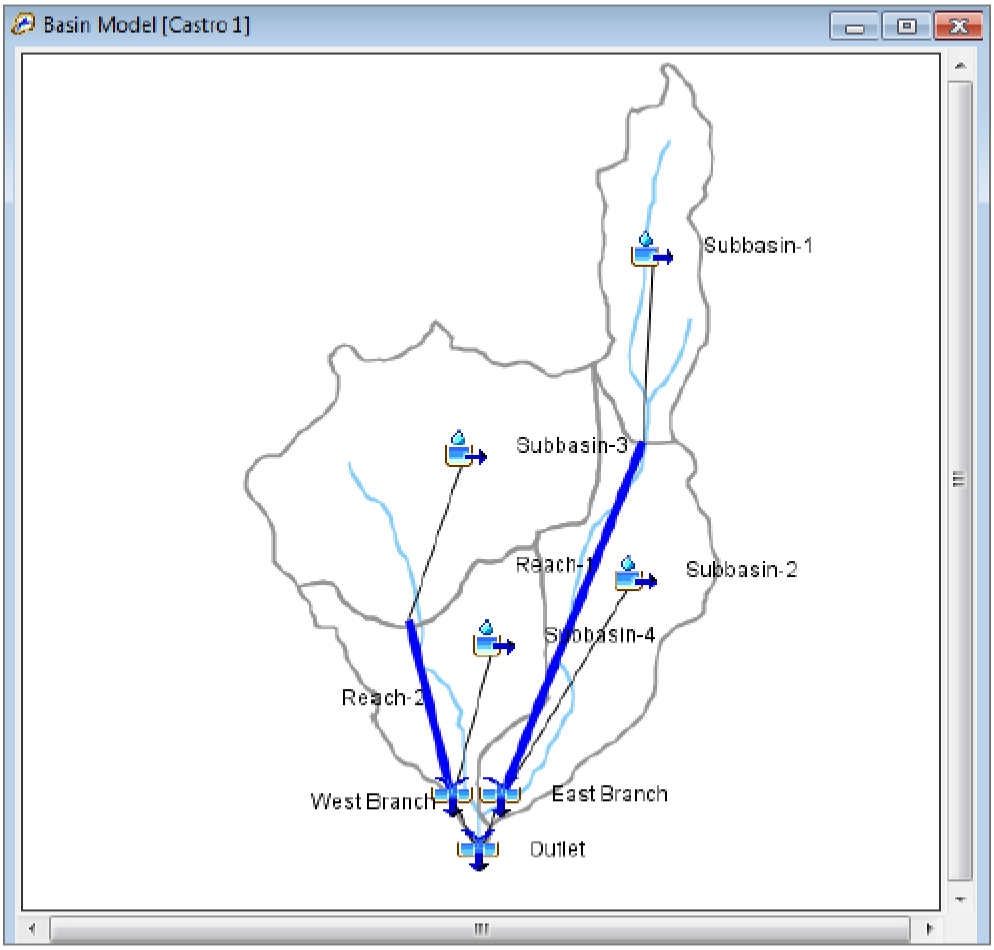

Figure 2.10: Basin model map opened in the desktop

2.7.6 Computation Result

There are many ways to compute the result of precipitation and runoff from HEC-HMS data. The result of stimulation can be generated in summary table, time series table and hydrograph. Generally, all data have been collected in the form of collection and those values are called as grid or raster. In order to predict HEC-HMS model, correlation of coefficient ($R^{2)}$ have to be used. The result is considered as satisfactory and good if the R^2 value close 1.0 respectively. (M.L Ramli and S. Harun, 2009).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This research is conducted for the porpose of study of development of the rainfall-runoff relationship. With the aim to determine how rainfall responds to watershed runoff, a few methodologies as shown in the flow chart **Figure 3.1** have been practiced:

- Read and go through the literature review in order to understand the relationship between precipitation and runoff
- Collection of data for rainfall distribution and runoff distribution for 15 year from 1999 - 2014
- Data analysis using HEC-HMS

This chapter discussed the full progression that was used for this research.

Rainfall and runoff data is important to analyze in order to achieve goals of this research. These data are collected every 24 hours, every day for 15 years in the study catchment area.

3.2 FLOW CHART OF METHODOLOGY

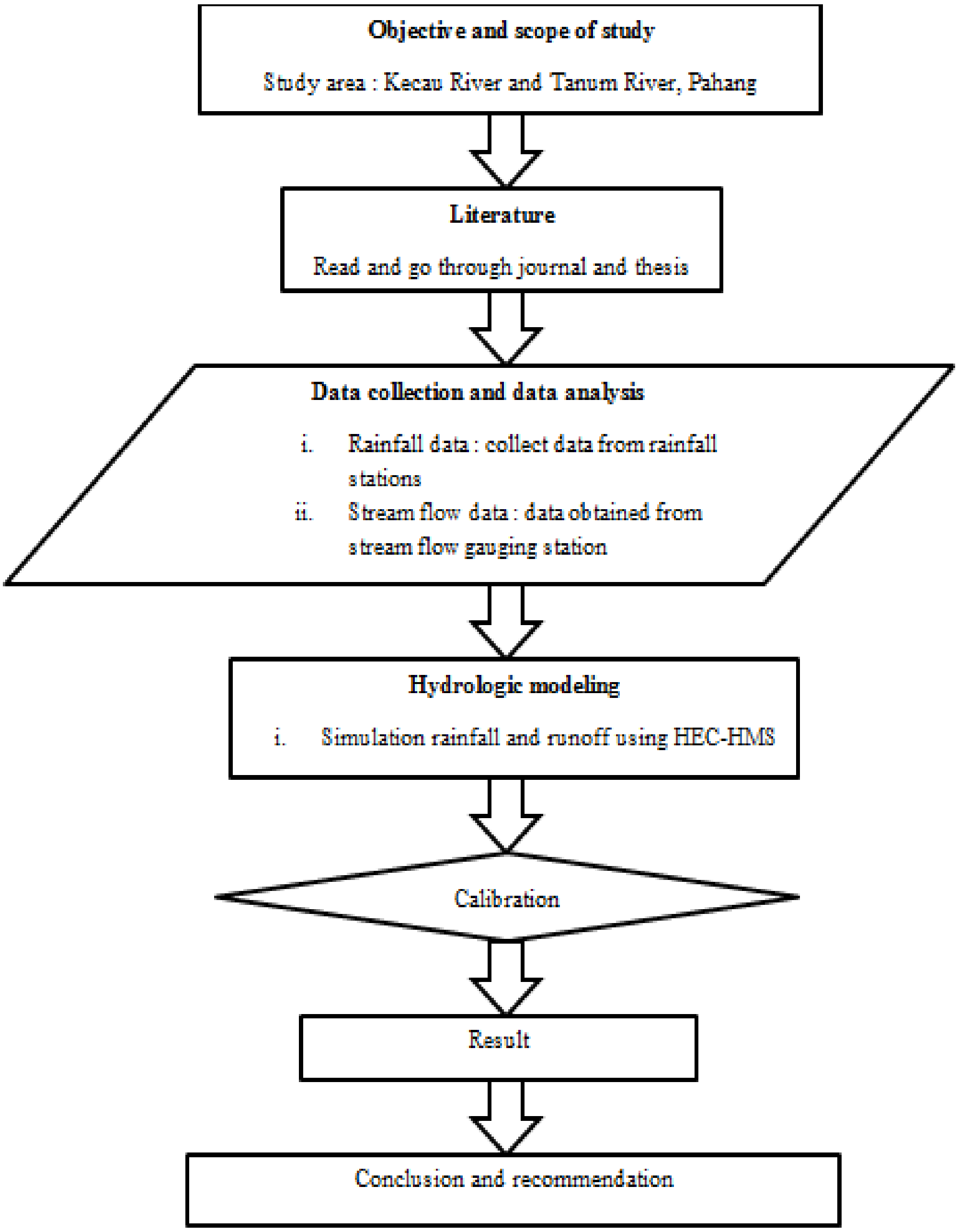

Figure 3.1: Flow chart of methodology

3.3 STUDY AREA

The study area to determine rainfall-runoff relationship using Hydrological Modeling System (HEC-HMS) is at Kecau River and Tanum River with 61.5 km long and Tanum River with 12.5 km long. These two rivers are located at Pahang. Rainfall station and stream flow gauge station used in this research are located along Kecau River and Tanum River.

Figure 3.2: Kecau River

Figure 3.3: Tanum River

3.4 DATA COLLECTION

The important data needed to have in this research are rainfall data and stream flow data. Data collection is very important for use analyzing, planning and stimulating rainfall and runoff process. All the data were taken every 24 hours. To analyze data from rainfall and stream flow, there are two equipments used in this research.

3.4.1 Rainfall Data

To determine the rainfall data and calibrate the model, suitable rainfall station should be determined first along the study catchment area. There are 3 rainfall station in Kecau River and Tanum River have been identified and all the data station with station no 4620045, 4319048 and 4320066 have been selected in order to determine rainfall data. For simulation of hydrograph, daily rainfall data have been used. Daily rainfall data, water level data and stream flow data are obtained from Jabatan Pengairan dan Saliran Ampang (JPS).

3.4.2 Stream Flow Data

There is 1 stream flow gauging station have been recognized in the study catchment area along Kecau River. Stream flow data was collected for 15 years. Location of stream flow station is at the station no 4320401. From this stream flow, runoff data can be obtained.

3.5 METHOD OF SIMULATION RAINFALL-RUNOFF DATA IN HEC-HMS

The Hydrologic Modeling System is designed to stimulate the hydrological process of the watershed system. The major problem in Malaysia due to hydrological problem is flooding. Thus, HEC-HMS is effective to use in wide geographical areas like Malaysiato prevent and solve flooding problem. Hydrograph will be produced from this software to be compared.

3.5.1 Clark Unit Hydrograph Method

Clark Unit Hydrograph method is one of the methods used in Unit Hydrograph. The Clark unit hydrograph requires three parameters to calculate a unit hydrograph which is the time of concentration for the basin (Tc), a storage coefficient (R) and a time-area curve. A time-area curve defines the cumulative area of the watershed contributing runoff to the subcatchment outlet as a function of time (expressed as a proportion of Tc).

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the data collection was analyzed in order to achieve the research objectives. There are one rainfall station and one stream flow gauging station were selected for Kecau River and two rainfall station were selected for Tanum River. The data from the both river was keyed in into the HEC-HMS software to analyze by using Clark Unit Hydrograph Method. The simulation of Kecau River is occur at stream flow station. Since Tanum River does not have stream flow station, calibration from stream flow of Kecau River is apply to Tanum River since both river is near and have same characteristic.

From the graph of analysis, the shape of the modeled hydrograph generally follows the observed hydrograph. Rainfall and runoff were used to calibrate and validate the HEC-HMS. The summary is produced to summarize the findings.

4.2 HEC-HMS LAYOUT MODEL FOR KECAU RIVER

The HEC-HMS layout model of Kecau River from Autocad and HEC-HMS is shown in **Figure 4.1.** For Kecau River, the observed discharged data recorded at Kg Dusun, Pahang (4320401)

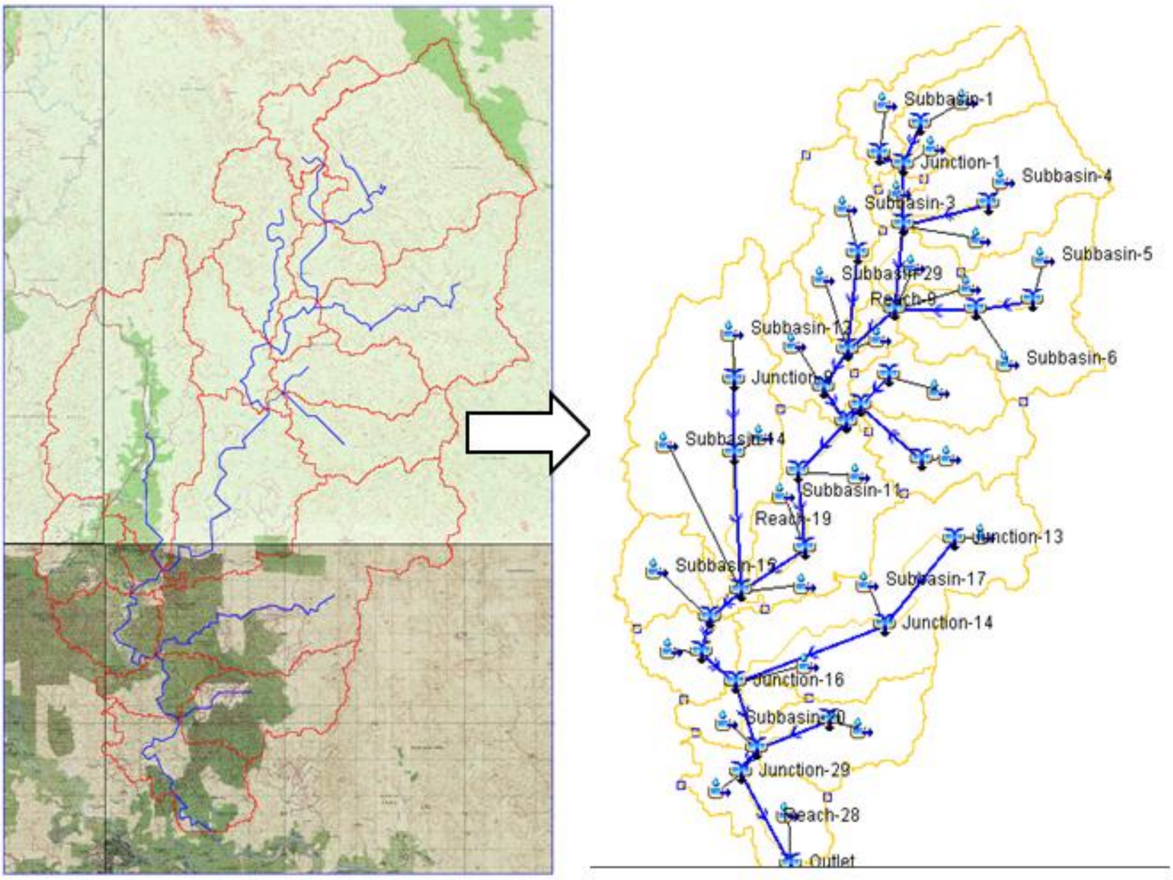

Figure 4.1: HEC-HMS layout model for Kecau River

4.3 RAINFALL AND RUNOFF RELATIONSHIP ANALYSIS FOR KECAU RIVER

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall events such as type of rainfall, duration, intensity and distribution. Clark Unit Hydrograph Method is used to analyze the data of rainfall and runoff for Kecau. The data is simulated at streamflow station which is Kg Dusun, Pahang (4320401) for month by month. Below is the analysis for rainfall runoff relationship for Kecau River from the 1999-2014. However, only the best graph is chosen. All the data based on simulated hydrograph and was taken every 24 hours.

Table 4.1: Summary data for analysis for Kecau River at station Kg Dusun, Pahang (4320401)

Year	Month	Qmax (m^3/s)
1999	May	44.1
2000	April	103.3
2001	January	32.7
	March	48.4
	April	64.3
2002	May	50.4
	November	34.8
2003	March	60.0
	April	37.6
	July	60.5
2009	November	54.2
2010	January	54.2
	May	108.2
	Jun	52.6
	July	37.8
	November	57.6
2011	January	66.3

In May 1999, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 107.27 m^3/s and the simulated flowrate is 60.0 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.2.**

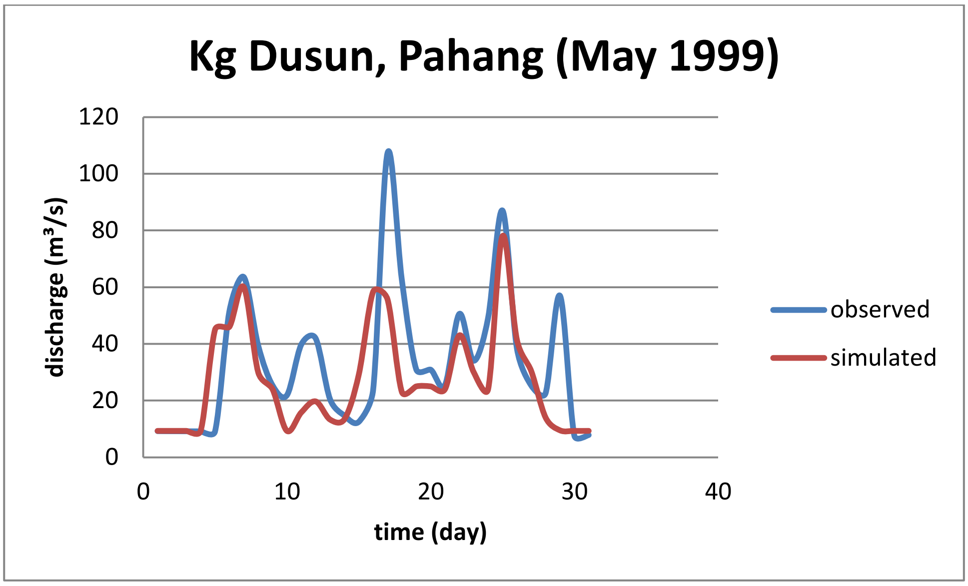

Figure 4.2: Runoff hydrograph Kg Dusun, Pahang (4320401) in May 1999

In April 2000, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 166.3 m^3/s and the simulated flowrate is 103.3 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.3.**

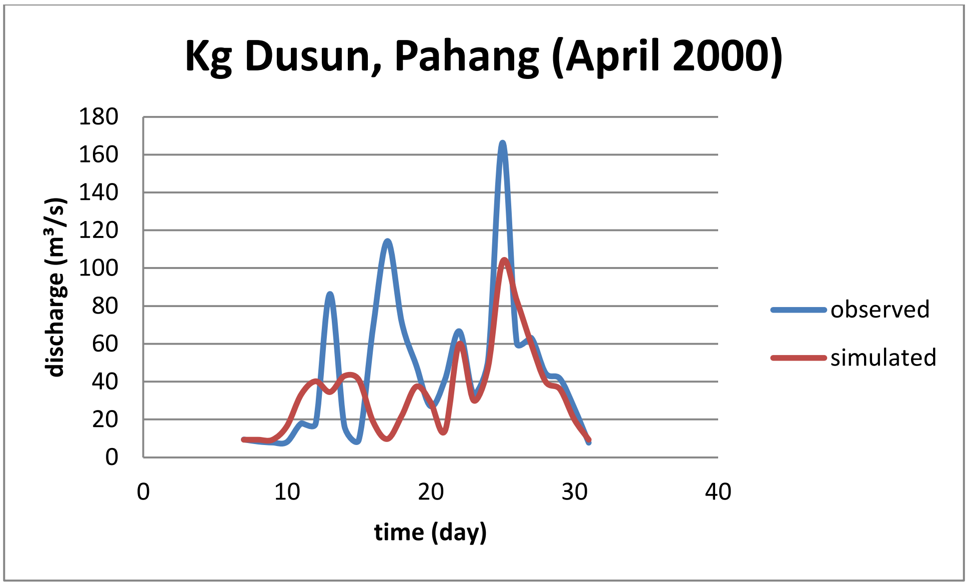

Figure 4.3: Runoff hydrograph Kg Dusun, Pahang (4320401) in April 2000

In January 2001, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 24.7 m^3/s and the simulated flowrate is 32.7 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.4.**

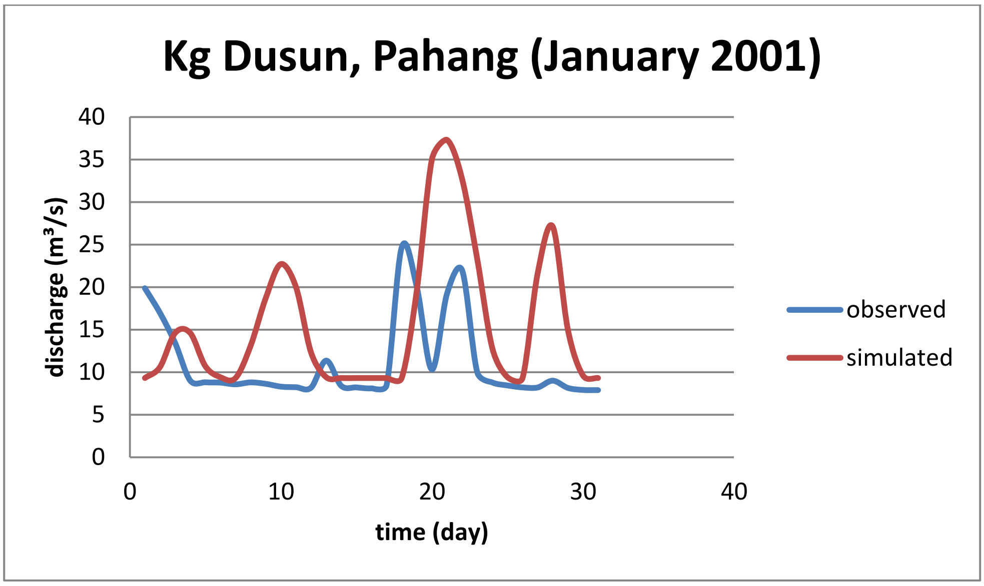

Figure 4.4: Runoff hydrograph Kg Dusun, Pahang (4320401) in Jan 2001

In March 2001, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 65.0 m^3/s and the simulated flowrate is 48.4 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.5.**

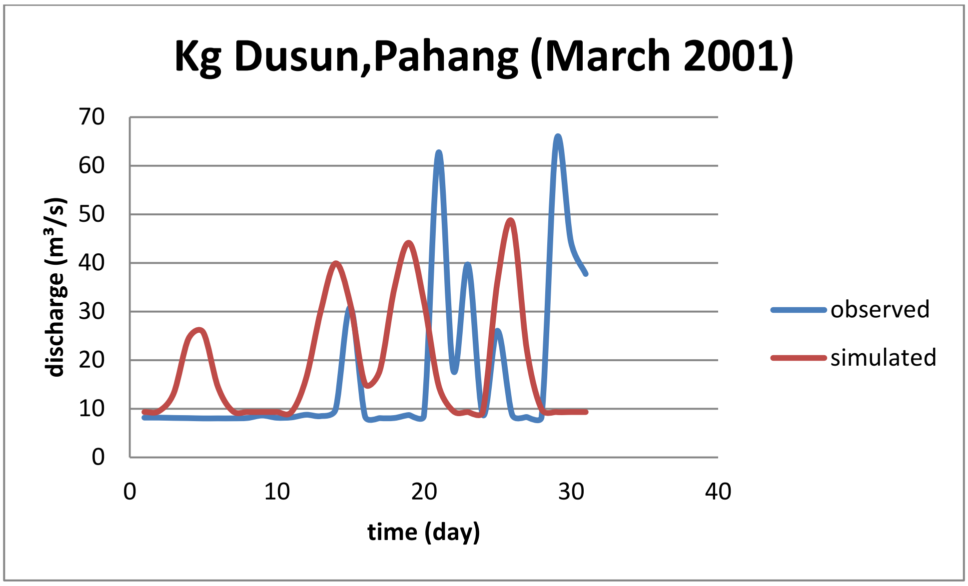

Figure 4.5: Runoff hydrograph Kg Dusun, Pahang (4320401) in March 2001

In May 2002, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 33.3 m^3/s and the simulated flowrate is 50.4 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.6.**

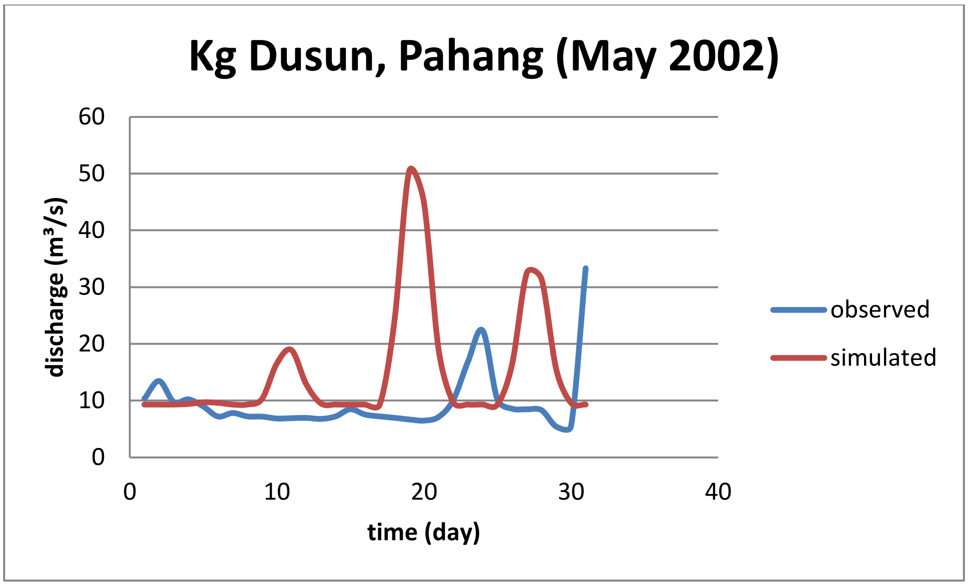

Figure 4.6: Runoff hydrograph Kg Dusun, Pahang (4320401) in May 2002

In November 2002, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 44.0 m^3/s and the simulated flowrate is 34.8 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.7.**

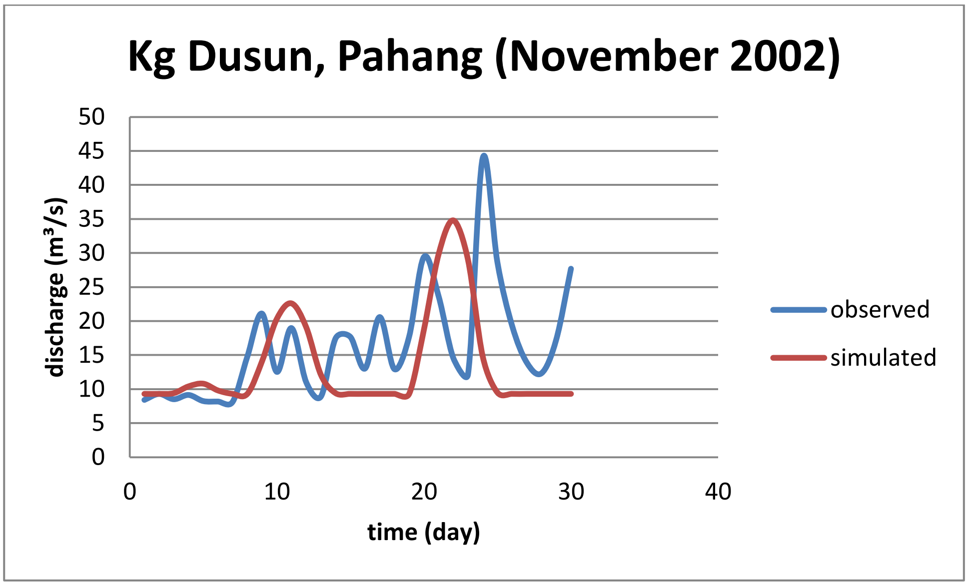

Figure 4.7: Runoff hydrograph Kg Dusun, Pahang (4320401) in Nov 2002

In March 2003, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 36.3 m^3/s and the simulated flowrate is 60.0 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.8.**

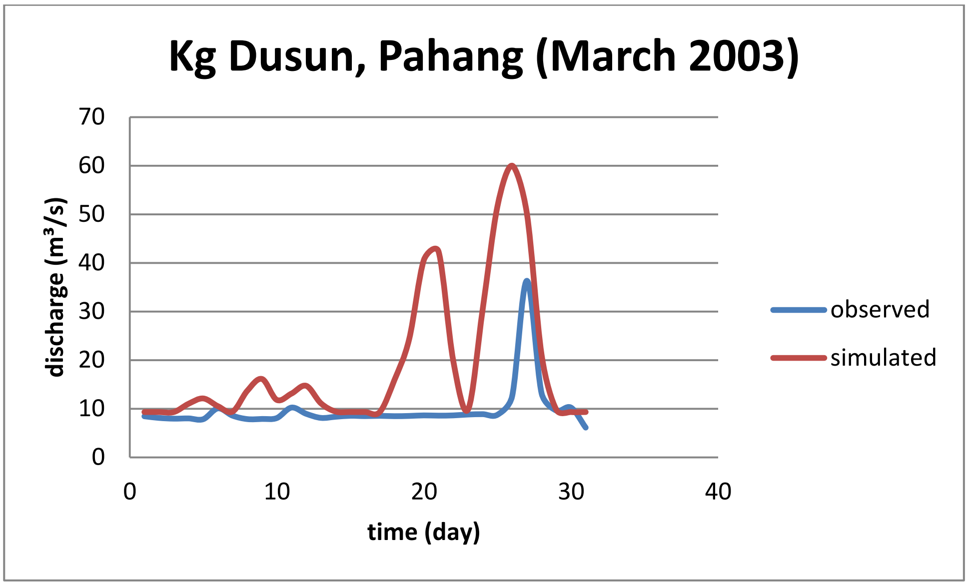

Figure 4.8: Runoff hydrograph Kg Dusun, Pahang (4320401) in Mar 2003

In April 2003, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 34.8 m^3/s and the simulated flowrate is 37.6 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.9.**

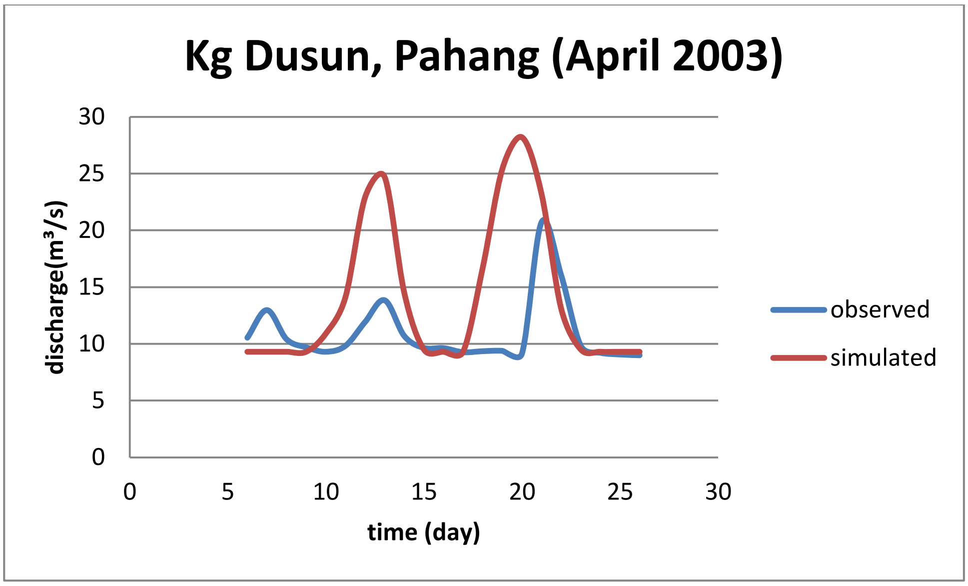

Figure 4.9: Runoff hydrograph Kg Dusun, Pahang (4320401) in Apr 2003

In July 2003, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 41.8 m^3/s and the simulated flowrate is 60.5 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.10.**

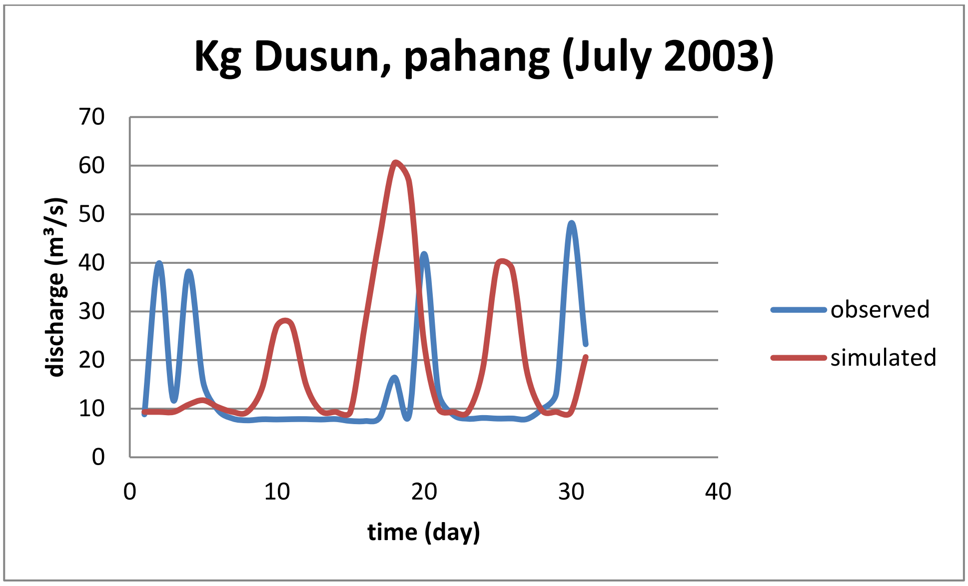

Figure 4.10: Runoff hydrograph Kg Dusun, Pahang (4320401) in July 2003

In November 2009, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 71.7 m^3/s and the simulated flowrate is 54.2 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.11.**

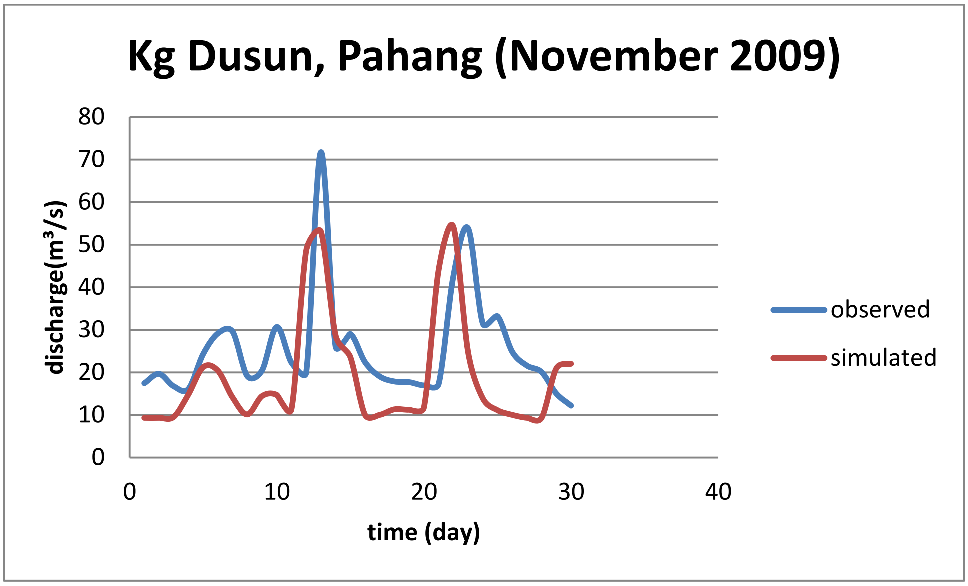

Figure 4.11: Runoff hydrograph Kg Dusun, Pahang (4320401) in Nov 2009

In January 2010, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 161.1 m^3/s and the simulated flowrate is 54.2 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.12.**

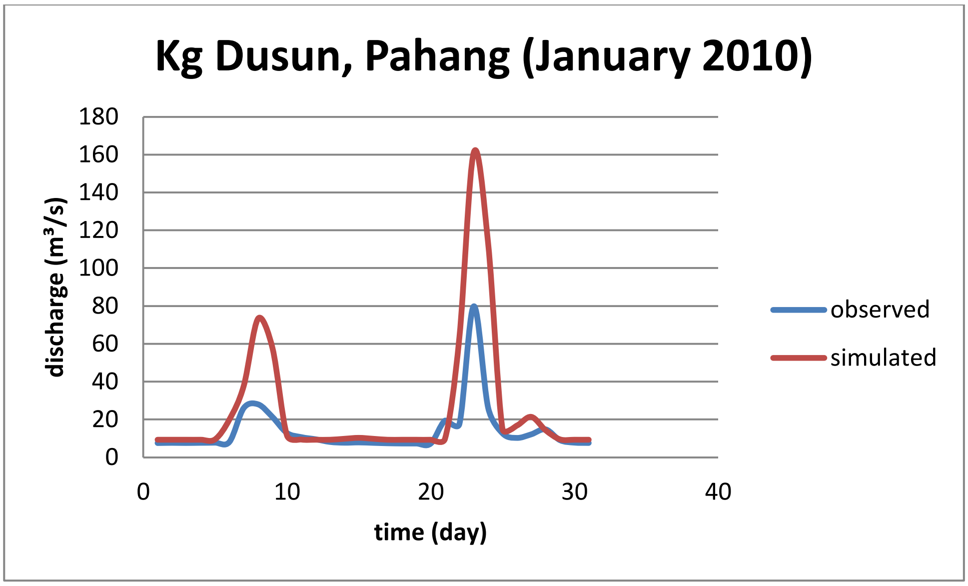

Figure 4.12: Runoff hydrograph Kg Dusun, Pahang (4320401) in Jan 2010

In May 2010, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 44.3 m^3/s and the simulated flowrate is 108.2 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.13.**

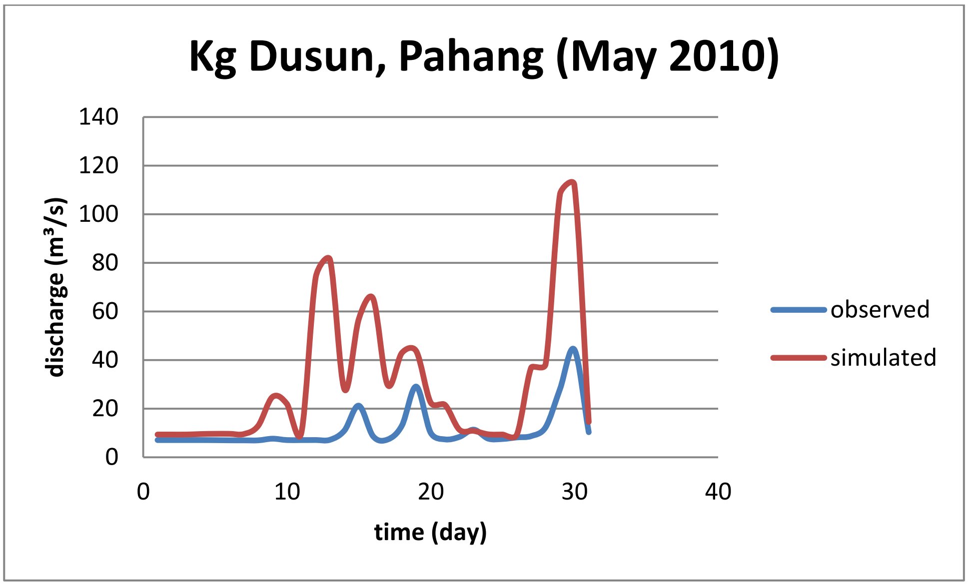

Figure 4.13: Runoff hydrograph Kg Dusun, Pahang (4320401) in May 2010

In Jun 2010, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 81.5 m^3/s and the simulated flowrate is 52.6 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.14.**

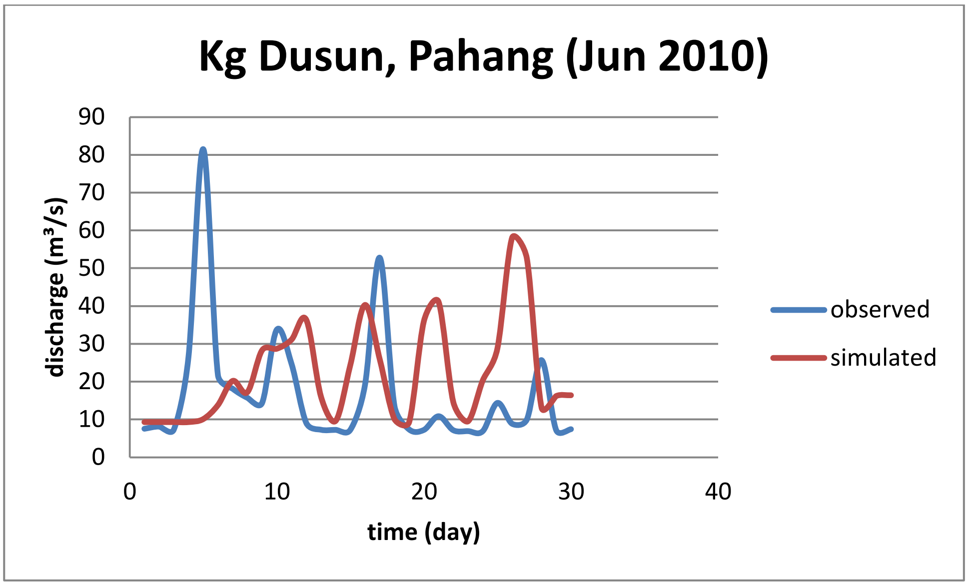

Figure 4.14: Runoff hydrograph Kg Dusun, Pahang (4320401) in Jun 2010

In July 2010, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 56.8 m^3/s and the simulated flowrate is 37.8 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.15.**

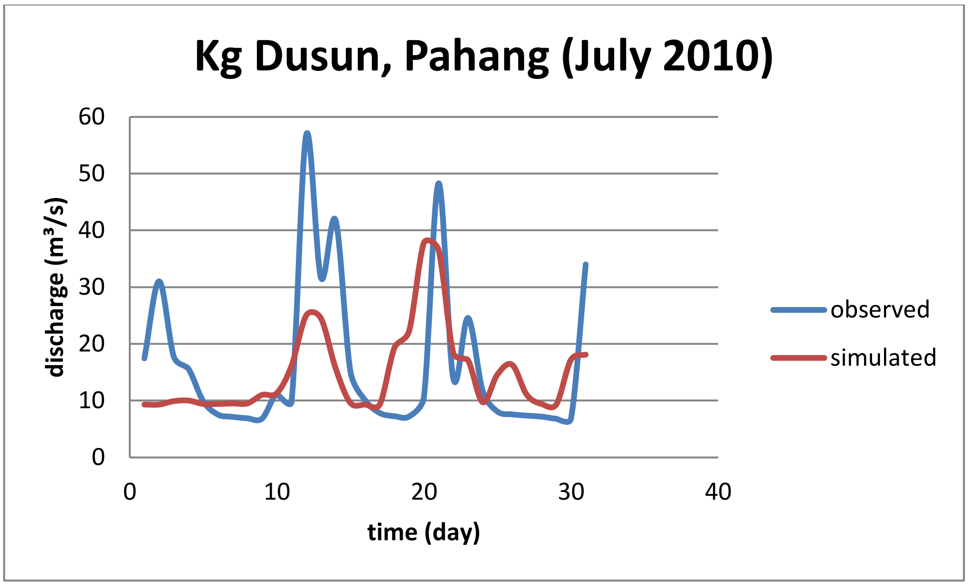

Figure 4.15: Runoff hydrograph Kg Dusun, Pahang (4320401) in Jul 2010

In November 2010, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 83.4 m^3/s and the simulated flowrate is 57.6 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.16.**

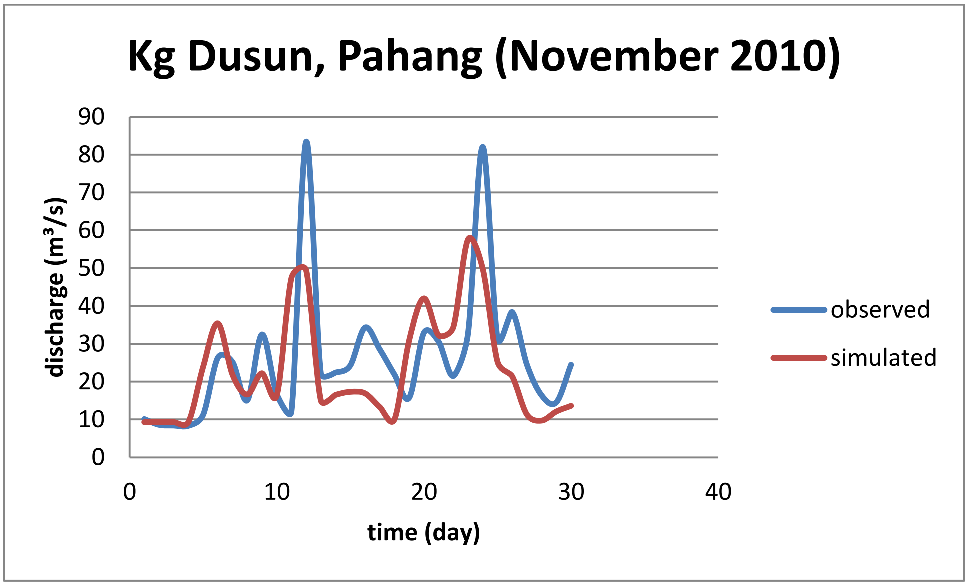

Figure 4.16: Runoff hydrograph Kg Dusun, Pahang (4320401) in Nov 2010

In January 2011, the rainfall and streamflow data were collected from 12.00 am that day until 12.00 am another day. The maximum observed flowrate is 62.5 m^3/s and the simulated flowrate is 66.3 m^3/s for Kg Dusun, Pahang (4320401). The comparison between observed and simulated hydrograph shown in **Figure 4.17.**

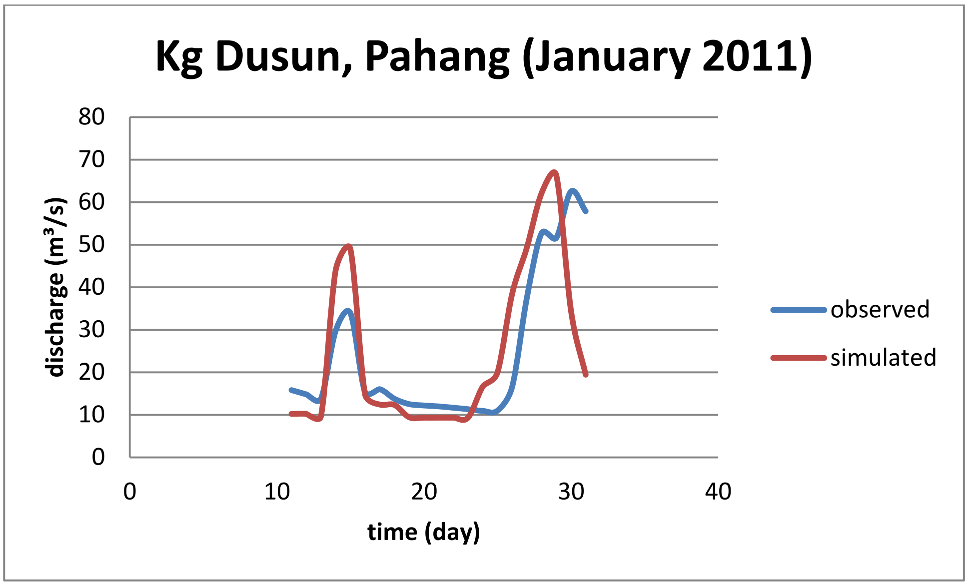

Figure 4.17: Runoff hydrograph Kg Dusun, Pahang (4320401) in Jan 2011

4.4 ANALYSIS AND SIMULATION FOR KECAU RIVER

This process will be carried out according to the data and parameter that was keyed in HEC-HMS. The result shown in graphic and summary are obtained after simulate and analyze all the data. To view the result of the modeling, click at any point that need to simulate and click to view result in term of graph, summary table and time series table.

Data required during analysis and simulation process are topography map that can be get from Jabatan Ukur dan Pemetaan Malaysia (JUPEM), rainfall data and stream flow data that can be get from Jabatan Pengaliran dan Saliran (JPS).

The next process is calibration. Calibration is the process to determine parameter used which can be describe the model. Parameter used during calibration process during calibration process are initial abstraction, curve number, impervious area, time of concentration, storage coefficient, baseflow and lag time. This process will be carried out by using loss rate, transform and baseflow method.

4.4.1 Model Parameter

Parameter is the important thing during keyed in data to get the result.The parameter used were SCS Curve Number (Loss Method), Clark Unit Hydrograph (Transform Method), and Constant Monthly (Baseflow Method) as shown in **Figure 4.18.**

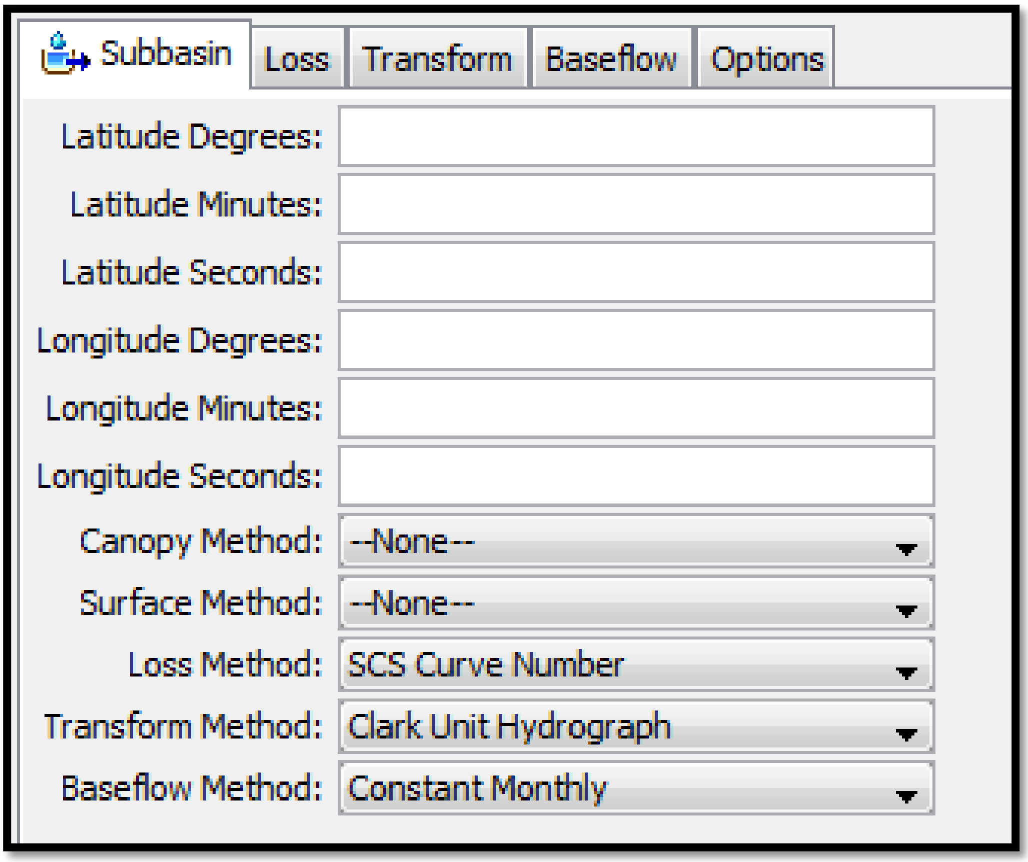

Figure 4.18: Parameter used in HEC-HMS at Kecau River

4.4.1.1 Loss Rate

In loss rate there are three parameters that need to consider which is initial abstraction, curve number and impervious area.

Curve number can be determine by using soil hydrologic type classification with soil map and land use type classification table with land use map**.** The example of loss rate parameter used is shown in **Figure 4.19.**

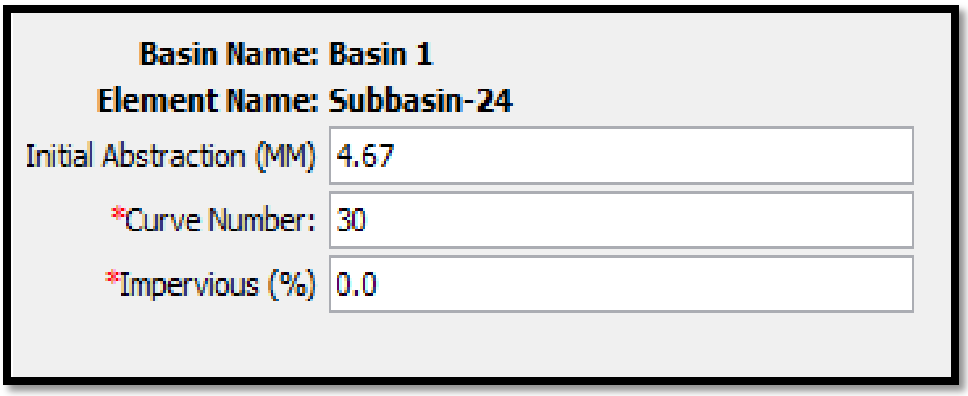

Figure 4.19: example of loss rate of parameter used for Kecau River

4.4.1.2 Transform

Time of concentration (Tc) and storage coefficient (R) were the parameter used in transform method which is different according to subbasin area.

Table 4.2: Transform Parameter for Kecau River

subbasin	A	Tc	R
1	17.16	1.21	0.32
2	12.57	2.44	0.77
3	24.38	2.17	0.44
4	79.21	1.09	0.10
5	86.31	20.91	1.46
6	63.46	9.74	0.90
7	68.97	6.48	0.60
8	30.38	3.65	0.57
9	26.34	5.23	0.86

10	31.68	4.20	0.67
11	54.45	20.37	1.91
12	23.50	4.22	0.75
13	17.02	7.72	1.68
14	37.94	18.32	2.33
15	38.94	5.51	0.75
16	50.17	3.74	0.45
17	19.03	2.00	0.44
18	8.50	0.63	0.24
19	13.53	0.85	0.24

4.4.1.3 Baseflow

The parameter used in baseflow method is constant monthly. **Figure 4.20** show the example of parameter used in this research.

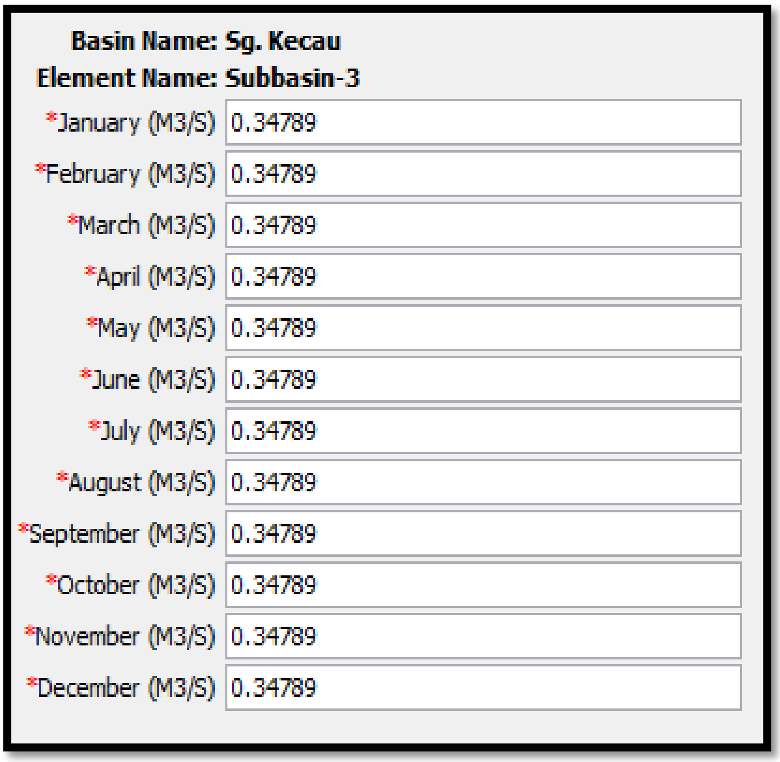

Figure 4.20: Constant baseflow for subbasin 3

4.4.1.4 Lag Time

In HEC-HMS, the parameter used for reach is lag time. Lag time used for Kecau River is shown in **Table 4.3**.

Table 4.3: Lag time for Kecau River

Reach	Lag time
1	5.0573
2	11.4527
3	39.9247
4	61.5873
5	22.7097
6	23.7256
7	5.3068
9	39.7945
10	8.2844
11	143.8193
12	4.6262
13	22.1040
14	24.6099
15	10.9122
16	45.5011
17	20.9198
18	193.9635
19	74.1002
20	3.3225
21	102.6134
22	116.3152
23	64.4268
24	16.4490
26	57.7530

27	3.3274
28	26.2937
29	39.4649
30	95.7319
31	15.2931
32	79.2408
33	8.1979

4.5 HEC-HMS LAYOUT MODEL FOR TANUM RIVER

The HEC-HMS layout model of Kecau River is shown in **Figure 4.21.** For Kecau River, the observed discharged data recorded at Junction 8 (outlet).

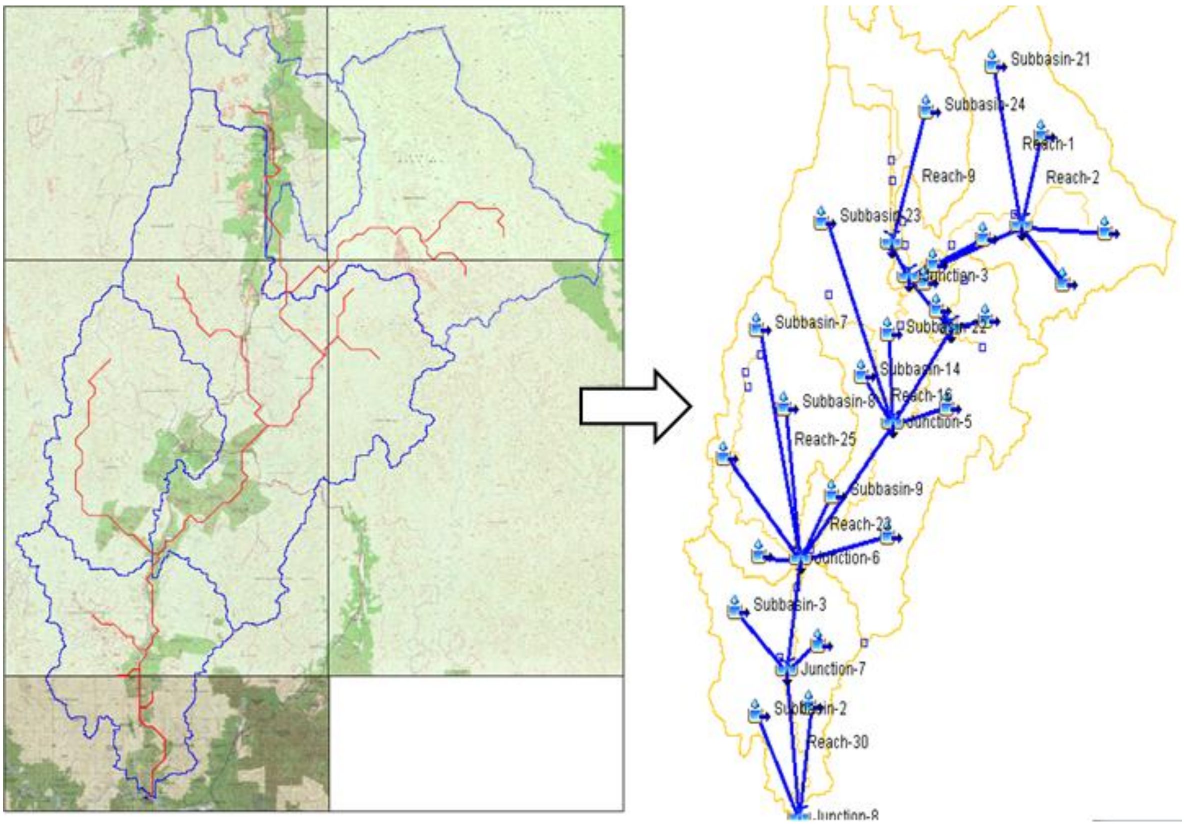

Figure 4.21: HEC-HMS Layout Model for Tanum River

4.6 RAINFALL AND RUNOFF RELATIONSHIP ANALYSIS FOR TANUM RIVER

For Tanum River, Clark Unit Hydrograph Method is used to analyze the data of rainfall and runoff. Since Tanum River does not have stream flow station so the data is simulated at outlet for year by year. Below is the analysis for rainfall runoff relationship for Tanum River from 2009 until 2014. All the data based on simulated hydrograph and was taken every 24 hours.

Table 4.4: Summary data for analysis for Tanum River at outlet

Year	Qmax (m^3/s)
2002	36.0
2003	36.8
2004	38.0
2005	41.5
2006	38.3
2009	29.1
2010	44.4
2011	29.4
2012	94.2
2013	51.8
2014	259.7

In 2002, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 36.0 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.22.**

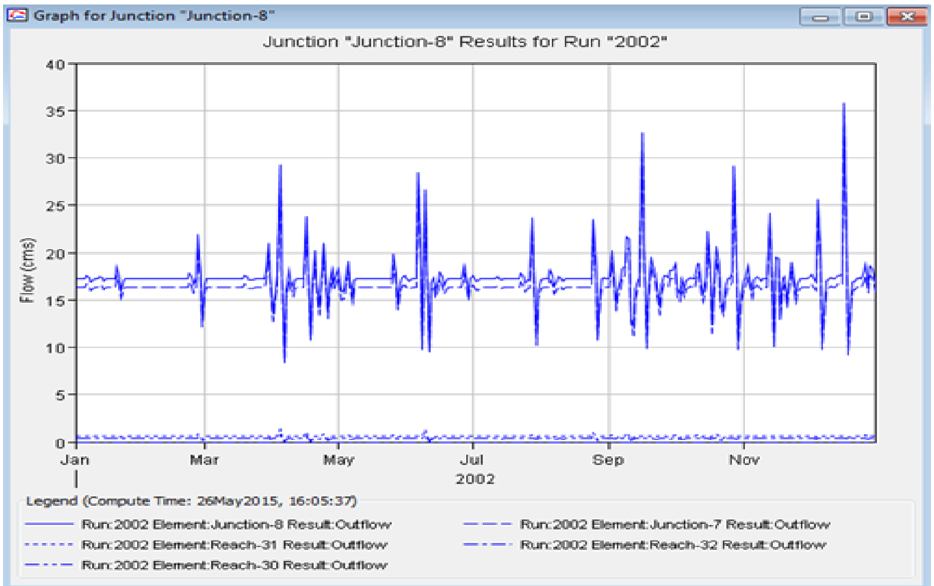

Figure 4.22: Runoff hydrograph of junction 8 (outlet) in 2002

In 2003, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 36.8 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.23.**

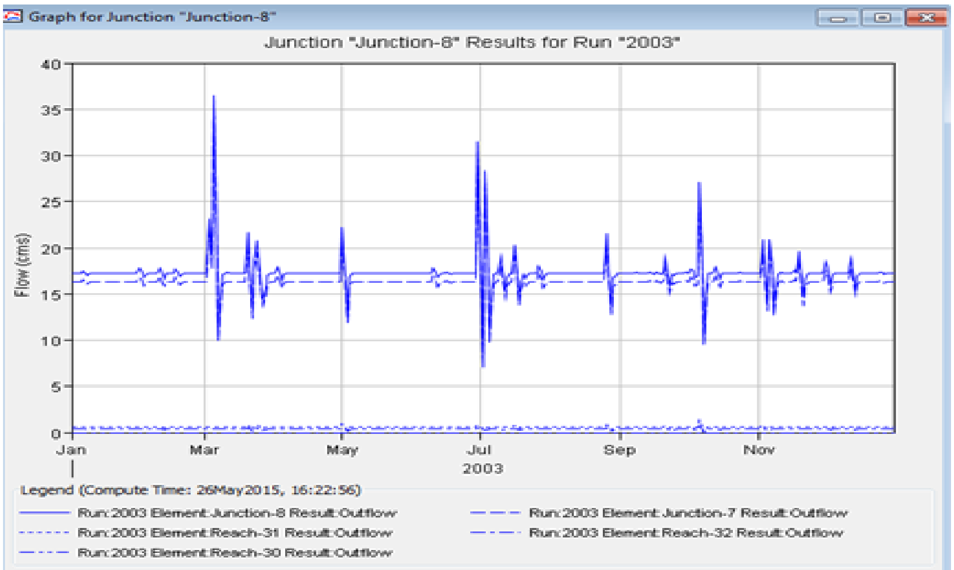

Figure 4.23: Runoff hydrograph of junction 8 (outlet) in 2003

In 2004, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 38.0 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.24.**

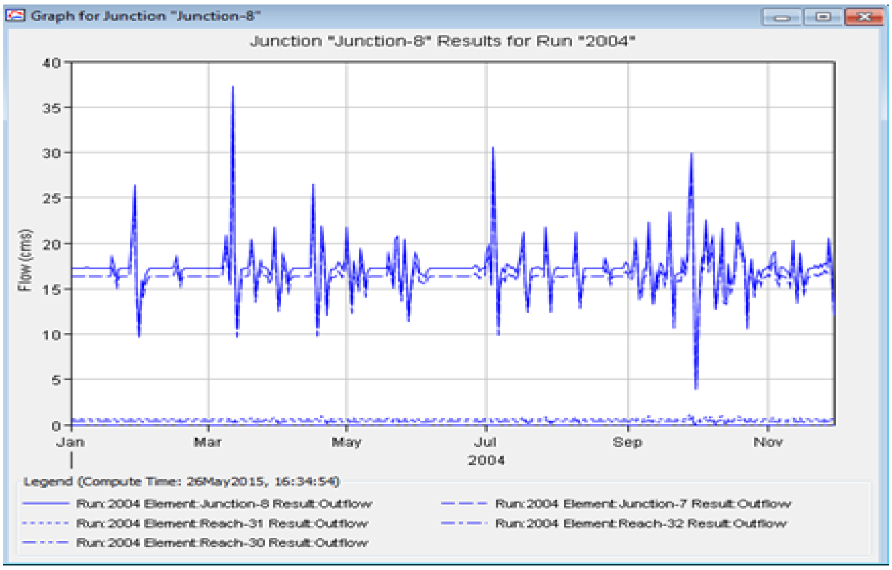

Figure 4.24: Runoff hydrograph of junction 8 (outlet) in 2004

In 2005, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 41.5 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.25.**

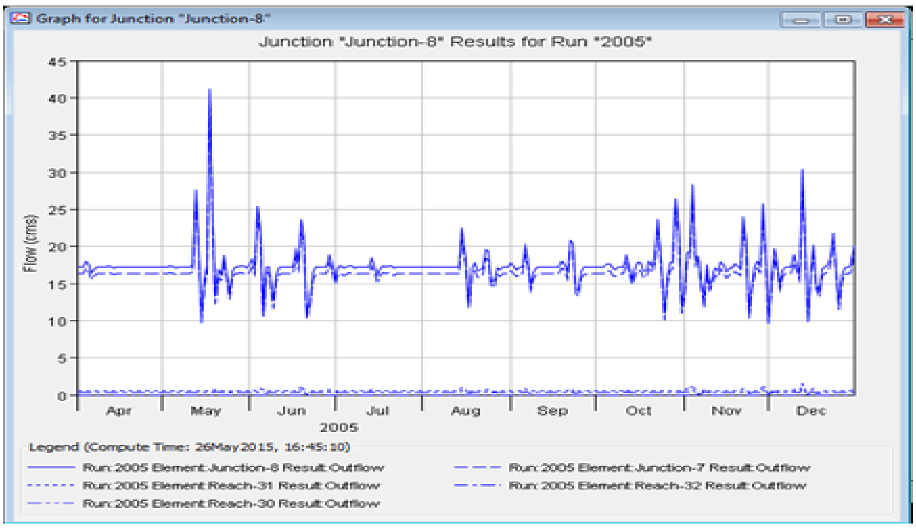

Figure 4.25: Runoff hydrograph of junction 8 (outlet) in 2005

In 2006, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 38.3 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.26.**

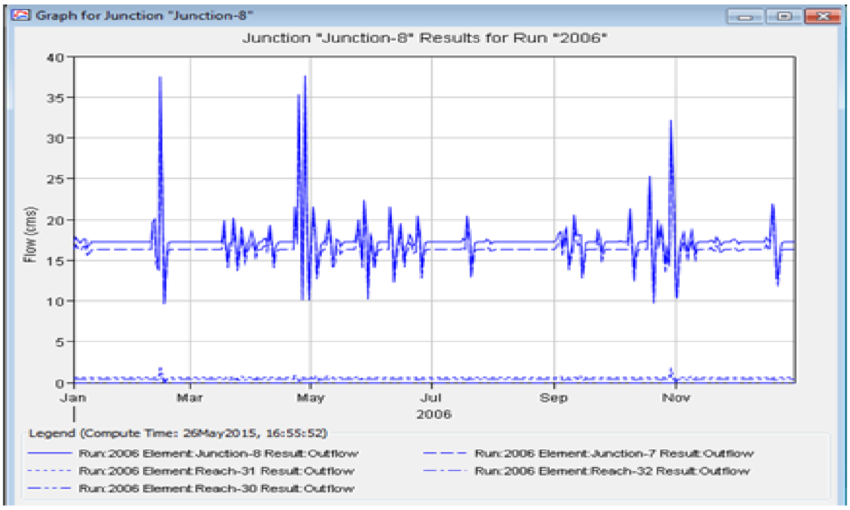

Figure 4.26: Runoff hydrograph of junction 8 (outlet) in 2006

In 2009, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 29.1 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.27.**

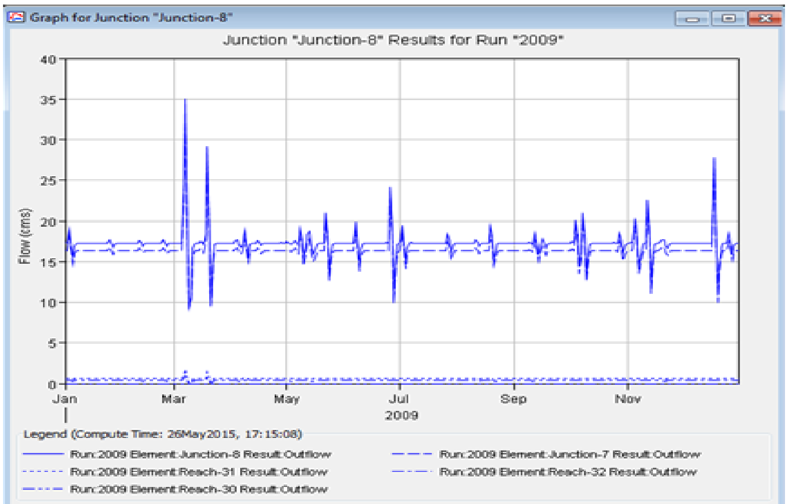

Figure 4.27: Runoff hydrograph of junction 8 (outlet) in 2009

In 2010, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 44.4 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.28.**

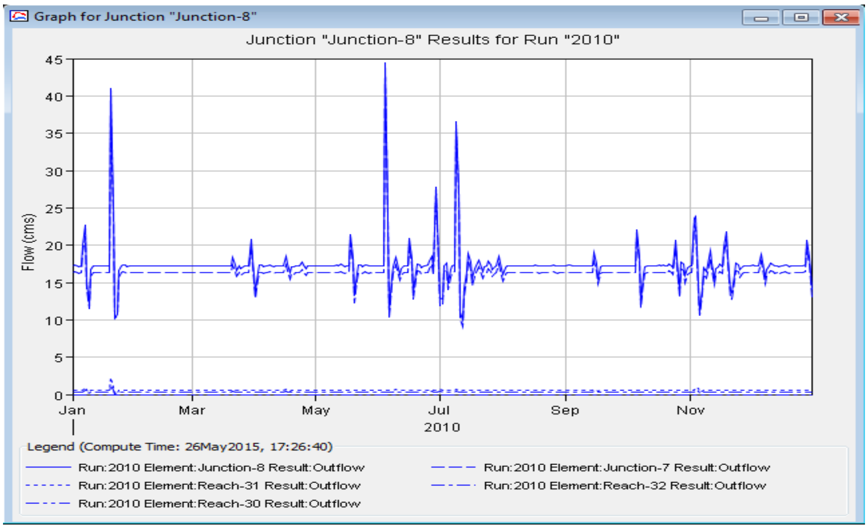

Figure 4.28: Runoff hydrograph of junction 8 (outlet) in 2010

In 2011, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 29.4 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.29.**

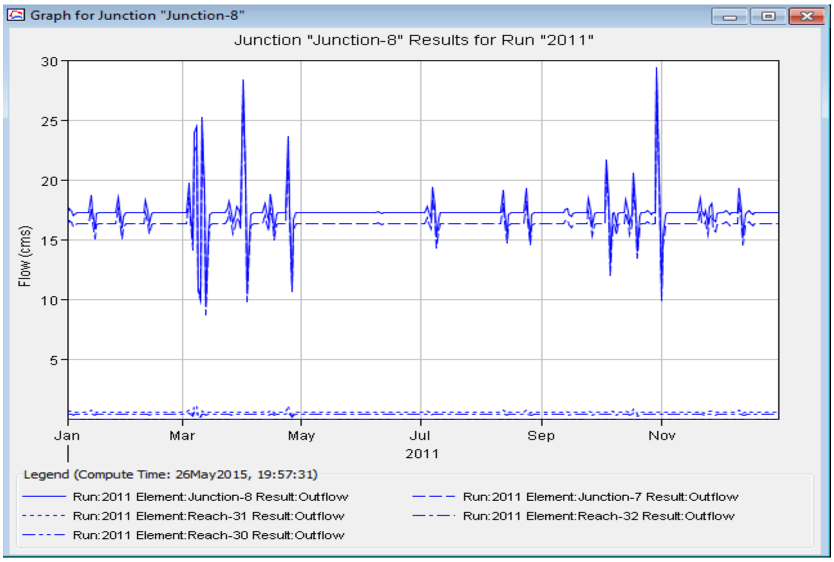

Figure 4.29: Runoff hydrograph of junction 8 (outlet) in 2011

In 2012, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 94.2 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.30.**

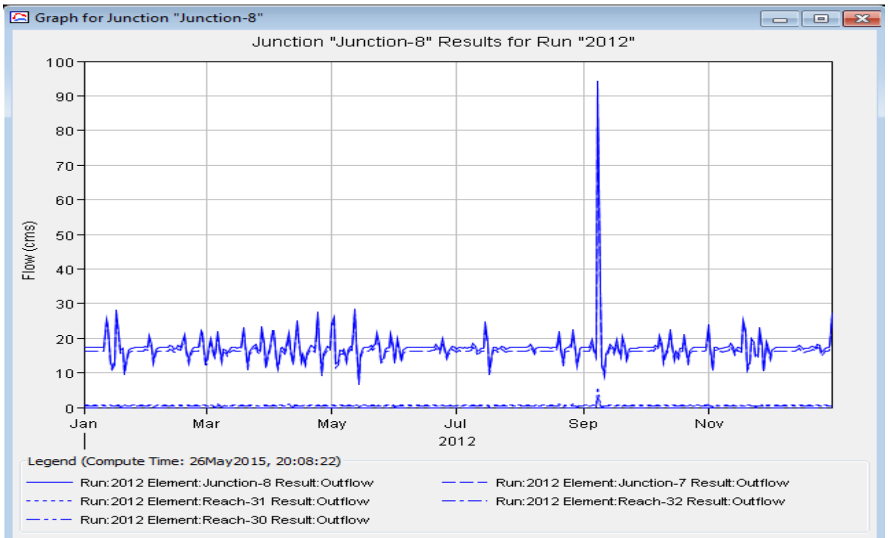

Figure 4.30: Runoff hydrograph of junction 8 (outlet) in 2012

In 2013, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 51.8 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.31.**

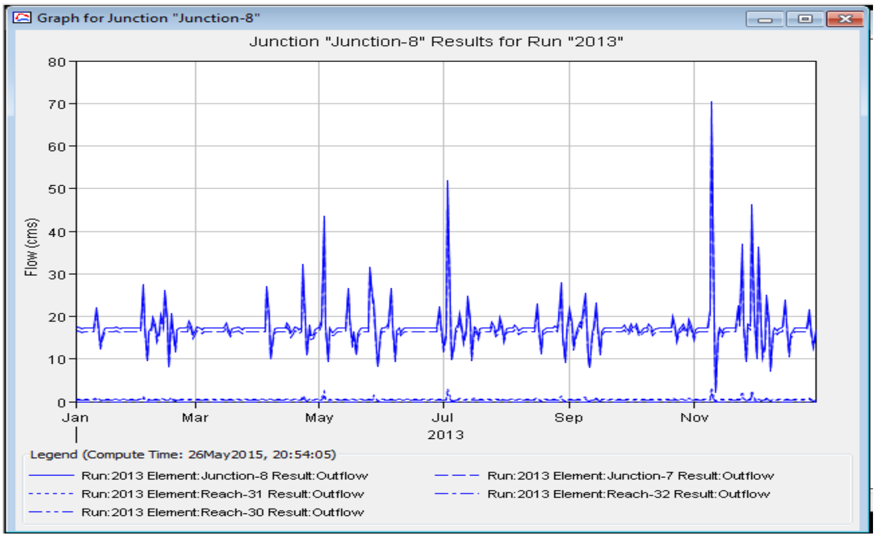

Figure 4.31: Runoff hydrograph of junction 8 (outlet) in 2013

In 2014, the rainfall data was collected from 12.00 am that day until 12.00 am another day. The maximum flowrate is 259.7 m^3/s for outlet of Tanum River. The simulated hydrograph shown in **Figure 4.32.**

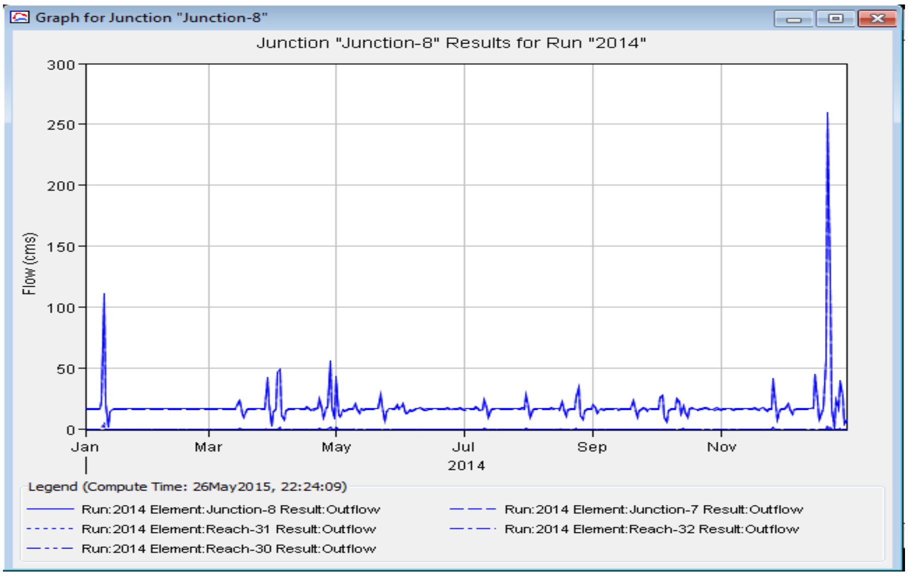

Figure 4.32: Runoff hydrograph of junction 8 (outlet) in 2014

4.7 ANALYSIS AND SIMULATION FOR TANUM RIVER

Same as Kecau River, This process will be carried out according to the data and parameter that was keyed in HEC-HMS. The result shown in graphic and summary are obtained after simulate and analyze all the data. To view the result of the modeling, click at any point that need to simulate and click to view result in term of graph, summary table and time series table.

Data required during analysis and simulation process are topography map that can be get from Jabatan Ukur dan Pemetaan Malaysia (JUPEM), rainfall data and stream flow data that can be get from Jabatan Pengaliran dan Saliran (JPS).

The next process is calibration. Calibration is the process to determine parameter used which can be describe the model. Parameter used during calibration process during calibration process are initial abstraction, curve number, impervious area, time of concentration, storage coefficient, baseflow and lag time. This process will be carried out by using loss rate, transform and baseflow method.

4.7.1 Model Parameter

The parameter used were SCS Curve Number (Loss Method), Clark Unit Hydrograph (Transform Method), and Constant Monthly (Baseflow Method) as shown in **Figure 4.33.**

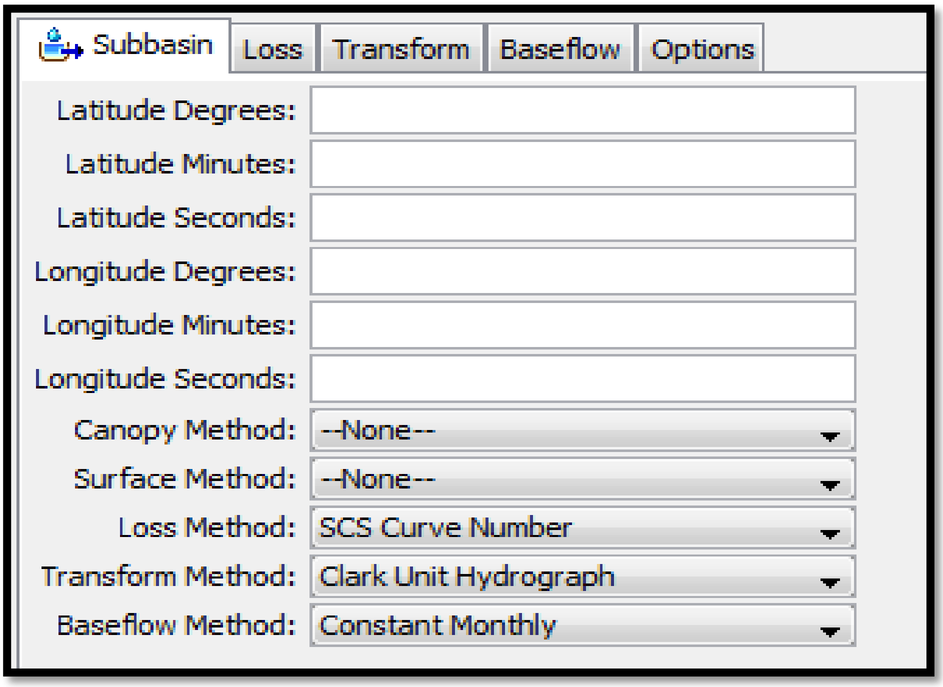

Figure 4.33: Parameter used in HEC-HMS at Tanum River

4.7.1.1 Loss Rate

In loss rate there are three parameters that need to consider which is initial abstraction, curve number and impervious area. The loss rate parameter used is shown in **Figure 4.34.**

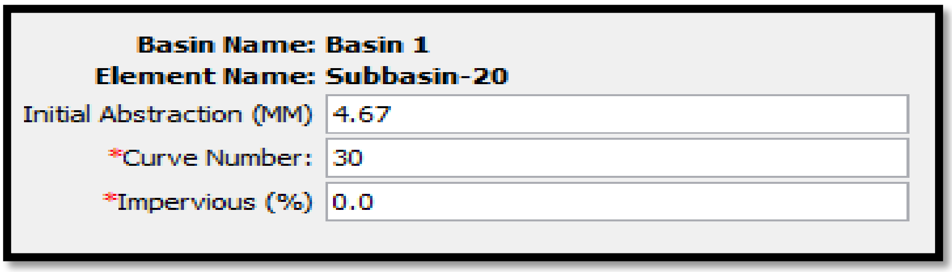

Figure 4.34: Loss rate of parameter used for Tanum River

4.7.1.2 Transform

Time of concentration (Tc) and storage coefficient (R) were the parameter used in transform method which is different according to subbasin area.

Table 4.5: Transform Parameter for Tanum River

subbasin	A	Tc	R
1	33.79	26.59	3.53
2	18.02	6.92	1.42
3	78.99	6.96	0.57
4	25.47	3.14	0.55
5	19.21	1.18	0.25
6	22.15	0.81	0.16
7	21.81	2.21	0.44
8	101.60	3.58	0.26
9	18.75	1.44	0.31
10	64.50	3.08	0.30
11	89.55	4.80	0.36
12	24.94	5.28	0.93
13	17.55	1.50	0.32
14	22.78	2.04	0.39
15	1.92	0.50	0.49
16	2.94	0.76	0.57

17	16.62	2.64	0.61
18	51.09	1.77	0.22
19	59.68	2.53	0.28
20	66.21	3.21	0.32
21	45.19	2.26	0.29
22	27.62	1.32	0.22
23	139.73	7.04	0.39
24	99.74	2.20	0.15

4.7.1.3 Baseflow

The parameter used in baseflow method is constant monthly. **Figure 4.35** show the example of parameter used in this research.

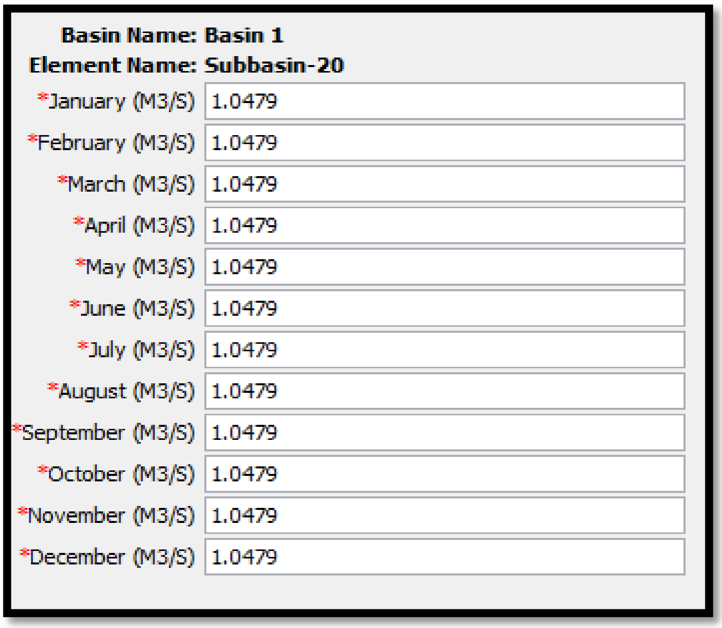

Figure 4.35: Constant baseflow for subbasin 20

4.7.1.4 Lag Time

In HEC-HMS, the parameter used for reach is lag time. Lag time used for Tanum River is shown in **Table 4.6**.

Table 4.6: Lag time for Tanum River

Reach	lag time
1	27.5713
2	44.5518
3	46.4343
4	18.6872
5	88.3057
6	84.0885
7	8.5055
8	7.2491
9	73.3789
11	27.2723
12	35.2720
13	17.8412
14	67.6364
15	14.2089
16	21.7339
17	77.9091
18	14.7220
19	64.4772
20	101.0347
21	38.0390
22	14.7389
23	12.1941
24	191.7862
25	133.8550
26	47.1851
27	71.3954
28	88.3367
29	88.4550
30	76.9005
31	18.6487

4.8 EVALUATION OF THE MODEL THROUGH CORRELATION COEFFICIENT, R^2 RESULT

Correlation coefficient will show the accuracy of a model and measure the performance of the modeling. A model with the R^2 value nearly to 1.0 considered as good and satisfactory. Example of the best Graph of simulated flow versus observed flows are shown in **Figure 4.36, Figure 4.37** and **Figure 4.38.**

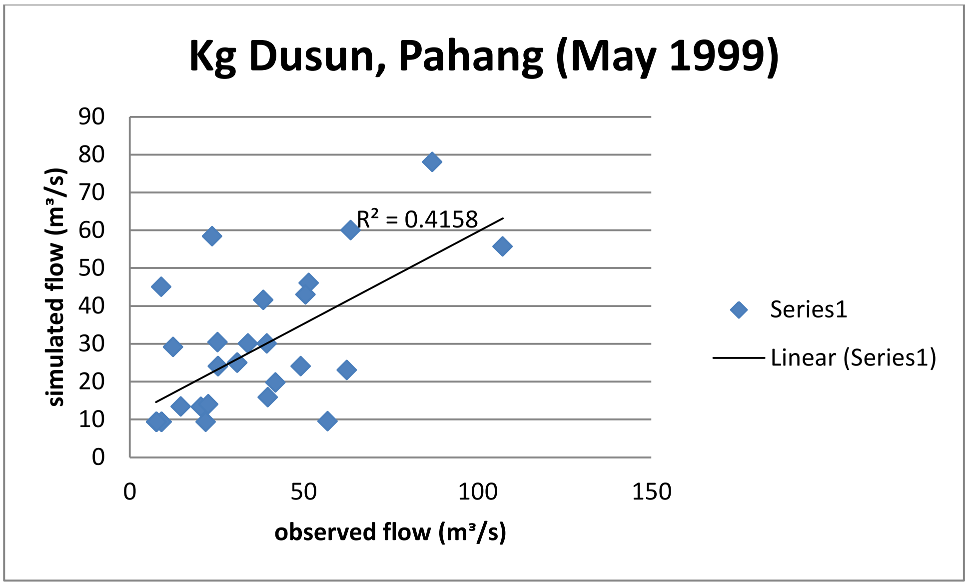

Figure 4.36: Graph of simulated versus observed flows for Kg Dusun, Pahang in Kecau River for May 1999

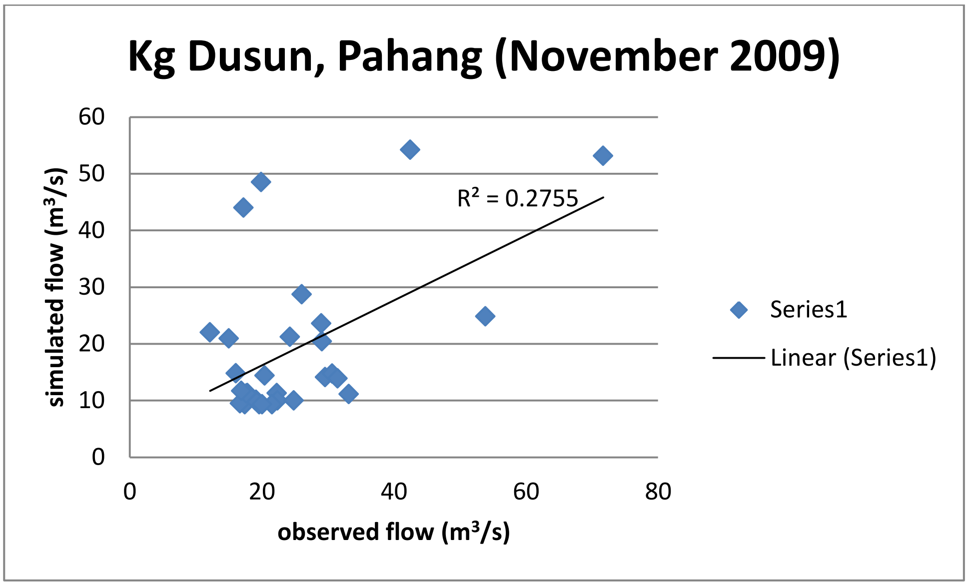

Figure 4.37: Graph of simulated versus observed flows for Kg Dusun, Pahang in Kecau River for November 1999

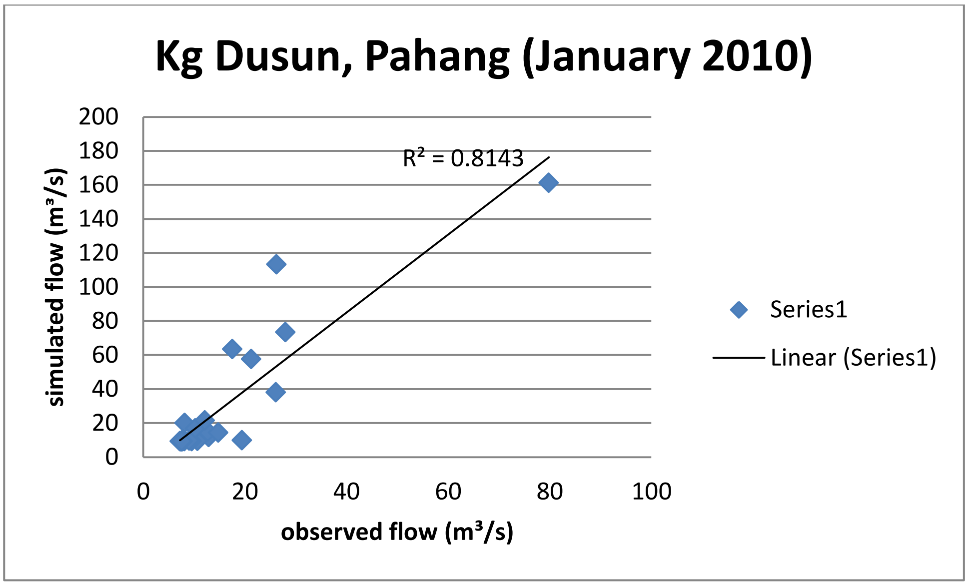

Figure 4.38: Graph of simulated versus observed flows for Kg Dusun, Pahang in Kecau River for January 2010

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study presents methodology and development of hydrologic modeling. By referring correlation coefficient, R^2 mostly graphs in this study are near to one. Value of R^2 for 4320401 station in May 1999 is 0.4158 and in Jun 2010 is 0.8143. If R^2 value is close to one then it will considered as good and satisfactory. So, it will conclude that all graphs in this study are best fit. I also can conclude that HEC-HMS is the best model to predict discharge using different set of rainfall data and Clark Unit Hydrograph also one of the best method for simulation in HEC-HMS. In addition, the application of calibrated rainfall- runoff of Kecau River to Tanum River is the best approach since this both river is near each other and have same characteristic. All of my objectives are achieved.

5.2 RECOMMENDATIONS

As a recommendation, this requires adjustment to the value of a few parameters used to get a better result and fit the graph. There are many advantages when using HEC-HMS model where the process of this model is done quickly and produce strong result that can be applied to predict flood level and solve flood hazard. Value of peak discharge also can be obtained quickly and easy to analyze the rainfall – runoff relationship which is one of my objectives. Besides, more automatic rainfall station should be installed with hourly incremental data to produce the best result. Lastly, it is strongly recommended that other method such as Snyder Method and ModClark Method can be used to produce more accurate result.

REFERENCES

Baharuddin, F, 2007. A study of rainfall-runoff characteristics of urban catchment of Sungai Kerayong

B. Bhaduri. 2000. Assessing Watershed-Scale, Long-Term Hydrologic Impacts of Land-Use Change Using a GIS-NPS Model. Volume 26, Issue 6, pp 643-658.

J. M. Canderlik and S. P. Simonovic. 2004. Calibration, Verification and Sensitivity Analysis of the HEC-HMS Hydrological Model.

M. L Ramli and S. Harun. 2009. Hydrological Modeling System (HEC-HMS). Jitra, Kedah.

N.S. Magesh, K.V. Jitheshlal, N. Chandrasekar and others. 2013. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. Applied Water Science, Volume 3, Issue 2, pp.467-477.

RAMP. 2007. Studying hydrological characteristics. pp. 346-349.

Sudmeyer, R.A. 2004. The Physical and Hydrological Characteristics of a South Coast Sandplain Site East Howick Site Survey. Resource Management Services Report No.167.

Strandhagen, E., Marcus, W.A., and Meacham, J.E. 2006. Views of the rivers: representing streamflow of the greater Yellowstone ecosystem. Cartographic Perspectives, no. 55, Fall.

USACE (2000). HEC-FDA User’s Manual. Hydrologic Engineering Center Davis, CA

USACE (2000). HEC-HMS Technical Reference Manual. Hydrologic Engineering Center, Davis, CA

USACE (2009). HEC-DSSVue User’s Manual. Hydrologic Engineering Center, Davis, CA

Walesh, Stuart G. Urban Surface Water Management. New York: John Wiley, 1989

X. Chu and Steinman, A. 2009. Event and Continuous Hydrologic Modeling with HEC-HMS. J. Irrig. Drain Eng., 135(1), 119–124.

APPENDIX A

SAMPLE DATA OF RAINFALL

Day	observed
1	0
2	7.2
3	2.8
4	0
5	0
6	0
7	13.4
8	13.4
9	3.2
10	0
11	0
12	0
13	0
14	0
15	0
16	15.5
17	17.5
18	4.4
19	0
20	0
21	0
22	19.5
23	7.5
24	0
25	0
26	22.8
27	16.7
28	3.1
29	0
30	0
31	0

APPENDIX B

SAMPLE DATA OF STREAM FLOW

Day	observed
1	8.35
2	9.09
3	8.51
4	10.27
5	8.6
6	65.55
7	23.93
8	32.89
9	20.59
10	19.6
11	51.72
12	59.46
13	23
14	13.16
15	22.47
16	10.06
17	9.51
18	9.75
19	9.23
20	9
21	48.4
22	17.87
23	75.92
24	77.55
25	29.37
26	59.11
27	28.59
28	20.01
29	9.25
30	9.23
31	13.07