RAINFALL RUNOFF MODEL FOR MOUNTAINOUS AREA BY USING HEC-HMS

CASE STUDY – CAMERON HIGHLAND

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SHARMILA A/P SEWAJJE

Thesis submitted in fulfilment of the requirements
for the award of the degree of
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Dedicated to my beloved family, friends, and lecturers for their endless support and encouragement throughout my journey as a student in Universiti Malaysia Pahang.

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ABSTRACT

This study is focused on discharge estimation in a mountainous watershed in which three rivers at CAMERON HIGHLAND are chosen as the case study based on the rainfall distribution. The three rivers are Sg.Lemoi, Sg.Bertam and Sg.Telum. The rainfall-runoff model is simulated using Hydrological Modelling System (HEC-HMS) version 3.5. The rainfall data and stream flow data used in this study are from four rainfall stations (RF4218042, RF4414037, RF4414038, RF4514032) and two stream flow stations (SF4218416, SF4219415). The data used from the rainfall and stream flow stations are from the period of 1999 until 2014. The precision of data used during calibration and verification process depends on parameter used in HEC-HMS. Results of simulation can be generated in the form of time series table, summary table and hydrograph. Root Mean Square Error (RMSE) calculated to show the relationship of the simulated flow and the observed flow. If the RMSE value is lesser, it would indicate that the variables are positively linear related. During evaluation of model, the best value of RMSE value is $11.1 m^3/s$ which is a low value. It shows that the simulated models were fit with the observed data and proves that the HEC-HMS is suitable to predict and analyse rainfall-runoff relationship at Sg. Lemoi, Sg.Bertam and Sg. Telum.

ABSTRAK

Kajian ini adalah tertumpu kepada anggaran pelepasan dalam menganjak yang bergunung-ganang di mana tiga sungai di CAMERON HIGHLAND dipilih sebagai kajian kes berdasarkan taburan hujan. Tiga Sungai ialah Sg.Lemoi, Sg.Bertam dan Sg.Telum. Model hujan-air larian adalah simulasi menggunakan sistem permodelan hidrologi (HEC-HMS) versi 3.5. Data hujan dan aliran aliran data digunakan dalam kajian ini adalah dari aliran dua aliran Stesen (SF4218416, SF4219415) dan empat stesen hujan (RF4218042, RF4414037, RF4414038, RF4514032). Data yang digunakan dari Stesen aliran hujan dan aliran adalah daripada tempoh 1999 hingga 2014. Ketepatan data yang digunakan semasa proses kalibrasi dan pengesahan bergantung kepada parameter yang digunakan dalam HEC-HMS. Keputusan simulasi boleh dijana dalam bentuk siri jadual waktu, jadual ringkasan dan hidrograf. Akar min Square ralat (RMSE) dikira untuk menunjukkan hubungan aliran simulasi dan aliran diperhatikan. Jika nilai RMSE adalah lebih rendah, ia menunjukkan bahawa pembolehubah adalah linear secara positif berkaitan. Semasa penilaian model, nilai nilai RMSE yang terbaik ialah 11.1 m ^ 3/s itulah nilai yang rendah. Ia menunjukkan bahawa model simulasi sesuai dengan data diperhatikan dan membuktikan bahawa HEC-HMS adalah sesuai untuk meramalkan dan menganalisis hubungan hujan-air larian di Sg. Lemoi, Sg.Bertam dan Sg. Telum.

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LIST OF ABBREVIATIONS

HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modelling System
RMSE	Root Mean Square Error
SCS	Soil Conservation Services
UH	Unit Hydrograph
JPS	Jabatan Pengaliran dan Salira

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The resource that cannot be created by man is water. The movement of water throughout Earth's surface, atmosphere, and underground is described as the water cycle. The processes of evaporation, precipitation, transpiration, condensation and runoff is causing the water to constantly move from one place to another. The two important processes that involve in this study will be precipitation and runoff. In Malaysia, the most common occurrence of precipitation is in the form of rain. When a part of the landscape are saturated or impervious, it leads to runoff process.

Fast response of runoff to precipitation events are specified to mountain catchments. The headwater of drainage basin are prone to create more runoff than lowland areas. Air is forced to be lifted and cooled causes mountain areas tend to get more precipitation generally. Water move downward more rapidly on steep mountainsides. There will be limited storage of water because of thinner soil on slope area and infiltration occurs in a very little amount where there is exposed bedrock. This phenomenon is called low retention capacity at high mountain area.

There are two concepts of runoff which includes infiltration –excess and saturation excess runoff. When the rainfall intensity is greater than the infiltration rate at the surface soil, overland flow occurs which is the infiltration-excess runoff. This paradigm usually found on gentle slopes because both biological activity and raindrop impact on soil surface which is continually changing. The saturation-excess runoff occurs when saturated soil surface at any further rainfall of low intensity causes runoff which lead to stream flow. This phenomenon usually occurs near existing stream channels and in depressions or hollows.

Generally, because of rapid runoff occurs at mountainous area, flash flood has become a very common problem not only all over the world but also at Malaysia. One of the biggest flood incident happened last year in Malaysia affected not only at urban catchment but also at CAMERON HIGHLAND which is a mountainous area. This has caused damage of millions of Ringgit of assets and also live of people. Although the Government has allocated money to repair the damages, but proper studies on the hydrological pattern at mountainous area is not done. But rather than that government is focusing on allocating money for the hydrological research in urban area.

Therefore, surface runoff estimation of a water shed in a mountainous area based on rainfall distribution must be done. This is a very common analysis in hydrology. There are three rivers is chosen in this study which includes Sg.Lemoi, Sg.Bertam, Sg,Telum. These three rivers are at CAMERON HIGHLAND which comply with the main criteria of this study as they have slopes. The hydrological data which includes rainfall data and stream flow data from these places helps in identifying their specific hydrological pattern.

It is vital to choose a suitable model whit simple structure, minimum input data requirement and reasonable precision is essential because measurement of all parameters affect watershed’s runoff is impossible. Therefore, HEC-HMS software is chosen which meet all these criteria and has been used widely in different hydrological studies.

1.2 STATEMENT OF THE PROBLEM

The study of runoff generation is the long standing issues on hydrology. In tropical climate, the studies on runoff and its characteristics are still scarce. The urban storm water designs applied in Malaysia mainly based on foreign experience which is the design chart of runoff coefficients in MSMA adopted from Australian data set (DID,2000). When solving hydrological problems such as flash floods in urban areas, the data may not be applicable to Malaysia and could cause failures in designing structure. Proactive measures are now taken in the process by the Government to allocate research grant for adding more information on hydrological data in urban areas.

But, mountainous area differ in hydrological pattern by the slope of the watershed. Government still not so aware on this issue. Therefore, it is vital to analysis the flood discharge pattern at mountainous area to have a better resource of information if mountainous area affected by flood which causes many damage in terms of assets and loss of people live.

1.3 OBJECTIVES OF STUDY

The main objectives of this research can be outlined below:

i. To analyse the rainfall- runoff relationship at Sg. Lemoi, Sg, Bertam, Sg.Telum.
ii. To identify the best method in analysing the rainfall- runoff relationship at mountainous area using HEC- HMS.
iii. To determine the pattern of discharge at Sg. Lemoi, Sg. Bertam, Sg. Telum.

1.4 SCOPE OF STUDY

CAMERON HIGHLAND is drained by the three main rivers which is chosen for this study namely, Sg. Lemoi, Sg. Bertam, Sg. Telum. Sg. Lemoi also known as Sg. Lemol is a stream class H (Hydrographic) located at an elevation of 354 meter above sea level. Sg. Bertam is also a stream class H (Hydrographic) located at an elevation of 29 meters above sea level. Sg. Telum also same as the other two river which is a stream clss H (Hydrographic) located at an elevation of 112 meters. The study involves taking the rainfall and stream flow data of these three rivers and simulate rainfall-runoff models by using HEC- HMS and analyse it according to the criteria needed.

1.5 THE IMPORTANCE OF THE STUDY

The rainfall runoff model is very important and necessary tools to be used in water and resource management. To forecast flood by determining the discharge pattern of an area is very important and quite difficult task. HEC- HMS software which is used to determine the hydrological changes in the study area will help in to design a better hydrological system at the mountainous area. This will decrease the amount of damage caused by flash floods at mountainous area.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Hydrology is a very crucial branch of Earth Science. Basically, hydrology is a research of the occurrences, distributions, movement and also the properties or quality of water on Earth. The hydrological cycle, water resources, and environmental watershed sustainability are the components in the scientific research. Hydrometeorology, surface hydrology, hydrogeology, drainage basin management and also water quality are the main aspects of hydrology. From the studies and researches carried in the field of hydrology, generally some of the scopes can be identified as stated below (H.M. Raghunath, 2006):

a) the frequency and the maximum probable flood that may occur at a proposed area can be determined in which to ensure the drains and culverts, dams and reservoirs, channel and other flood control structures are designed safely.
b) the frequency, quantity and also the occurrence of water in a basin can be identified to design components such as dams, municipal water supply, water power, and also river navigation.
c) the formation of soil, recharge facilities like streams and reservoirs, rainfall pattern are the knowledge of hydrology in which from developed ground water.
d) the frequency and the maximum intensity of storm to be used for the design of a drainage project in that area. .

Hydrological science plays a vital role in water resource management where the complex water systems of the Earth is analysed and in turn solves water problems that arises. This job scope is always done by hydrologists. From here, it can be clearly understood that water acts as the central element in hydrology. 70 percent or three quarter of earth's surface is covered by water which includes oceans or salt water and also fresh water that makes up the hydrosphere. From that, when divided into more specific portion, oceans or salt water makes the highest portion which is 97 percent. The remaining three percent will be further divided into 2 percent of frozen glaciers and polar ice caps, 1 percent of freshwater which 1/5 percent containing salt where it can be found in term of still water and also running water. Snow, snowfall, dew are some of the forms in which fresh water sustain its availability (P.S.Verma and V. K. Agarwal, 2000).

The importance of study or research in hydrology is getting attention at all levels of the world because of its contribution in the assessment, utilisation, development and also the management of water resources in any region. It is noted that from year 1965 until 1974, the period is recognized as the International Hydrological Decade by the United Nations. During this period of time, all the academic places such as Universities, Research Institutions and not only that, but also including Government Organisations were promoted with hydrological education research, evolution of analytical techniques and collection of hydrological information on a global range (H.M. Raghunath, 2006).

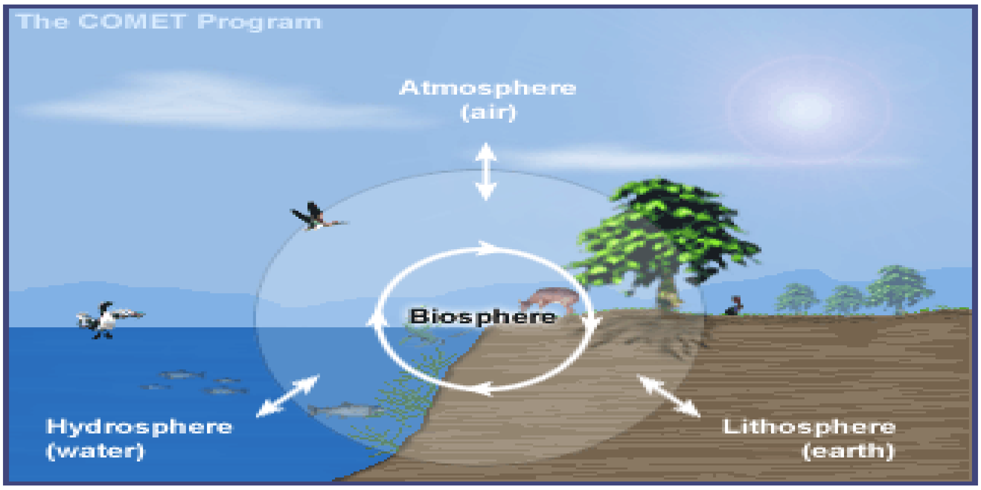

Figure 2.1: Illustration of hydrosphere

Source: UCAR 2000

2.2 HYDROLOGICAL CYCLE

The water transfer cycle occurs continuously in nature is called the hydrological cycle (H.M. Raghunath, 2006). Movement of the pathway of water in different phases through the atmosphere to the Earth, through the land, to the ocean and back to the atmosphere is called the hydrological cycle. As the total amount of water in the hydrological cycle is constant, it can be considered as a closed system for Earth (Mohammad Karamouz, Ferenc Szidarovszky and Banafsheh Zahraie, 2003). There are nine major physical processes involved in the global water cycle which forms the water movement (NWRFC, 2013). The hydrological cycle's basic characteristic is that it has no starting and no ending. The nine processes involved in the hydrological cycle are as below:

a) evaporation
b) condensation
c) precipitation
d) interception
e) infiltration

f) percolation
g) transpiration
h) runoff
i) storage

The nine processes each can have a simplified description. Evaporation is the change of physical state of water from liquid state to gaseous state. The factors that affect the amount of evaporation are solar radiation, air temperature, vapour pressure, wind and atmospheric pressure. Free water surface are one of the places in which evaporation occurs. Condensation happens when water vapour transforms into liquid state. It occurs by the cooling of the vapour or air. The energy needed for the change in state will be 600 calories of energy per gram. When all forms of water particles fall from the atmosphere to ground, it is called precipitation. The rainfall can flow over and get into stream channels through the land, penetrate into the soil, and also absorbed by plants. Interception interrupts the movement of water going to the streams. During snow time on conifer forests and hardwood forests which yet to lost their leaves, the highest level of interception occurs. When the atmosphere came in contact with soil, the water move through the boundary area in which the process is called infiltration. Percolation uses gravity and capillary forces to move the water through the soil. When water form plant evaporated to the atmosphere in the vapour form, the process is called transpiration. A liquid flow that can be seen in surface streams from a drainage basin or watershed can be called runoff. Water in the water cycle is and will be stored in the atmosphere, in the ground and also on the surface of the earth such as lakes, rivers and etc. (NWRFC, 2013).

As the study is focused on rainfall and runoff model, therefore the explanation in the following parts will be specified to these topics.

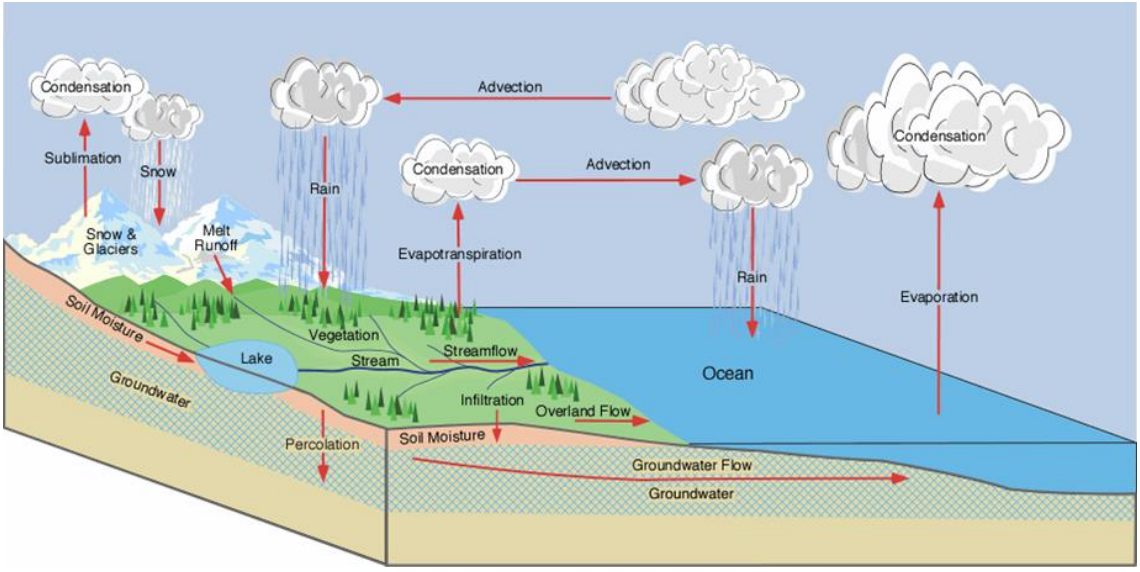

Figure 2.2: Hydrological cycle schematic diagram.

Source: Saskatchewan 2012

2.2.1 Rainfall

As mentioned previously, rainfall is one of the form of precipitation. The other form of precipitations are hail, dew, rime, snow, hoar frost and also fog precipitation. Rainfall is categorized as the liquid precipitation as the precipitation reaches the ground in the form of water droplets. The size of raindrops range usually starting from 0.5 millimetre and very hard to reach the size until 6 millimetre because heavy rain will destroy the droplets as it reaches the ground. Not only that, the velocity of a rain droplets usually ranges from 2 metre per second and can go up to 10 metre per second according to the intensity of the rainfall whether it is light or heavy (Irena I. Borzankova,).

2.2.1.1 Types of Rainfall

There are few types of rainfall and they are as below (Dr. Micheal Pdwirny, 2008):

a) Convectional Rainfall

The process occurs by convection when the moisture laden air rises because of the heating of surface layer of the atmosphere. Convection is the condition when the rising current of warm air and wide spread areas of slowly sinking airs are separated. This types of rainfall usually found year round in regions near the equator.

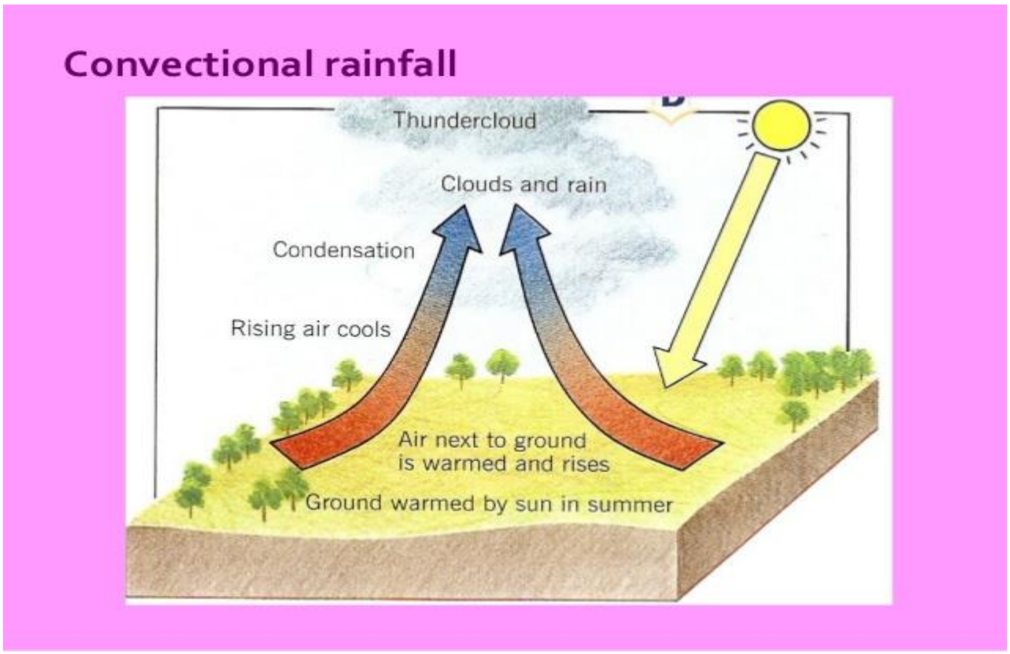

Figure 2.3: Illustration of Convectional Rain

Source: slide share, 2013

b) Cyclonic Rainfall

Depression or lows causes this type of rain to occur. When warm tropical air meets cold polar air or to be simple, when warm air overrides the cold air, the cyclonic rainfall occurs. There are two situations occur in this type of rainfall which are WARM FRONT and also COLD FRONT. Generally the rainfall is heavy but brief in duration.

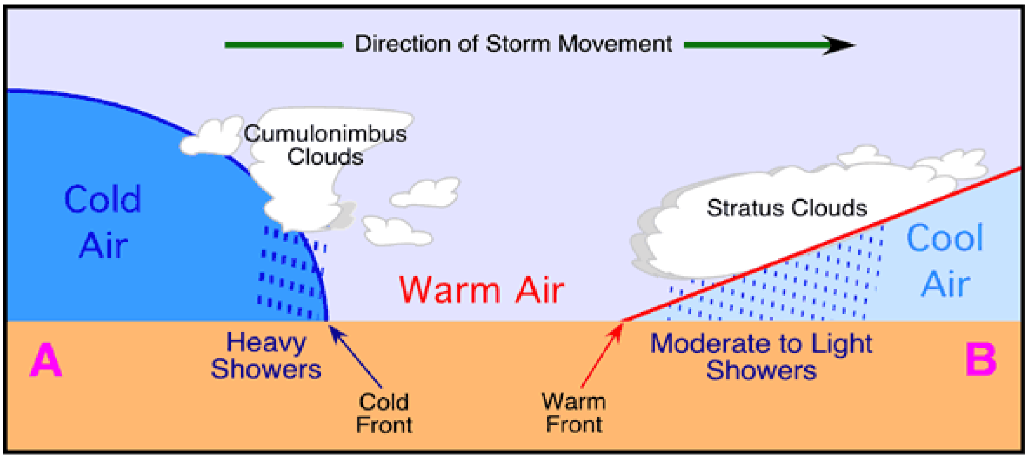

Figure 2.4: Illustration of cyclonic rainfall

Source: The Mid Latitude Cyclone, 2006

c) Orographic Rainfall

This type of rainfall occurs when a bulk of air containing water vapour is forced upwards the mountain that blocks its way. The air forced upwards expand and cools where later the water vapour condenses and rainfall occurs.

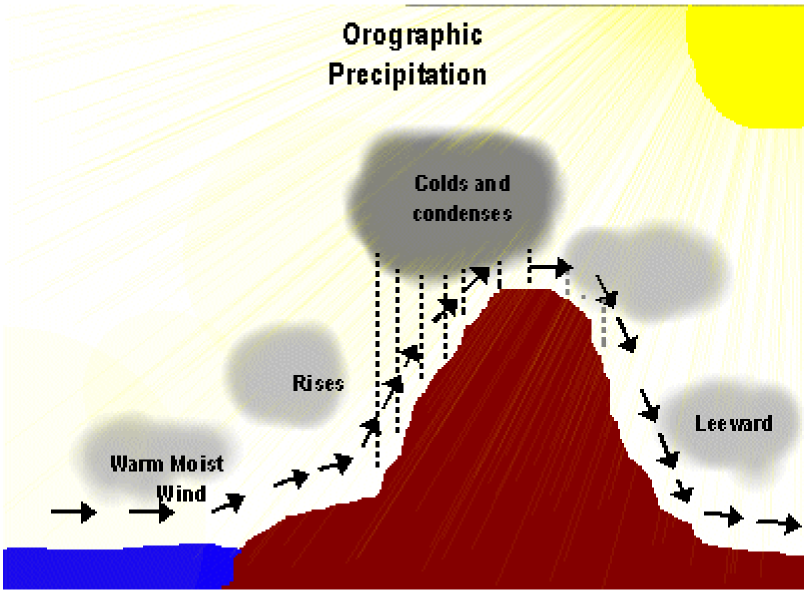

Figure 2.5: Illustration of Orographic Rainfall

Source: suprmchaos, 2012

d) Frontal Rainfall

Air masses with different temperature and density will not mix readily when they meet. Therefore, there will be front occur which is an imaginary line separating the different air masses.

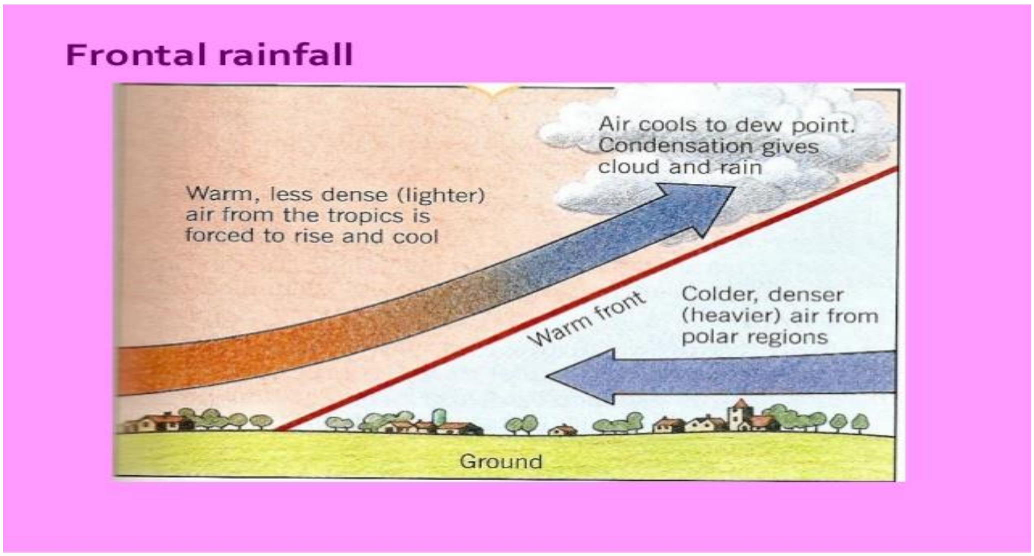

Figure 2.6: Frontal Rainfall

Source: The Mid Latitude Cyclone, 2006

e) Artificial Rainfall (Cloud Seeding)

The occurrence of rainfall by making a cloud which uses its moisture. The dry ice or silver iodide particles released and form cold clouds.

2.2.1.2 Instruments used to measure rainfall

The rainfall data can be obtained by using various types of rain gauges. The list of the types of the rain gauges are as follow (H. M. Raghunath, 2006):

a) Recording Rain Gauge
b) Weighing Type Rain Gauge
c) Tipping Bucket Rain Gauge with the recorder
d) Float Type Rain Gauge
e) Automatic- radio- reporting Rain Gauge

2.2.2. Runoff

2.2.2.1 Surface runoff

After the occurrence of precipitation especially rainfall onto the earth surface, apart from infiltration, storage, the remaining water flows according to the law of gravity and in other words, it can be said that the water flows downhill where it is called surface runoff. Surface runoff is a very important part in the hydrological cycle as it ensures the rivers and lakes are full of water, but at the same time it also damages the landscape by the act of erosion. A very big amount of water flows as runoff during storms. In 2001, the amount of runoff flowed in one day during a major storm at Peachtree Creek in Atlanta, Georgia, was 7 percent of all the stream flow for that particular year (USGS, 2014). Surface runoff or overland flow occurs when high rate of precipitation more than an abstraction. (M.J.Deodhar, 2008).

2.2.2.2 Factors affecting surface runoff

The factors affecting runoff in terms of meteorologically includes the types of precipitation which can be rain, snow, sleet and so on. Apart from that, rainfall intensity, the rainfall amount and also the rainfall duration plays key roles in affecting runoff.

In terms of factors involving physical characteristics, it includes the land use, vegetation, soil type, drainage area, basin shape, elevation, the topography especially the slope of the land, the drainage network patterns at the specific area, ponds, lakes, reservoirs and so on in the basin that prevent or delay the runoff from continuing to downhill.

Human activities also affects the runoff pattern. Urbanization and development occurring rapidly all over the world as the world's population increases year by year which in turn increases the necessity of improvement. With this nonstop improvement, people failed to realise that the natural landscape of earth are being replaced by impervious surfaces which includes roads, houses, parking lots, and most importantly millions and billions of buildings which reduces the infiltration of water into the ground and fasten the stream flow speed or velocity. To add to it, the removal of vegetation and soil and replace it with constructing drainages causes the runoff volume to increase and decreases the time for runoff or stream flow to get into lakes and rivers. With this, it can be clearly seen that the peak discharge, volume, and frequency of flood get a shoot up in streams (USGS, 2014).

2.3 PHYSICAL CHARACTERISTICS OF BASIN

Generally, a watershed usually starts at the top of a hill, mountain or ridge because of the movement of water to downhill. Not only that, slopes and river valley are very common in a watershed. The water flows to seas and oceans by going through Main River or stream and also joining to other watersheds.

A watershed's drainage pattern is affected by the existence of slopes. The rainwater is very difficult to absorb into the ground because of very steep slope. This in turn will causes the water to runoff and increases erosion. The establishment of plant cover becomes more difficult and the surface water infiltration reduces on steep slopes.

The flat area starting from the river's edge until the beginning of the surrounding highlands will be considered as the watershed's floodplain. The floodplains plays an important role as it is the rich zone for biodiversity and agricultural soils. Because annual flooding of the floodplain renews the soil's fertility for farming, it is very well welcomed in many parts of the world. The action of damming is very harmful to floodplains.

The factors that affect the quality of the usage of the land and the crops grown there are the watershed's exposure to the sun that in turns affects temperature, evaporation, and also transpiration. Evaporation and transpiration causes the rapid loss of soil moisture on steep slopes facing the sun. Different plants than those facing away from the sun usually supported by the slopes exposed to the sun. Similar effects also for orientation with regard to the prevailing winds.

There watershed generally have all sizes and larger size usually contains many smaller watersheds. The network of a typical watershed consists of smaller rivers or streams called tributaries links to each other and finally goes to a bigger river. The streams can be divided into three types based on how often they carry water. The streams are:

a) Ephemeral streams

   This type of streams happen only during a rainstorm or after a flood in which they are small and have temporary paths. The channels are vary from storm to storm and are not defined.

Figure 2.7: Example of Ephemeral Stream

Source: Texas Logger, 2007

b) Intermittent streams

This types of streams flow only when there is wet season.

Figure 2.8: Example of Intermittent streams

Source : Peter Frei, 2009

c) Perennial streams

This type of streams are usually have well defined channels which may have some smaller tributaries joining them and they flow all year round.

Figure 2.9: Example of Perennial steams

Source: CDFW,2015

The surrounding physical characteristics of a watershed related to the physical, chemical and biological makeup of a stream. The research on these characteristics helps in understanding the stream and watershed relationship which in turn the effects of the influence of human on different stream types can be predicted (International Rivers, 2015).

2.4 RAINFALL AND RUNOFF

2.4.1 Rainfall and Runoff Model

Various hydrological models was used in conducting various hydrological studies to stimulate the hydrology catchment. Some of the example are:

a. The simulation of Charongo, Ngomberi and 1DD1 catchments in the southern slopes of Mt. Kilimanjaro by using a modified conceptual HBV model (Rinde,1999) by Rohr (2003).
b. The simulation of 1DD1 catchment by using a semi distributed hydrological modelling system (HEC-HMS) by Moges (2003)

2.4.2 Rainfall and Runoff Analysis

Hydrograph is used to show the relationship between rainfall and runoff in terms of discharge of water in the watershed with respond to time series of flow. The parameters of peak flow in a hydrograph can derive from regional regression equation that shows all peak flow magnitudes (C.K. Francis, Ting and others, 2011). There are various methods in analysing the rainfall and runoff data.

2.4.2.1 Peak Discharge Method

Peak Discharge Method is also known as the Slope Area Method. This method of indirect measurement is the most commonly used in analysis of rainfall and runoff data. The discharge at the study area is calculated based on the uniform flow equation which includes the channel characteristics, water surface profiles and also roughness or retardation equation. The losses caused by bed roughness is represented by the water-surface profile for a uniform reach of channel. The most basic equation used in this analysis will be the Chezy equation. Manning Equation is used in Geological Survey. The equation is simple and the result obtained is reliable because of the equation has been used many years and flaws are corrected along the time.

The Manning Equation in term of discharge is as below

$$\mathbf{Q = \frac{1}{n} A R^{\frac{2}{3}} \sqrt{S}} \qquad \textbf{(2.1)}$$

where:

Q = Flow Rate, (m^3/s)

v = Velocity, (m/s)

A = Flow Area, (m^2)

n = Manning's Roughness Coefficient (s/$m^{\frac{1}{3}}$)

R = Hydraulic Radius, (m)

S = Channel Slope, (m/m)

2.4.2.2 Rational Method

This method is the most widely used uncalibrated equation is the Rational Method. Mathematically, the rational method relates the peak discharge (q, m^3/sec) to the drainage area (A, ha), the rainfall intensity (i, mm/hr), and the runoff coefficient (C).

$$\mathbf{q = 0.0028CiA} \qquad \textbf{(2.2)}$$

where:

q = design peak runoff rate in m^3/s

C = the runoff coefficient

i = rainfall intensity in (mm/hr) for the design return period and for a duration equal to the “time of concentration” of the watershed.

There are a few assumptions to be followed for using rational method:

- Rainfall intensity and duration is uniform over the area of study
- Storm duration must be equal to or greater than the time of concentration of the watershed.

2.4.2.3 Transform Method

The transform method uses Unit Hydrograph concept to predict the discharge pattern. The hydrograph of surface runoff resulting from relatively short, intense rain, called a unit storm (Wisler & Brater, 1949). The hydrograph that results from 1-inch of excess precipitation (or runoff) spread uniformly in space and time over a watershed for a given duration. The rules of thumb for derivation of Unit Hydrograph are as below:

- the storm should be fairly uniform in nature and the excess precipitation should be equally as uniform throughout the basin. This may require the initial conditions throughout the basin to be spatially similar.
- the storm should be relatively constant in time, meaning that there should be no breaks or periods of no precipitation.
- the storm should produce at least an inch of excess precipitation (the area under the hydrograph after correcting for base flow).

Synthetic Unit Hydrograph is one of the type of Unit Hydrograph. Synthetic Hydrograph is a plot of flow versus time and generated based on a minimal use of stream flow data. The hydrograph is developed for basin that were un- gauged and based on data from similar gauged basins. Most methods are very similar in nature.The method have revolutionized ability to predict hydro response. The method can be divided into four categories which are Synder's Unit Hydrograph, Soil Conservation Service (SCS), Clark's Unit Hydrograph Method and also Root Mean – Square Error (RMSE).

Synder's Unit Hydrograph

Since peak flow and time of peak flow are two of the most important parameters characterizing a unit hydrograph, the Snyder method employs factors defining these parameters, which are then used in the synthesis of the unit graph (Snyder, 1938). The parameters are C_p, the peak flow factor, and C_t, the lag factor. The basic assumption in this method is that basins which have similar physiographic characteristics are located in the same area will have similar values of C_t and C_p. Therefore, for ungaged basins, it is preferred that the basin be near or similar to gaged basins for which these coefficients can be determined.

The most important characteristic of basin due to storm- basin lag (lag time). Lag time is the time difference between the centroid of the input (rainfall excess) and the output (DRH). It represent time of travel of water from all parts of watershed to the outlet during a given storm.

The formulas for the methods are as below:

$$\mathbf{t_p = 5.5t_r} \tag{2.3}$$

$$\mathbf{t_{pR} = t_p - \frac{t_r - t_R}{4}} \tag{2.4}$$

$$\mathbf{\frac{U_p}{A} = C\frac{C_p}{t_p}} \tag{2.5}$$

$$\mathbf{\frac{U_{pR}}{A} = C\frac{C_pR}{t_p}} \tag{2.6}$$

where:

$\boldsymbol{t_{pR}}$ **=** lag of desired unit hydrograph (s)

$\boldsymbol{t_p}$ **=** duration of desired UH (s)

$\boldsymbol{U_p}$ **=** peak of standard UH (m^3/s)

$\boldsymbol{A}$ **=** watershed drainage area (m^2)

$\boldsymbol{C_p}$ **=** UH peaking coefficient

C = conversion constant (2.75 for SI unit)

Soil Conservation Service (SCS)

SCS Hydrograph is a dimensionless UH. The method is based on a study of large number of UH and developed by US Soil Conservation Services (SCS). For large watersheds, time of concentration t_c is more than duration (D) of constant rainfall intensity. Rainfall cannot last long enough that the peak flow, Q_p, will occur at time t_c. Instead, the peak flow, Q_p, will occur at time t_p, which is a function of rainfall duration D and the watershed characteristics represented by t_c.

The formulas for this method are below:

<u>UH (UNIT HYDROGRAPH) PEAK / DISCHARGE</u>

$$\mathbf{U_P = q_P = C\,\frac{A}{T_P}} \qquad \textbf{(2.7)}$$

where:

A = watershed area (m^2)

C = conversion constant (2.08 in SI unit)

TIME OF PEAK

$$T_P = \frac{\Delta t}{2} t_{lag} \tag{2.8}$$

where:

Δt = excess precipitation duration (s)

t_{lag} = the basin lag (s)

Clark's Unit Hydrograph

The method is based on the use of time-area method. The method of analysis uses the concept of instantaneous unit hydrograph (IUH). The excess precipitation is applied uniformly over a watershed which is broken into time-area increments. This method is unique in its derivation, which draws from the parameters and theories of Muskingum hydrograph routing, and its application. The method was developed for gaged sites only, although later work has produced some suggestions for transfer of Clark parameters to ungaged sites.

In addition to the linearity assumptions common to all unit hydrograph methods, the Clark unit hydrograph method assumes that the runoff volume generated from each time-area increment is proportional to the area size of that increment. Clark (1943) noted the following theoretical and practical limitations to his method:

- Hydrographs are likely to under predict on the recession side between the point of maximum recession rate and the point where subsurface flow begins to dominate.
- The method may not be applicable to very large drainage areas. The application may cause too slow a rise and too rapid a recession, due to the use of the same storage factor for points which are both near to and far from the outlet. Not provided with a recommendation on the maximum size of the drainage basin, but there is indication that the basin may be subdivided to overcome this drawback.

- While the method appears to account for drainage basin shape and the capacity to produce high peak flows, it is possible that these influences are exaggerated by the method.

The formula for the method as below:

AVERAGE OUTFLOW

$$\bar{O}_t = \frac{O_{t-1} - O_t}{2} \qquad \textbf{(3.0)}$$

where:

O_t = outflow from storage at time t

O_{t-1} = outflow from storage at time t-1

Root Mean Square Error (RMSE)

The Root Mean Square Error (**RMSE**) (also called the root mean square deviation, RMSD) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

The RMSE of a model prediction with respect to the estimated variable X_{model} is defined as the square root of the mean squared error:

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \tag{3.1}$$

where :

X_{obs} = observed values

X_{model} = modelled values at time/place i.

The calculated RMSE values will have units. However, the RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models.

2.4.2.4 Soil Conservation Service (SCS) Curve Number

The SCS curve number method is a simple, widely used and efficient method for determining the approximant amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The requirements for this method are very low, rainfall amount and curve number. The SCS Runoff Curve Number is developed by the United States Department of Agriculture (USDA) Soil Conservation Service. Despite the wide use of the curve number procedure, documentation of its origin and derivation are incomplete. (Hjelmfelt, 1991). The major disadvantages of the method are sensitivity of the method to Curve Number (CN) values, fixing the initial abstraction values ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions (AMC). However, the method is widely used and is accepted in numerous hydrological studies.

The formula for the method as below:

<u>ACTUAL RUNOFF</u>

$$Q = \frac{(P - 2S)^2}{(P + 0.8S)} \qquad (3.2)$$

where:

Q = actual retention after runoff begins

P = potential maximum runoff

S = potential maximum retention after runoff begins

2.5 SOFTWARE FOR ANALYSING RAINFALL AND RUNOFF DATA

2.5.1 HEC-HMS

HEC-HMS can help to set up the hydrologic model system and simulate the rainfall-runoff process of a watershed. Use of the hydrologic model as the parameter depending on rainfall characteristics and general ground is regarded as the independent variable to establish the relationship between model parameters and rainfall characteristics and geological factors. According to the discharge of hydrographs of selected rainfall events, the characteristics of a hydrologic parameter in the basin can be determined by trial and error. HEC-HMS is a hydrological modelling programme from Hydrological Engineering Centre (HEC) to stimulate the hydrological process of the watershed system. (M.L Ramli and S. Harun, 2009).

CHAPTER 3

METHODOLOGY

3.1 SITE DESCRIPTION

The area of study to determine the rainfall and runoff relationship using Hydrological Modelling System (HEC-HMS) is at Sg. Lemoi, Sg. Bertam and also Sg. Telum. These three rivers are located at CAMERON HIGHLAND which have an area of 712km^2. The estimated terrain elevation above sea level of Sg. Lemoi is 164m. Rainfall and stream flow stations are at the selected places at these three rivers and the analysis will be done based on the data collected from these stations

3.2 FLOW CHART OF METHODOLOGY

This flow chart shows the methodology used in this research as shown in Figure 3.1.

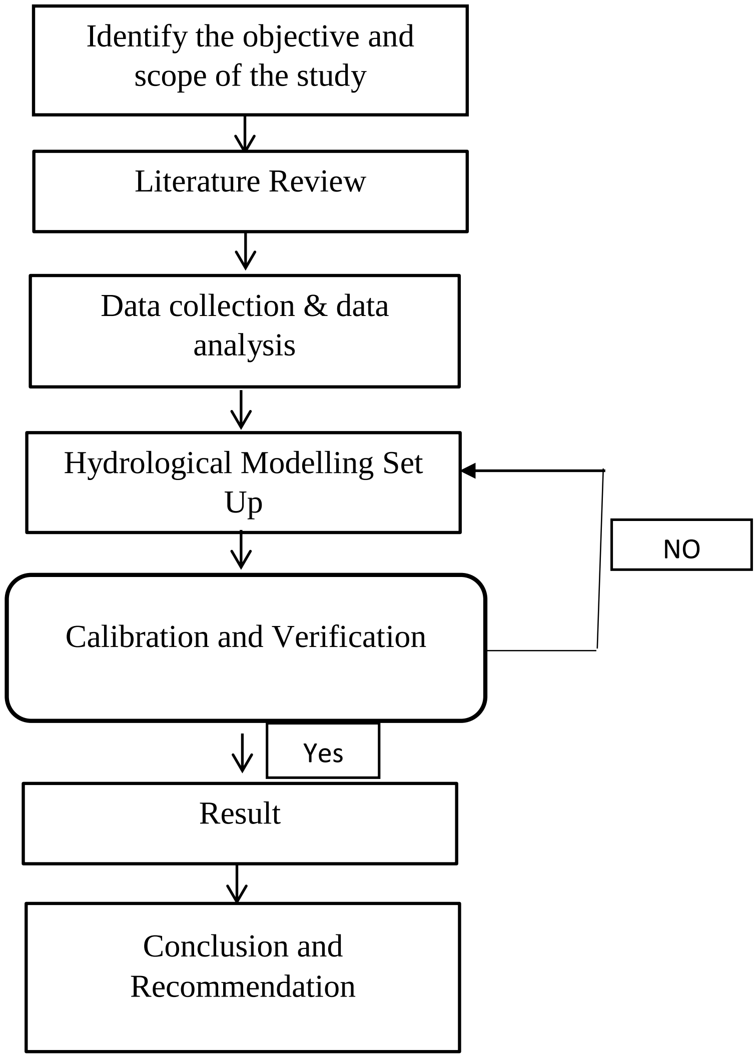

Figure 3.1: Flowchart of the study

3.3 DATA COLLECTION

The data needed in doing this study will be the rainfall data and also the stream flow data at the study area. The data needed was taken from Jabatan Pengairan dan Saliran (JPS) from the year 1999 until 2014. For the rainfall data, in order to have the rainfall data and calibrate the model, suitable rainfall stations have been identified at the study area. The stations have the numbers which are 4414037, 4414038, and 4514032. As for the stream flow data, there is stream flow gauging station at Sg, Jelai in Kuala Medang that have a number of 4218416.

3.4 HEC-HMS

The Hydrological Modelling System is a software used to stimulate a rainfall and runoff model of the proposed area using the available rainfall runoff data and also the streamflow data. Hydrograph will be produced from the analysis of the model created. The methods to be used in the analysis of basin will be Transform Method (Clark Unit Hydrograph) and also SCS Unit Hydrograph method. Not only that, in the basin analysis, SCS Curve Number method also be used. Whereas for the river routing, Lag method will be used for the analysis. For the basin analysis, there will be two methods to be used because there will be a comparison between the results obtained between the two methods and the best method will be proposed.

Clark Unit Hydrograph

Clark Unit Hydrograph is one of the synthetic unit hydrograph and it is based on linear reservoir model. The parameters involved are the time of concentration which is the time of flow from the farthest point on the watershed to the outlet, storage time which is the storage constant with the linear reservoir model. The process of the Clark Unit hydrograph are as follow:

1. Estimate the contribution area with the time-area relationship.
2. Calculate the average inflow to the storage at specific time.
3. Calculate the Unit Hydrograph ordinates.

SCS Curve Number

The method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. The parameters involved are actual retention after runoff begins, potential maximum runoff and also the potential maximum retention after runoff begins.

CHAPTER 4

RESULT AND DISCUSSION

4.1 HEC-HMS

The software Hec-Hms used in this study to simulate the rainfall-runoff relationship model. The catchment model of the study area is shown in **Figure 4.1**. The catchment consists of 29 proposed sub basins. The result analysed consist of data from three rainfall station in this study and also data from RF4218042 and first trial station RF4514032 data. The same goes for RF4620046 which is the second trial.

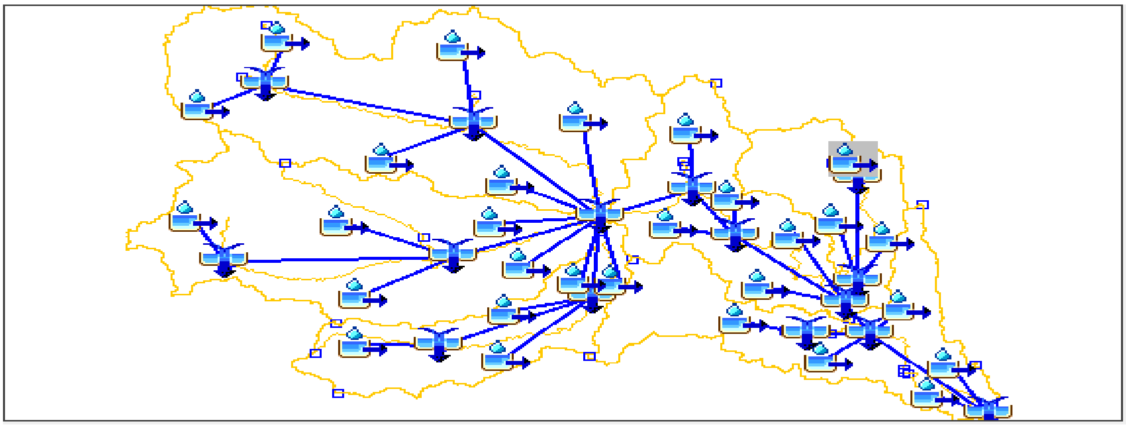

Figure 4.1: Simulated Rainfall-Runoff Model using Hec-Hms

4.1.1 Model Parameters

The parameters used in this study plays important role in obtaining best analysis result. The following are the parameters used in this study:

Transform Method (Clark Unit Hydrograph)

The storage coefficient, R and time of concentration, T_c are the parameters involved in the analysis. The values of each R and T_c are different for each of the sub basins.

The formula used for the method as below:

<u>AVERAGE OUTFLOW</u>

$$\boldsymbol{T_c \text{ (Time of concentration)} = 2.32\, A^{-0.1188} L^{0.9573} S^{-0.5074}} \quad \textbf{(4.1)}$$

$$\boldsymbol{R \text{ (Storage coefficient)} = 2.976\, A^{-0.1943} L^{0.9995} S^{-0.4588}} \quad \textbf{(4.2)}$$

where:

A = Area of Sub basin (km^2)

L = Length of river (km)

S = Slope of river ($\frac{\Delta h}{L}$)

Table 4.1 shows the values calculated.

Table 4.1: Values of R and T_c for each sub basin

No. of Sub basin	R	T_c
1	2.0562	1.7266
2	1.4847	1.2444
3	1.9214	1.5953
4	1.3765	1.1460
5	0.7875	0.6246
6	0.6676	0.5293
7	0.7373	0.5953
8	1.8514	1.6068
9	0.8880	0.6824
10	0.6008	0.4646
11	1.3758	1.1445
12	1.9489	1.5811
13	0.4750	0.3646
14	0.4274	0.3098
15	0.3551	0.2662
16	0.2208	0.1630
17	1.8908	1.5919
18	0.4639	0.3583
19	0.4707	0.3398
20	0.4105	0.3125
21	1.0981	0.8593

22	0.3789	0.2861
23	0.5521	0.4432
24	0.2917	0.2251
25	0.5802	0.4556
26	0.5215	0.3993
27	1.1503	0.9214
28	0.3212	0.2336
29	1.7366	1.3887

SCS Curve Number

The parameters in this method includes initial abstraction where it is the value to account for interception and depression storage, the curve number determined by using the soil hydrological type classification with land use type classification tables, impervious area in percentage represents the friction of the area that is impervious.

The formula used for the method as below:

$$\boldsymbol{I_a = 0.2S} \qquad \textbf{(4.3)}$$

where:

$S = \frac{25400 - 254CN}{CN}$

CN(Curve Number) = 30

Impervious = 10%

The **Figure 4.1 (a)** shows the example for a sub basin in Hec-Hms in which the parameters are inserted.

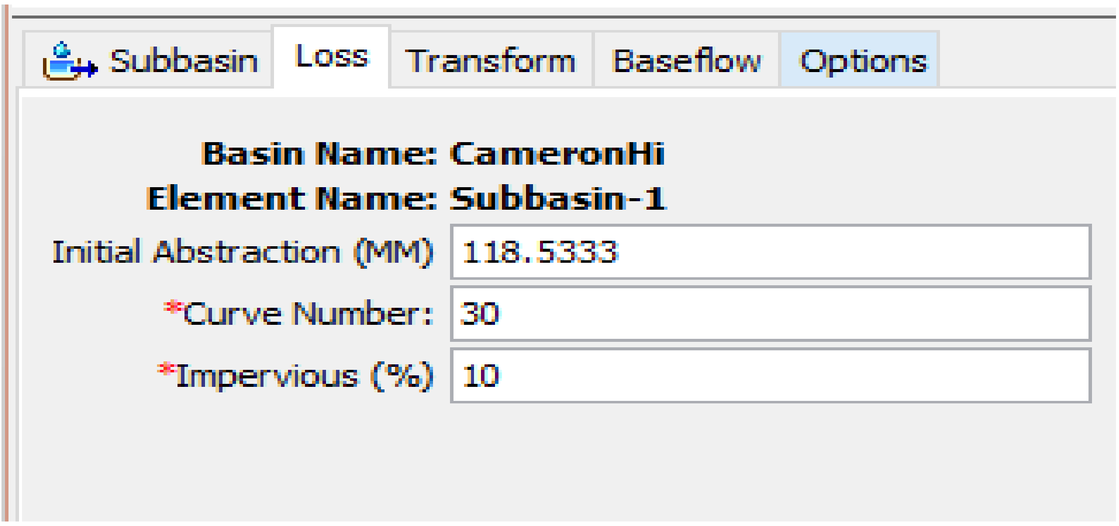

Figure 4.1(a): Example of SCS Curve Number parameter inserted in one of the sub basin

Baseflow

There are few types of parameters that can be used in this method which include constant monthly, recession and nonlinear reservoir. The parameter used in this study is constant monthly. The **Figure 4.1(b)** shows an example of base flow value in one of the sub basin.

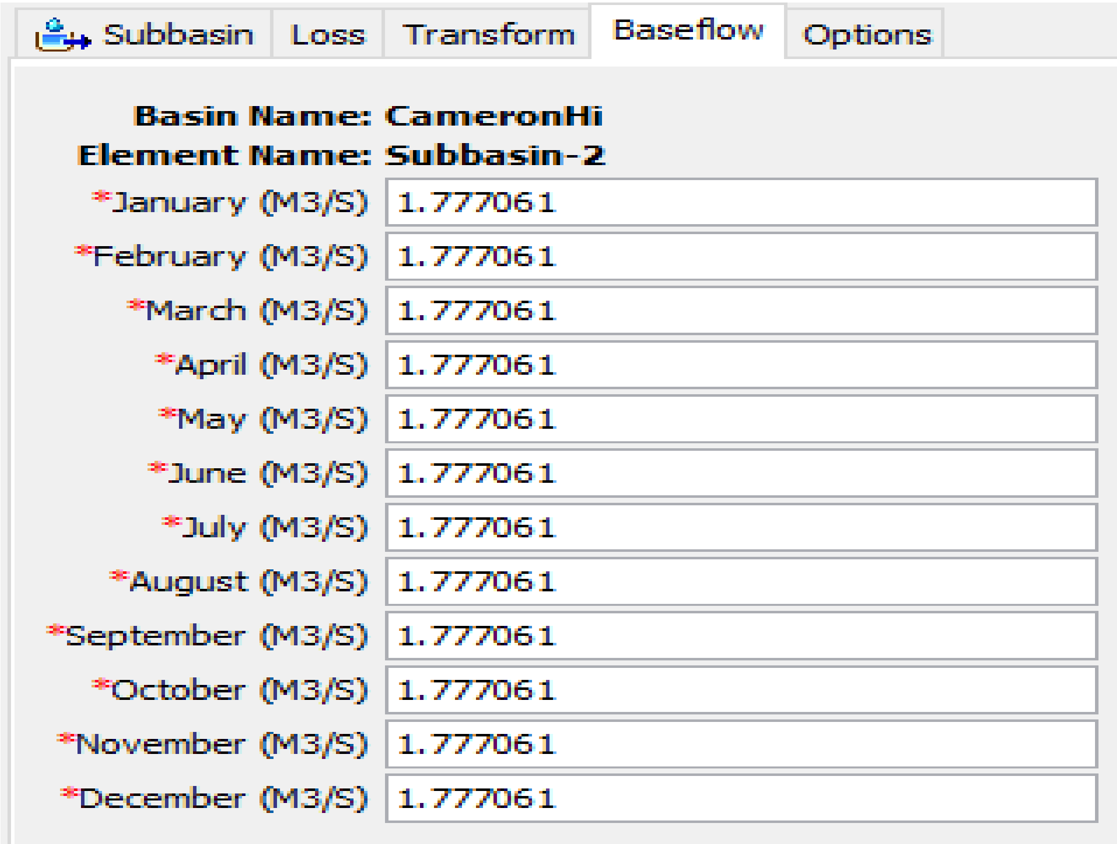

Figure 4.1(b): Example of Base flow parameter inserted in one of the sub basin

Lag Time

Lag time is also one of the parameter used in this study. Lag time is the time from centroid of rainfall excess to the peak flow at the point of analysis. The lag time is inserted for each reach in the Hec-Hms model. The **Table 4.1(a)** shows the values of lag time for each reach.

Table 4.1(a): Value of Lag Time for each reach

No. of Reach	Lag Time (minute)
1	15.76
2	14.76
3	40.89
4	14.28
5	6.7
6	39.92
7	5.66
8	13.42
9	5.01
10	49.95
11	15.44
12	13.39
13	22.37
14	6.97
15	4.76
16	13.64
17	16.86

18	3.68
19	2.57
20	13.9
21	2.84
22	1.52
23	11.68
24	8.79
25	10.11
26	2.14
27	46.08
28	4.02
29	3.65
30	2.27
31	46.89
32	4.82
33	2.79
34	19.09
35	5.26
36	3.65
37	9.07
38	44.5
39	3.10
40	3.10
41	2.39
42	1.44
43	8.88

4.2 RAINFALL AND RUNOFF RELATIONSHIP ANALYSIS

Characteristics of rainfall including its duration and intensity affects the quantity of runoff generated. Clark Unit Hydrograph method used in this study to analyse the observed rainfall data to produce runoff values and determine the peak discharge in the catchment and compare it with the observed discharge data. The result of hydrographs and tables shown are the analysis of rainfall and stream flow for April and December 1999, November 2002, April and June 2003, September 2010 and January 2014. The data taken in term of 24 hours period of time. The sample of observed stream flow and rainfall data are shown in **Appendix A** and **Appendix B**.

April 1999

For April 1999, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be 261.41 m^3/s and the maximum simulation discharge will be $155.6m^3$/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be 261.41 m^3/s and the maximum simulation discharge will be $185.1m^3$/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.2**. The hydrographs are shown in **Figure 4.2 (a) and (b)**.

Table 4.2: Simulated Discharge, (Q - m^3/s) values

APRIL 1999	RF4514032	RF460046
5	92.8	93
6	107.7	107
7	106.3	102.9
8	90	86.5
9	95.7	93.1
10	97.5	94.6
11	91.1	87.6
12	86	84
13	92.3	91.1
14	119.8	118.5
15	155.6	156.1
16	153.5	155.8
17	124.2	126.4
18	106.6	110.5
19	100.3	107.7
20	119.2	127.2
21	125.3	132.7
22	103.1	111.4
23	94.9	103.1
24	94.1	100.5
25	87.3	91.9
26	82.6	89.8
27	80.2	101
28	81.6	122.5

29	83.2	139.3
30	129	185.2

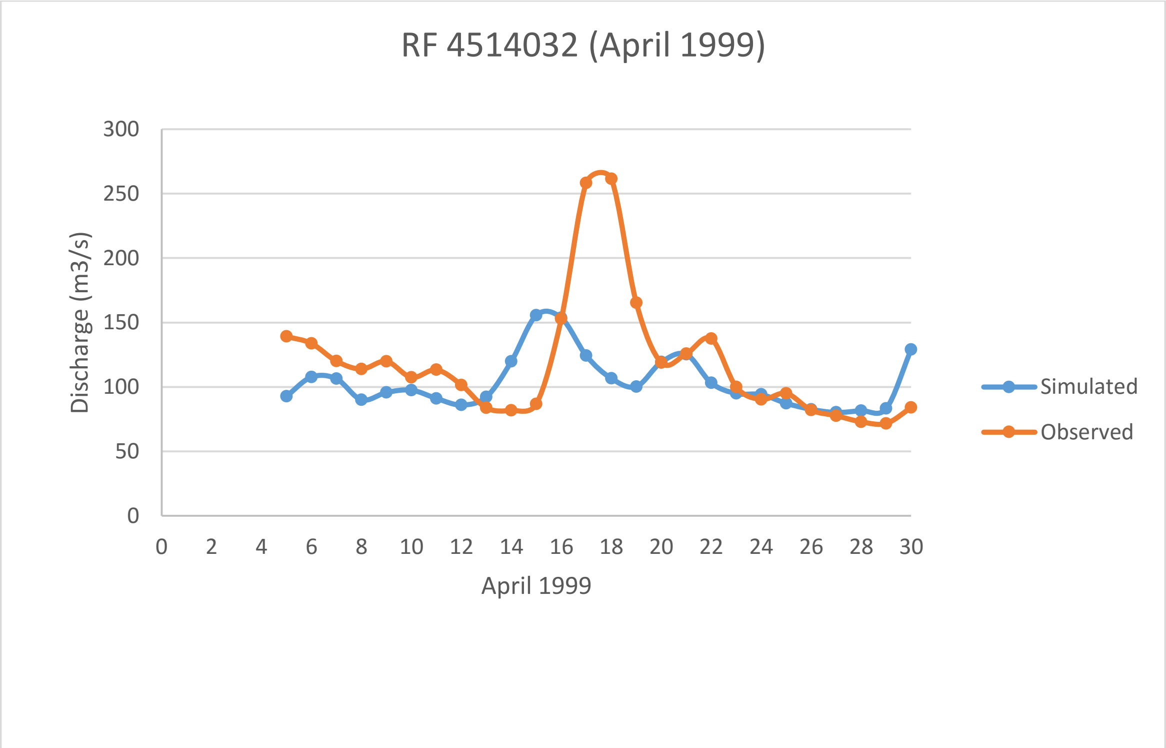

Figure 4.2(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for April 1999

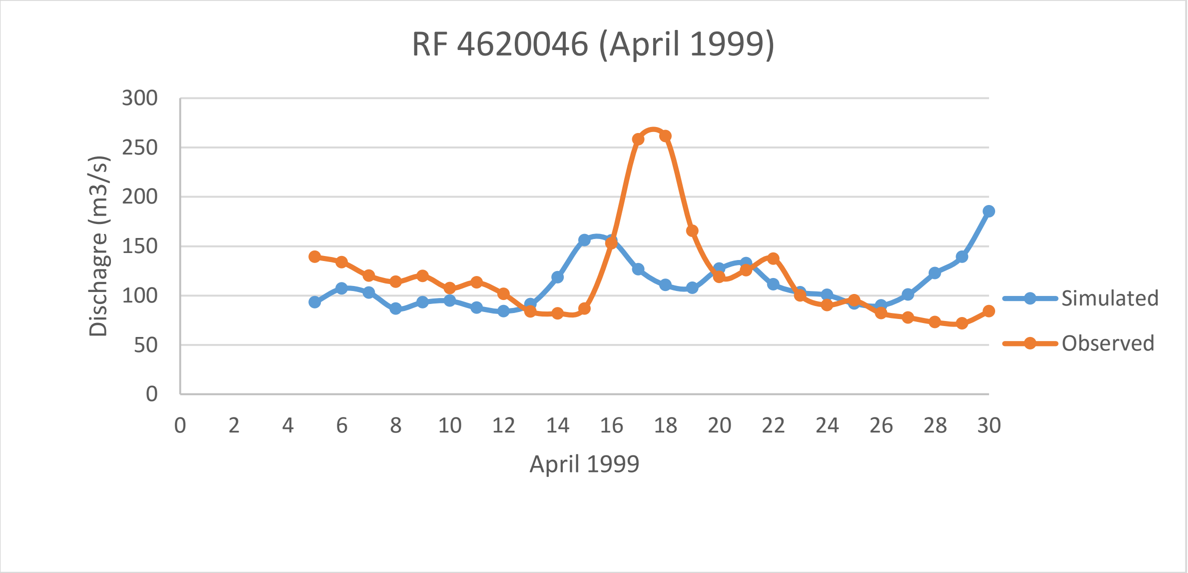

Figure 4.2(b): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for April 1999

December 1999

For December 1999, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be 412.98 m^3/s and the maximum simulation discharge will be $279.1m^3$/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be 412.98 m^3/s and the maximum simulation discharge will be $253.8m^3$/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.3**. The hydrographs are shown in **Figure 4.3 (a) and (b)**.

Table 4.3: Simulated Discharge, (Q - m^3/s) values

DECEMBER 1999	RF4514032	RF460046
1	70.3	70.3
2	77.8	75.6
3	87.7	81.8
4	110.3	101.6
5	120.3	110.1
6	103.7	94.2
7	92.9	85.2
8	84.3	78.2
9	79.8	75.3
10	81.1	77.7
11	83.3	80.8
12	84.7	82.5
13	105.4	103.2
14	160.3	156.3
15	184.2	177.4
16	141.2	132.5
17	152.8	141.1
18	199.5	180.7
19	279.1	253.8
20	267.5	239.7
21	179.9	152.5
22	163.6	139.8
23	126.4	107.5
24	107.1	89.4

25	130.5	110.7
26	145.3	123.4
27	131	102.8
28	122.5	86.7
29	117.1	80.8
30	127.9	91.5
31	164.1	124.5

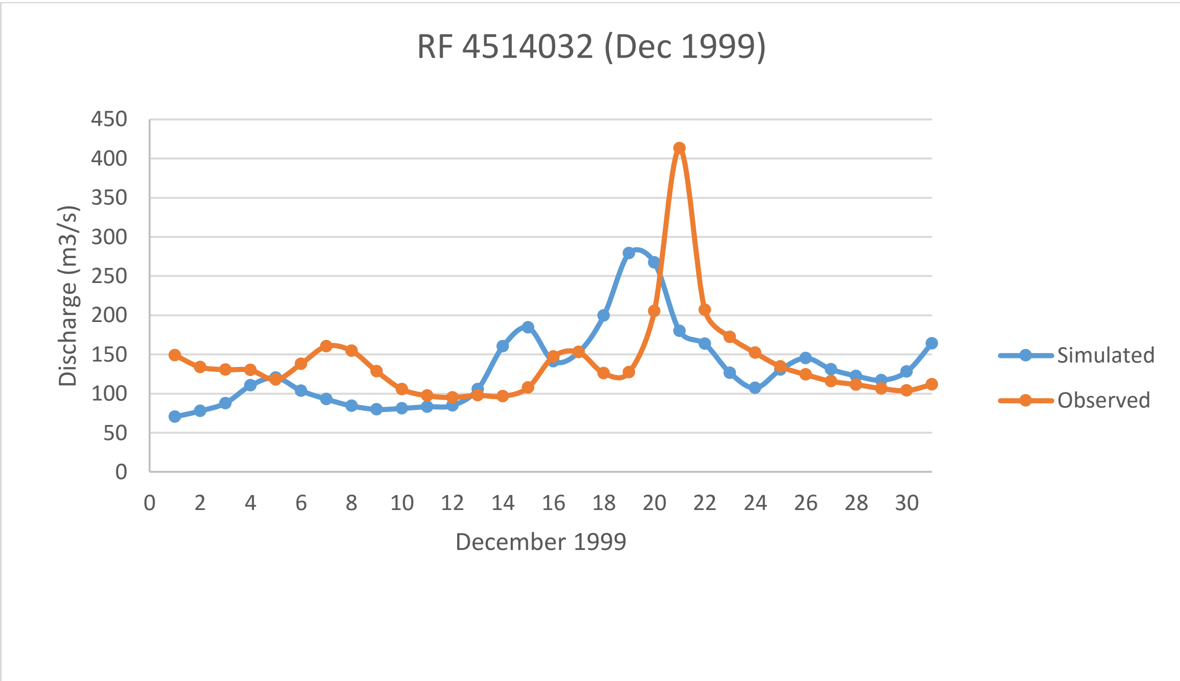

Figure 4.3(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for December 1999

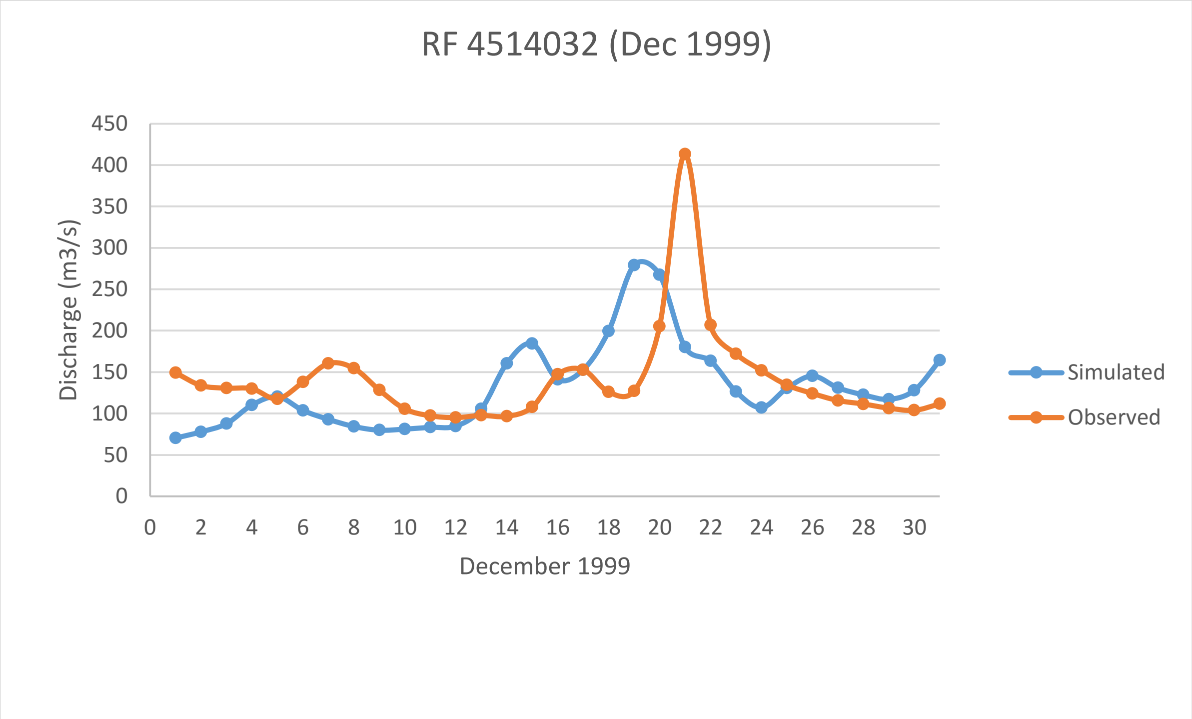

Figure 4.3(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for December 1999

November 2002

For November 2002, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be 269.34 m^3/s and the maximum simulation discharge will be $270.3m^3$/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be 269.34 m^3/s and the maximum simulation discharge will be $214.8m^3$/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.4**. The hydrographs are shown in **Figure 4.4 (a) and (b)**.

Table 4.4: Simulated Discharge, (Q - m^3/s) values

NOVEMBER 2002	RF4514032	RF460046
1	70.3	70.3
2	71.7	71.7
3	72.3	72.3
4	75.4	74.5
5	78.6	76.5
6	99.7	94.5
7	108.8	99.4
8	95.7	85
9	109.9	100.3
10	119.9	111.2
11	107.1	97.2
12	96.2	84
13	93	80.8
14	109	94.3
15	116.8	98.1
16	108.2	88.1
17	122.7	96.6
18	183.7	146.2
19	198.9	154.5
20	175.8	133.6
21	149.8	116.1
22	139.8	107.2
23	223.3	176.9
24	270.3	214.8

25	207	158.9
26	144.1	108
27	123.8	97.1
28	118.8	98.6
29	114.7	98.8
30	103.5	90.6

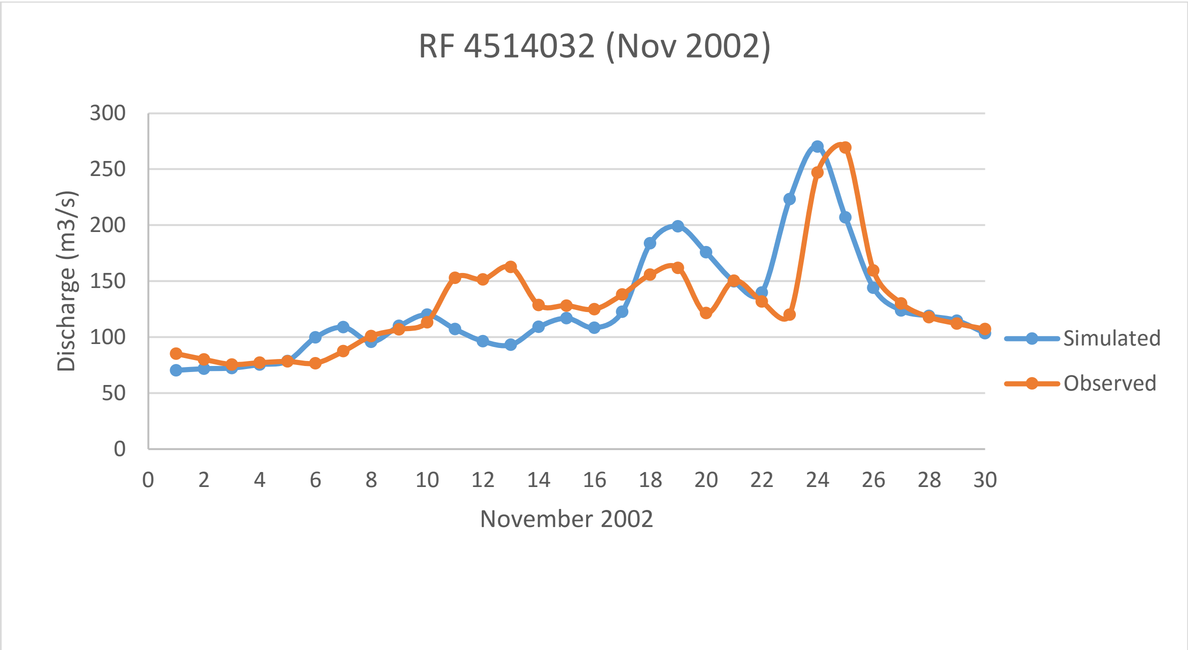

Figure 4.4(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for November 2002

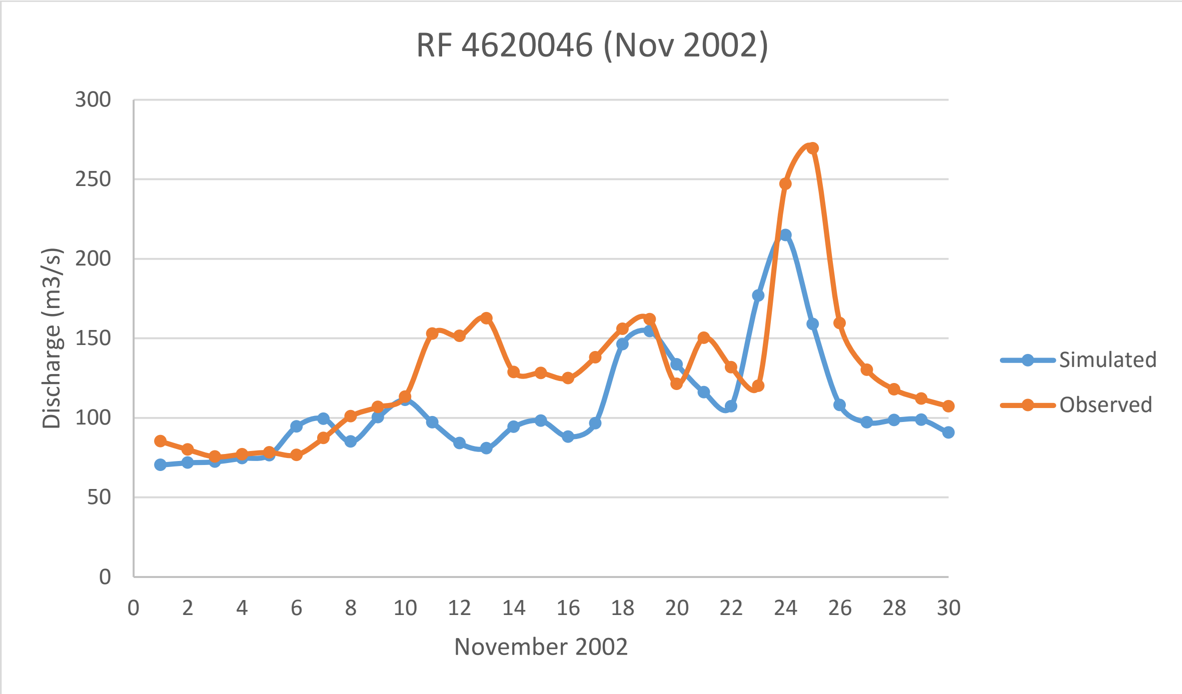

Figure 4.4(b): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for November 2002

June 2003

For June 2003, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be $127.27m^3$/s and the maximum simulation discharge will be $135.4m^3$/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be $127.27\ m^3$/s and the maximum simulation discharge will be $130m^3$/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.5**. The hydrographs are shown in **Figure 4.5 (a) and (b)**.

Table 4.5: Simulated Discharge, (Q - m^3/s) values

JUNE 2003	RF4514032	RF460046
5	73	72.4
6	74.4	72.3
7	76.6	72.5
8	75.6	71.1
9	114.3	109.4
10	135.4	130
11	98.5	93.7
12	76.8	73
13	74.4	71.5
14	85.5	82.4
15	89.2	85.4
16	87.8	84.3
17	98.9	95.8
18	93.8	91.2
19	115.3	112
20	119.5	113.9
21	130.5	121.2
22	132.5	119.6
23	92.7	79.6
24	87	76.1
25	83	74.5

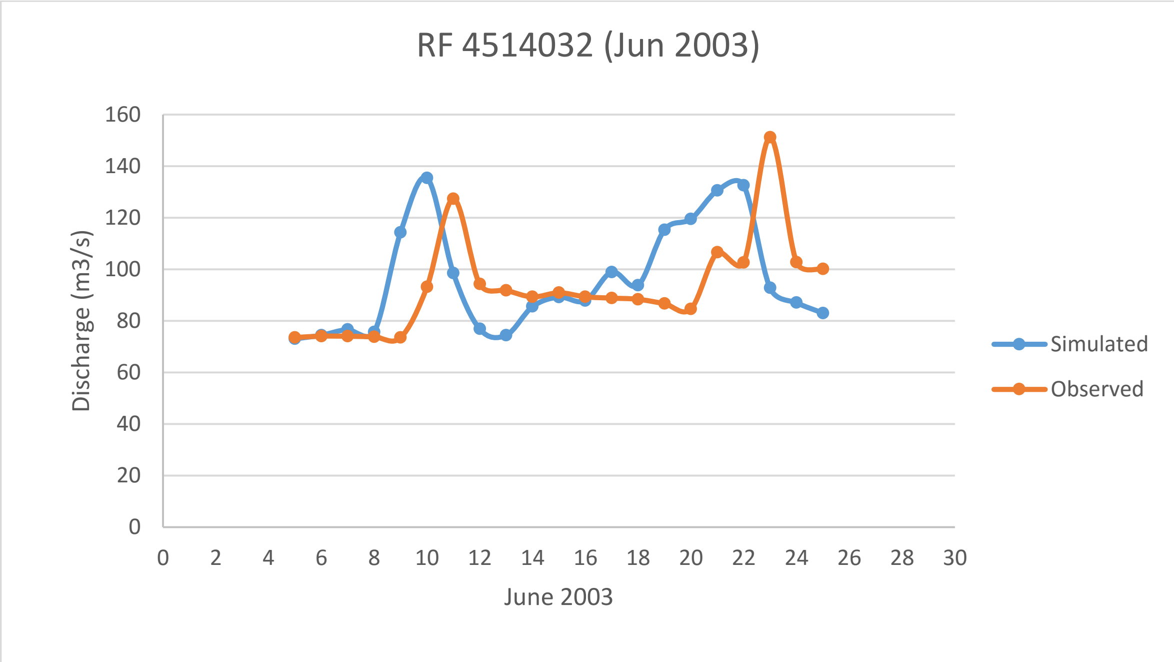

Figure 4.5(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for June 2003

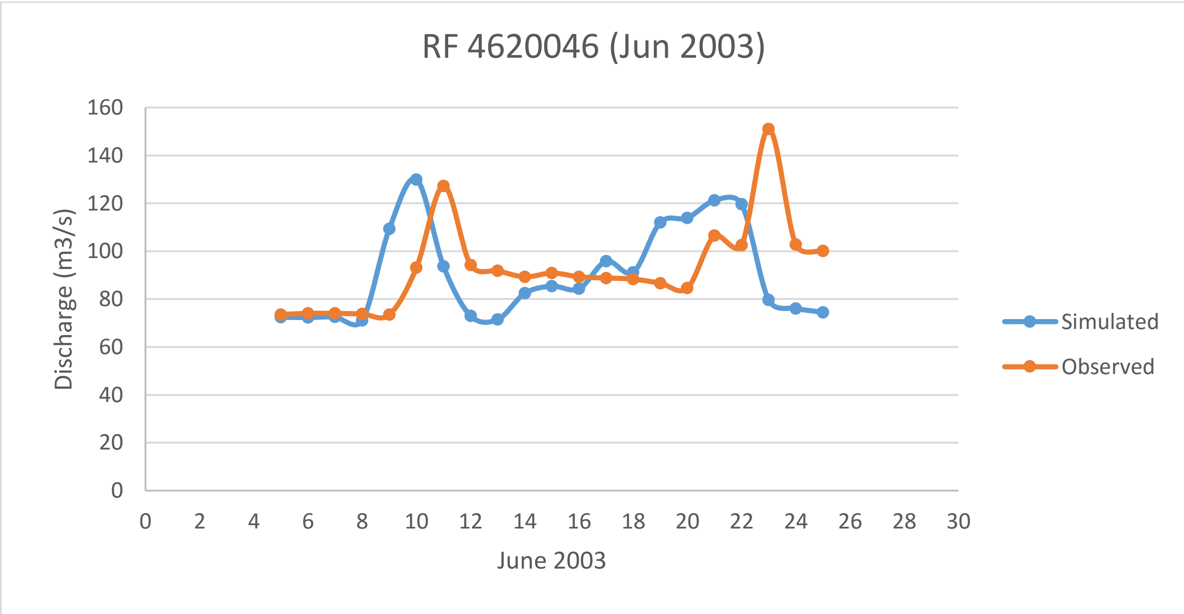

Figure 4.5(b): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for June 2003

September 2010

For September 2010, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be 265.66 m^3/s and the maximum simulation discharge will be 215.8m^3/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be 265.66 m^3/s and the maximum simulation discharge will be 178.2m^3/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.6**. The hydrographs are shown in **Figure 4.6 (a) and (b)**.

Table 4.6: Simulated Discharge, (Q - m^3/s) values

SEPTEMBER 2010	RF4514032	RF460046
1	70.3	70.3
2	71.6	71
3	74.6	72.8
4	77.9	76.6
5	77.2	77.9
6	77	79
7	78.1	80.9
8	75.6	79.3
9	76.4	80.7
10	77.4	81.2
11	89.1	92
12	93.9	98.1
13	81.8	87
14	79.1	83.2
15	78.5	81
16	82.5	86.2
17	87.8	92.1
18	107	108.1
19	156.3	145.5
20	242.1	212.3
21	233.5	191.4
22	172.8	125.5
23	163.3	117
24	138.9	98.9

25	130.7	98.2
26	143.5	108
27	201.3	159.5
28	215.8	178.2
29	202.6	170.5
30	169.5	142

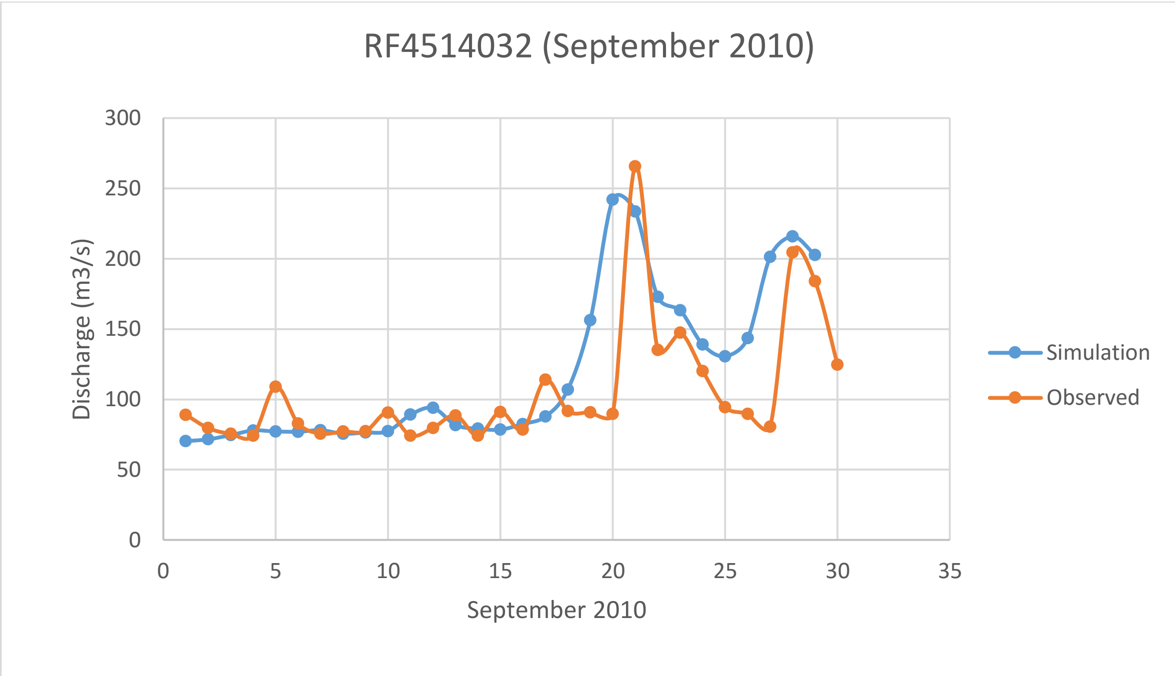

Figure 4.6(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for September 2010

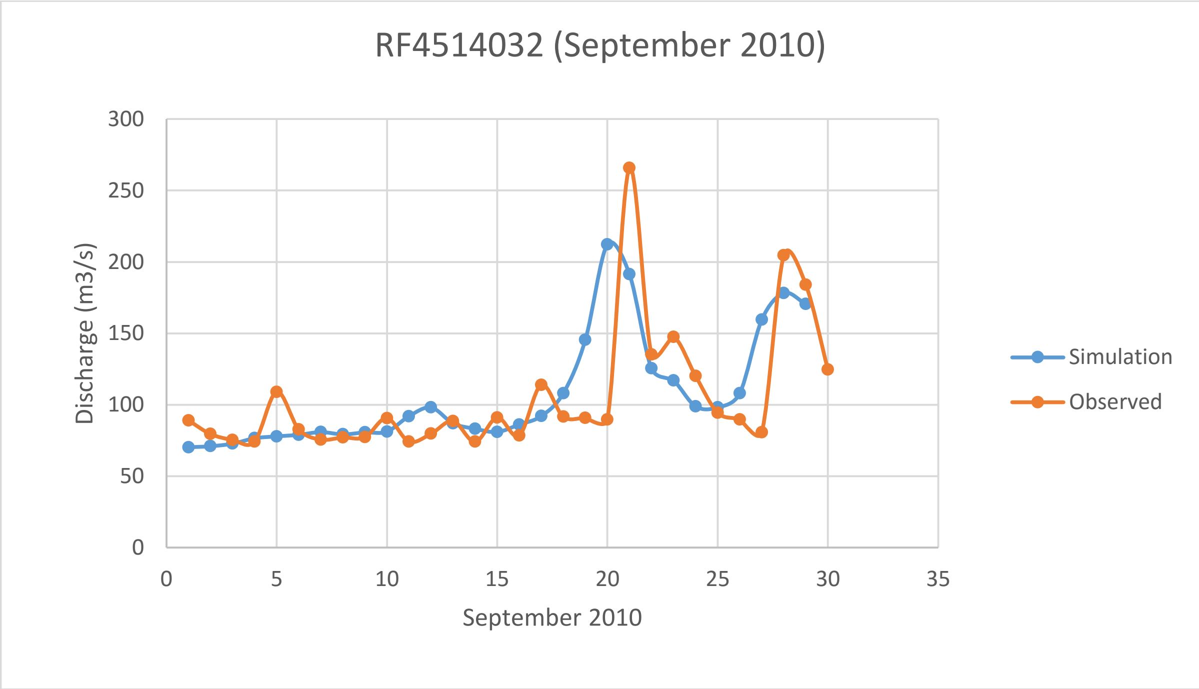

Figure 4.6(b): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for September 2010

January 2014

For January 2014, the observed rainfall and stream flow data used is taken for 24 hours per day which is starting from 8.00 morning till the same time next day. The graph shows the comparison between observed stream flow data and also the outflow result from the simulation. For rainfall station RF4514032, the maximum observed discharge at the stream flow station SF4218146 will be $345.33m^3$/s and the maximum simulation discharge will be $159m^3$/s. On the other hand, for rainfall station RF4620046, the maximum observed discharge at the stream flow station SF4218146 will be 345.33 m^3/s and the maximum simulation discharge will be $157.4m^3$/s. The simulated discharge values for both the rainfall stations are shown in **Table 4.7**. The hydrographs are shown in **Figure 4.7 (a) and (b)**.

Table 4.7: Simulated Discharge, (Q - m^3/s) values

JANUARY 2014	RF4514032	RF460046
1	70.3	70.3
2	70.8	70.8
3	76.9	77
4	77.6	77.9
5	73.7	74.2
6	75	75.9
7	74.6	75.6
8	73.4	74.4
9	89.1	89.9
10	151	150.8
11	159	157.4
12	113.5	111.6
13	101.8	100.2
14	93.7	92.2
15	87.5	86.4
16	86	85.2
17	84	83.2
18	79.6	78.9
19	77.2	76.5
20	75.5	75
21	74.5	74.1
22	73.7	73.4
23	73.1	72.8
24	72.6	72.4

25	72.2	72
26	72.4	72.2
27	73.4	73.1
28	73	72.5
29	71.9	71.3
30	71.4	71
31	71.2	70.9

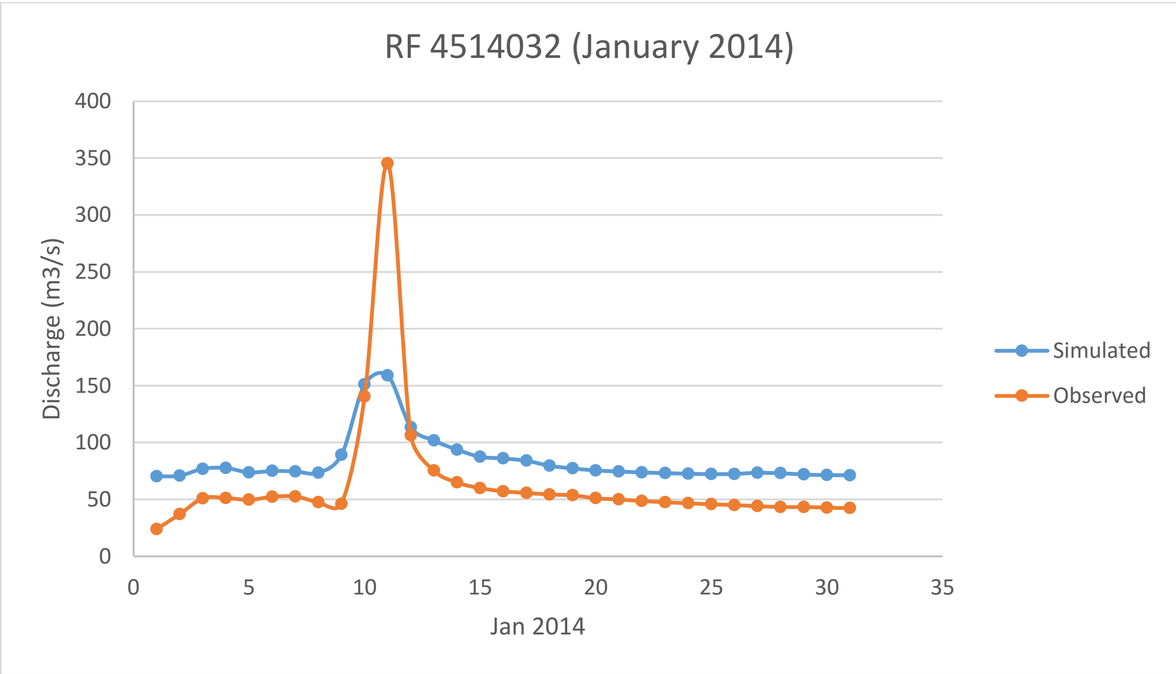

Figure 4.7(a): Hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for January 2014

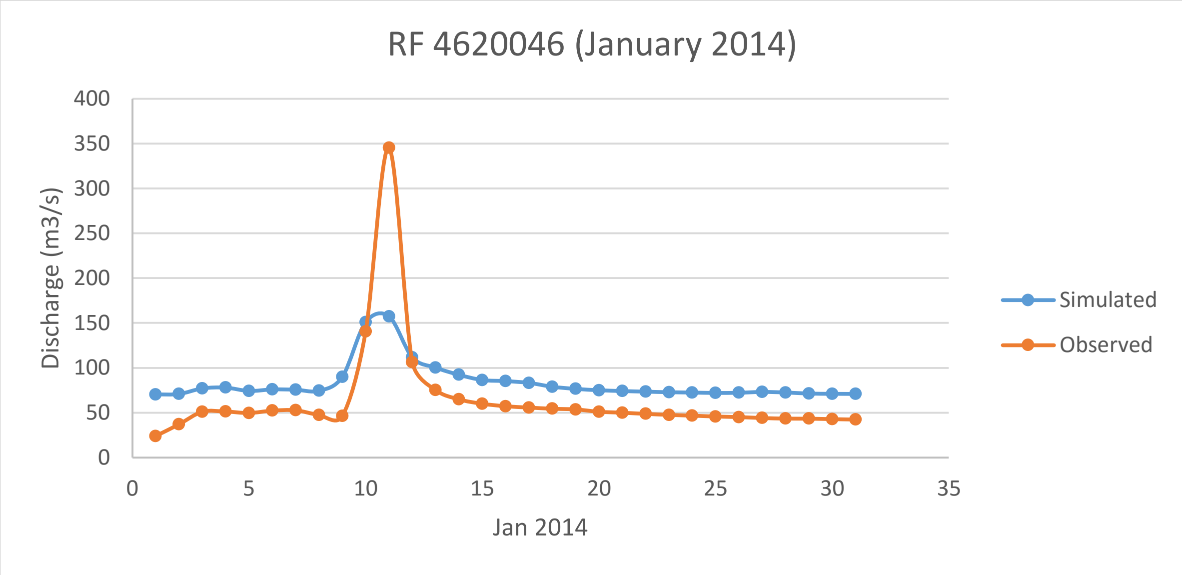

Figure 4.7(b): Hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for January 2014

4.3 CALIBRATION

The simulated model in Hec-Hms is calibrated in term of base flow values. As stated before, the method used to insert the values of base flow in Hec-Hms is constant monthly. The value of base flow inserted for 12 months for each sub basin. The original equation for base flow multiplied by coefficient of 0.43 to calibrate the model. The model is calibrated to confirm whether the model is suitable to analyse the relationship between the observed data and also simulation data. As a result from the calibration process, **Figure 4.8 (a) and (b)** shows the hydrographs generated for August 2003, **Figure 4.9 (a) and (b)** shows the hydrographs generated for February 2004.

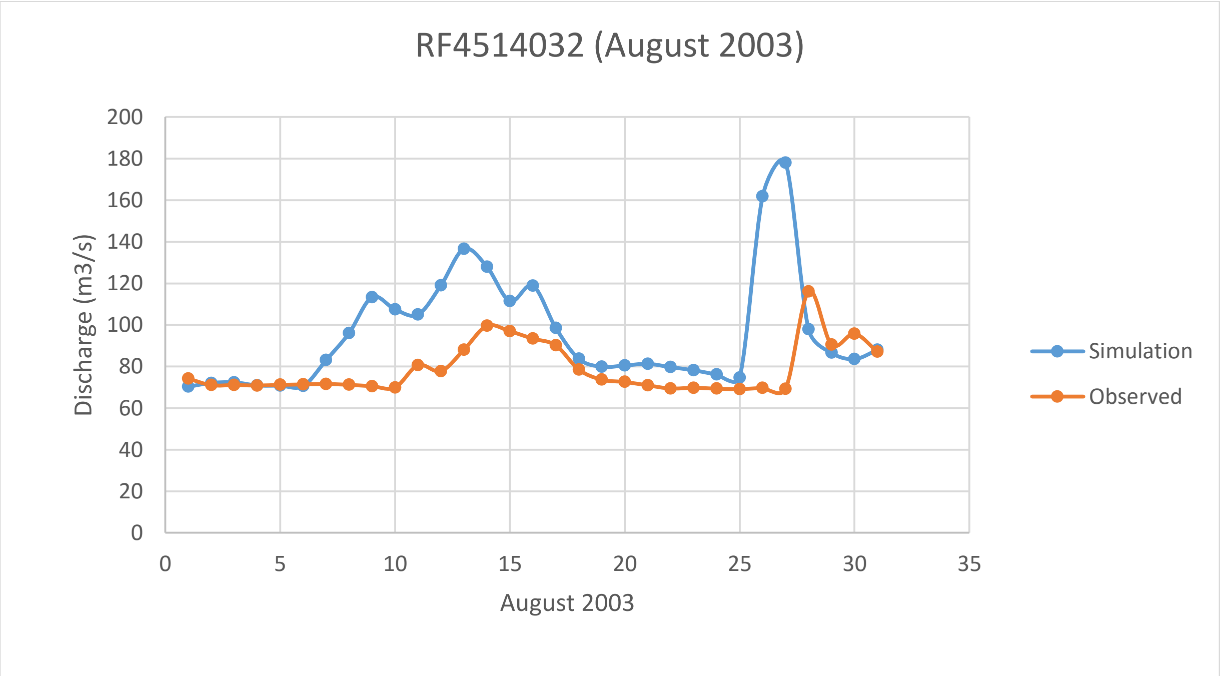

Figure 4.8(a): Calibrated hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for August 2003

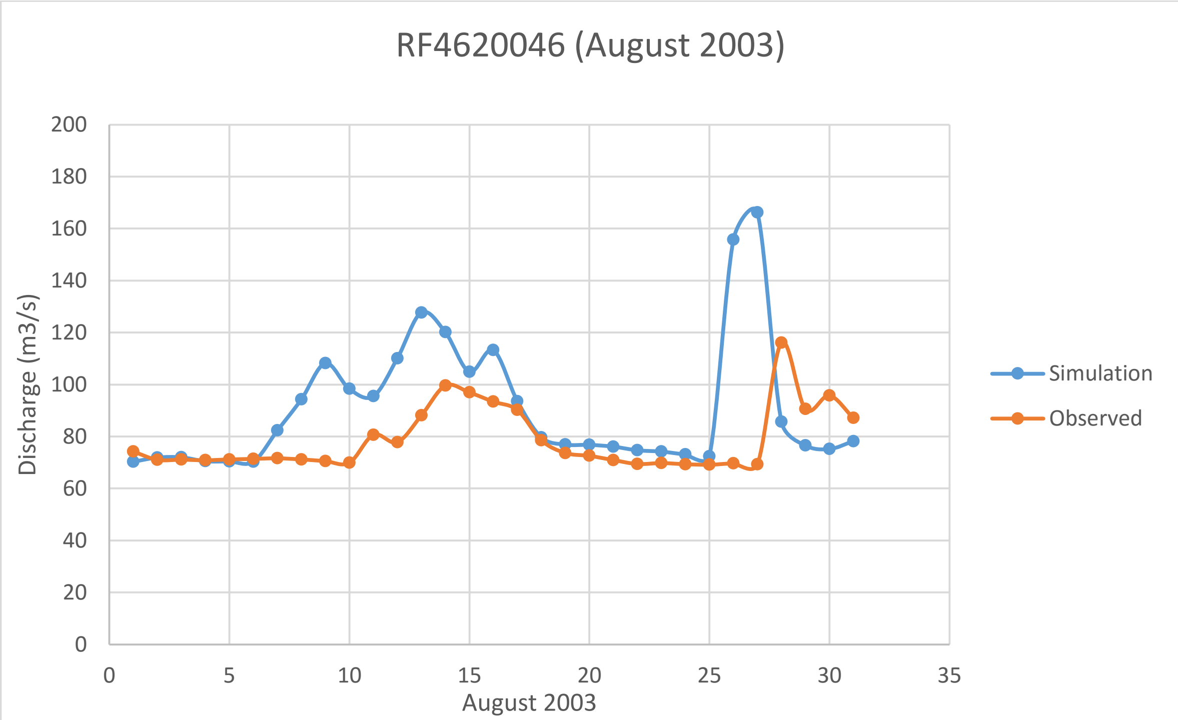

Figure 4.8(b): Calibrated hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for August 2003

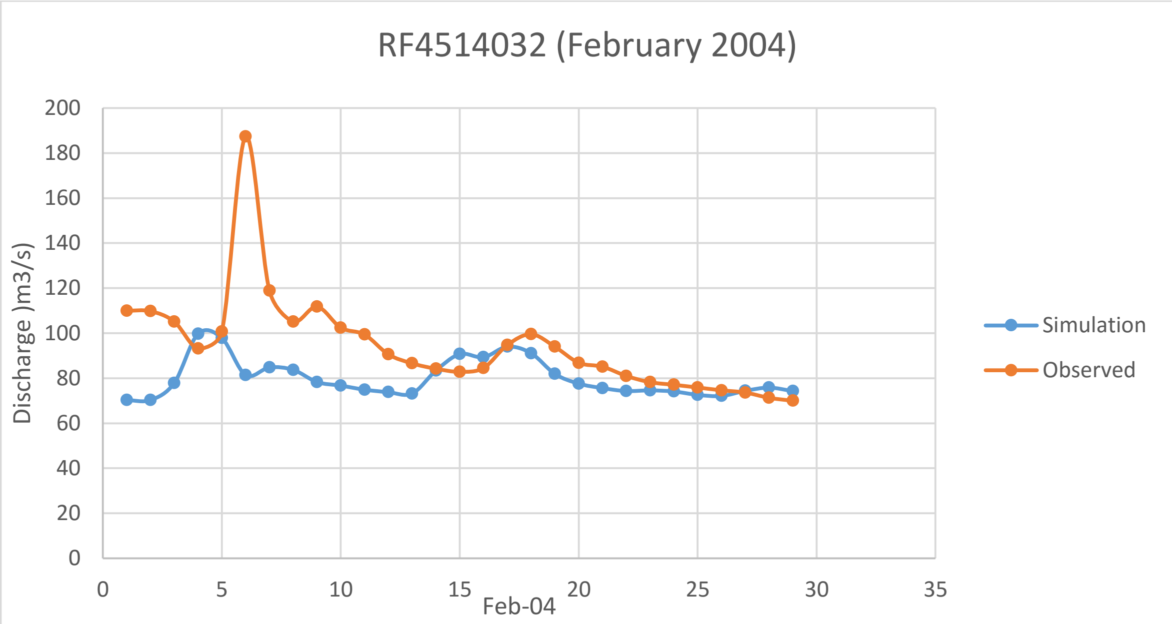

Figure 4.9(a): Calibrated hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for February 2004

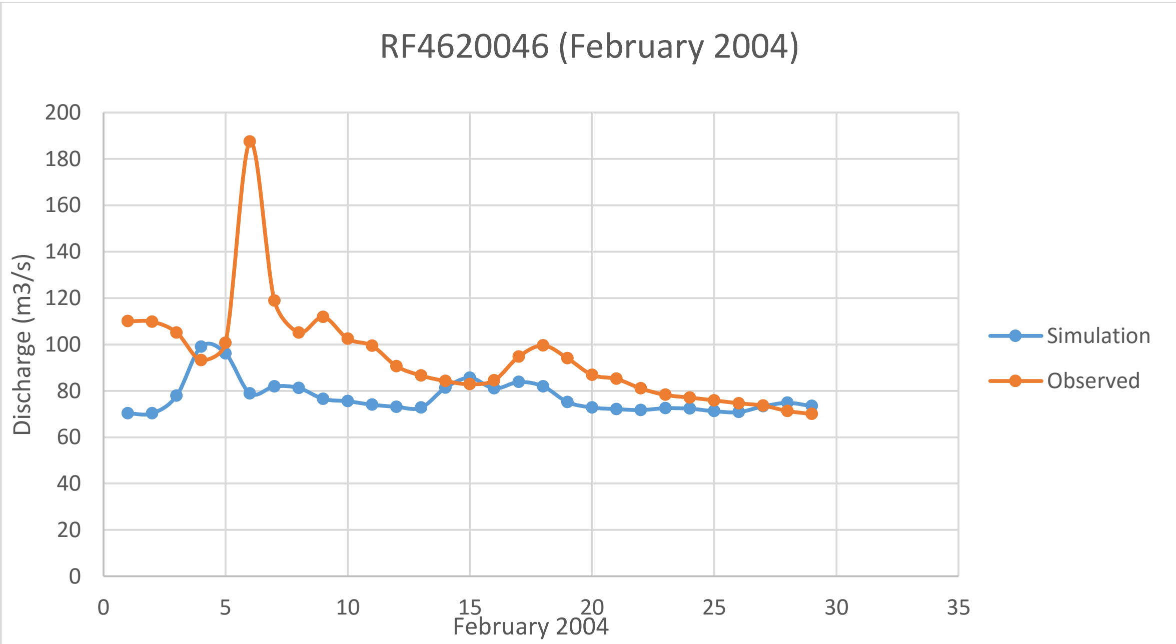

Figure 4.9(b): Calibrated hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for February 2004

4.4 EVALUATION OF MODEL USING ROOT MEAN SQUARE ERROR (RMSE)

Root Mean Square Error (RMSE) calculated to show the relationship of the simulated flow and the observed flow. If the RMSE value is lesser, it would indicate that the variables are positively linear related. During evaluation of model, the best value of RMSE value is $11.1 m^3/s$ which is a low value. It shows that the simulated models were fit with the observed data and proves that the HEC-HMS is suitable to predict and analyse rainfall-runoff relationship at the study area.

Figure 4.10 (a) and (b) shows the hydrographs generated for July 2000 with the RMSE value, **Figure 4.11 (a) and (b)** shows the hydrographs generated for February 2001 with the RMSE value.

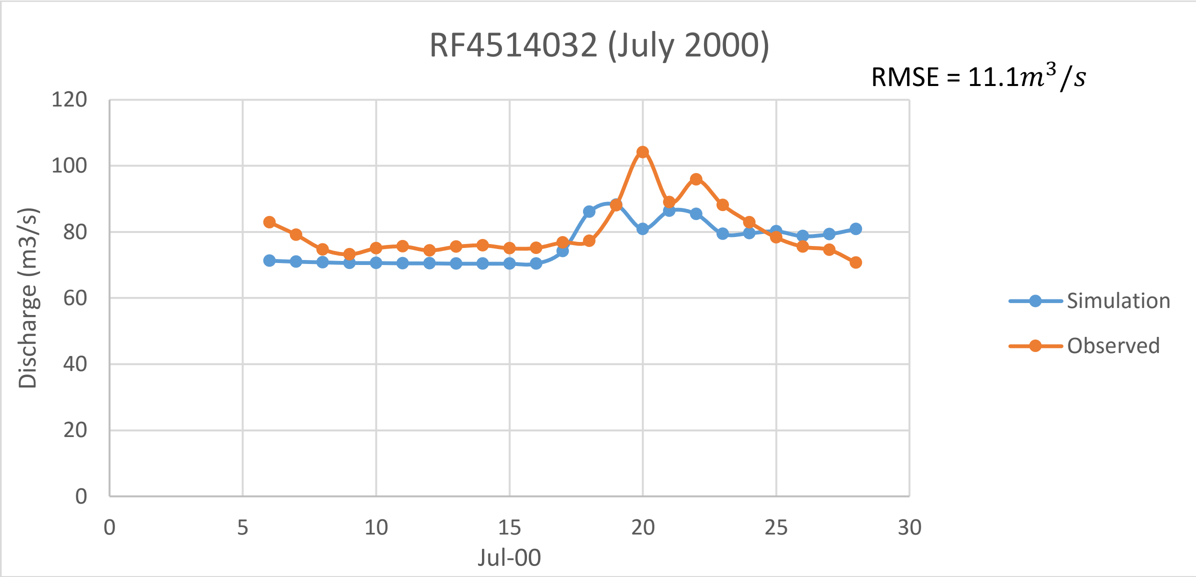

Figure 4.10(a): RMSE value hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for July 2000

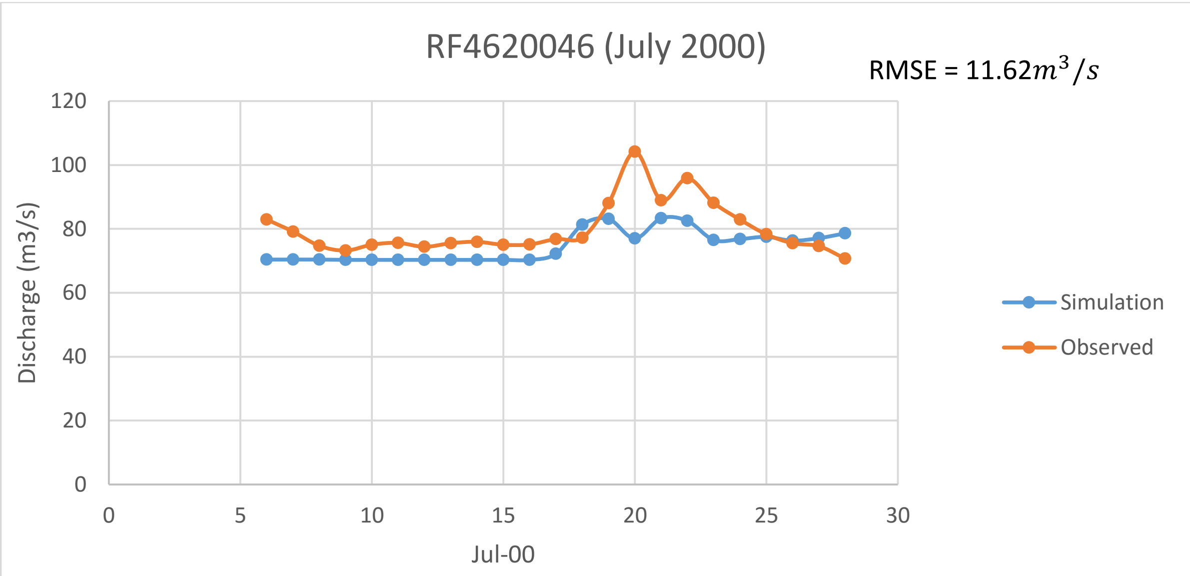

Figure 4.10(b): RMSE value hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for July 2000

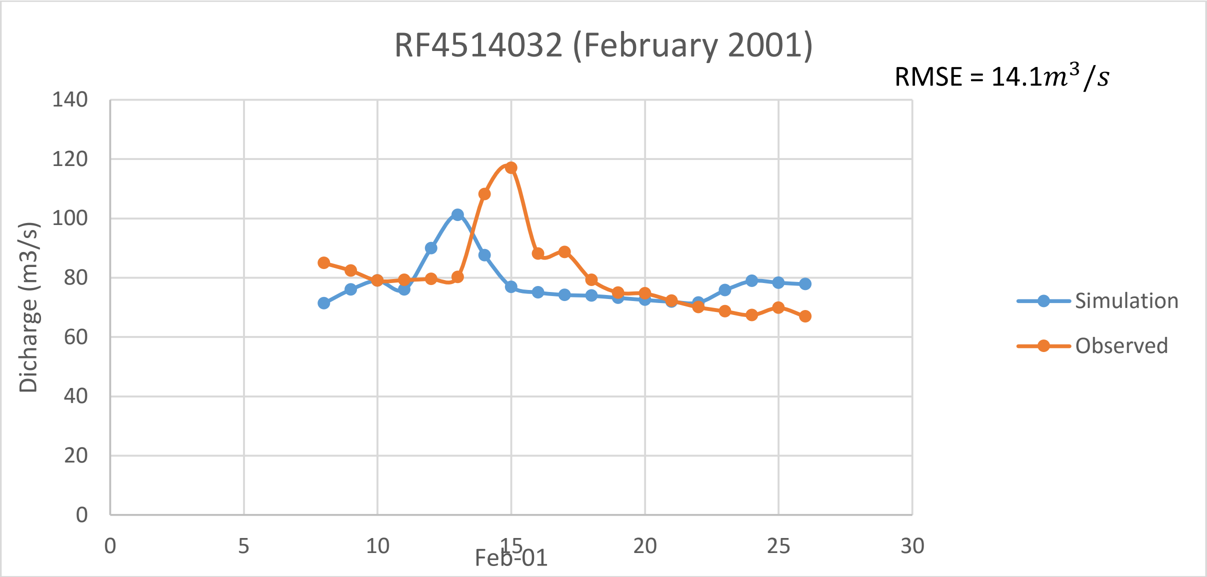

Figure 4.11(a): RMSE value hydrograph of Simulated Discharge and Observed Discharge for RF4514032 for February 2001

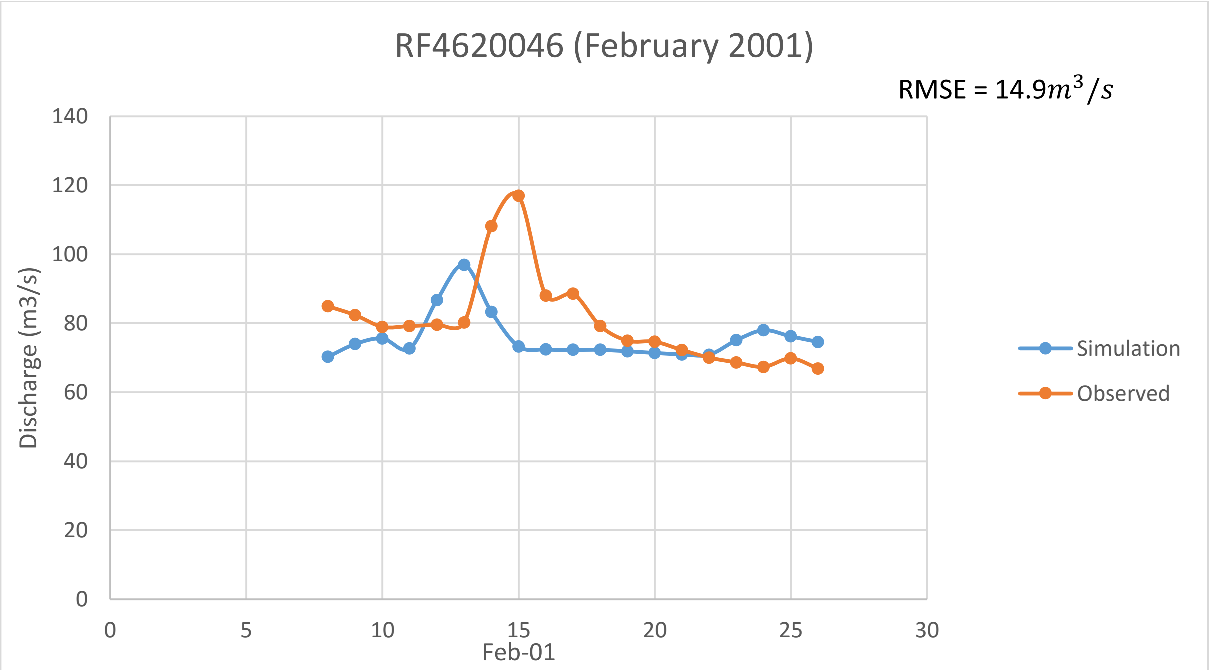

Figure 4.11(b): RMSE value hydrograph of Simulated Discharge and Observed Discharge for RF4620046 for February 2001

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

By referring Root Mean Square Error (RMSE), the lesser the value for one model, the more accurate the model is. Based on the calculated RMSE, the best RMSE value is from simulated versus observed graph of July 2000. The RMSE value from the calculation is 11.1m^3/s, which is a low value. From the calculation of RMSE, it can conclude that the graphs in this study are best fit. In addition, the objectives of this study are successfully achieved. The simulation of the results shows that the rainfall-runoff relationship can be determined by using HEC-HMS. Besides, it also concludes that software HEC-HMS can be used to predict discharge using different set of rainfall data and Clark Unit Hydrograph Method is one of the methods that can be used for simulation in HEC-HMS.

5.2 RECOMMENDATIONS

To get a much more accurate result or in simple to get RMSE value near to zero, other parameters can be used to calibrate the model. For example, the Curve Number used in this study is 30 throughout the analysis, but for getting a better result, the different values of Curve Number can be used to calibrate the model according to the land used type table. The main advantage of using Hec-Hms is the model can be created in short period of time and with high accuracy so that it can be used to predict flood level without hesitation. The data used per day can be changed to hourly data if there are more automatic rainfall stations installed to get a high accuracy result. The other methods that also can be used in this study are Synder Unit Hydrograph Method and Soil Conservation Services (SCS).

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APPENDICES

APPENDIX A – SAMPLE OF RAINFALL DATA (RF4414037)

NOVEMBER 2002	RAINFALL (MM)
1	0.0
2	9.0
3	0.0
4	21.0
5	19.0
6	18.0
7	10.0
8	12.0
9	26.0
10	6.0
11	0.0
12	6.0
13	21.0
14	24.0
15	11.0
16	6.0
17	53.0
18	10.0
19	19.0
20	7.0
21	7.0
22	13.0

23	22.0
24	2.0
25	0.0
26	2.0
27	0.0
28	0.0
29	0.0
30	0.0

APPENDIX B – SAMPLE OF STREAMFLOW DATA (SF4218146)

NOVEMBER 2002	STREAMFLOW (m^3/s)
1	85.21
2	80.03
3	75.52
4	77.1
5	78.22
6	76.64
7	87.27
8	100.95
9	106.73
10	113.28
11	152.78
12	151.46
13	162.55
14	128.67
15	128.15
16	124.88
17	138.05
18	155.8
19	161.85
20	121.29
21	150.31
22	131.83
23	119.99
24	247.12

25	269.34
26	159.51
27	130.15
28	117.81
29	111.96
30	107.21