RAINFALL-RUNOFF MODEL DEVELOPMENT FOR UN-GAUGED CATCHMENT AREA

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor in Civil Engineering

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This hard work is dedicated to my beloved family and my precious friends who love me and support me during my whole journey of education at University of Malaysia Pahang.

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ABSTRACT

In this study, rainfall-runoff model have been used to determine the rainfall-runoff relationship for un-gauged catchment area in Pahang. This research is aim to develop a rainfall-runoff model using HEC-HMS for un-gauged catchment area and to predict the streamflow in un-gauged catchment for Sungai Betau, Sungai Jelai Kecil, and Sungai Serau. HEC-HMS 3.5 is used for this study to stimulate the discharge for the un-gauged catchment area. This study use three rainfall data and one streamflow data, starting from year 1999 to 2014. The parameters used for this study included time of concentration, storage coefficient, and lag time. Few methods are being used to perform this analysis, that is transform method (Clark Unit Hydrograph), baseflow method (Constant Monthly), and loss method (SCS Curve Number). Hydrological model will be stimulated to predict flood discharge after calibration and verification models. To evaluate the performance of hydrological model, root mean square error (RMSE) will be used. The calibrated model can be used for flood discharge prediction. By comparing the RMSE, it can be conclude that RF 4514032 are more suitable to be used to predict the discharge for un-gauged catchment area at Sungai Betau, Sungai Jelai Kecil, and Sungai Serau.

ABSTRAK

Dalam kajian ini, model hujan-air larian telah digunakan untuk menentukan hubungan hujan-air larian bagi kawasan tadahan yang tidak diukur di Pahang. Kajian ini adalah bertujuan untuk membentuk model hujan-air larian yang menggunakan HEC-HMS untuk kawasan tadahan tiada bacaan dan untuk meramalkan aliran sungai di kawasan tadahan yang tidak diukur untuk Sungai Betau, Sungai Jelai Kecil dan Sungai Serau. HEC-HMS 3.5 digunakan untuk kajian ini bagi merangsang pelepasan di kawasan tadahan yang tidak diukur. Kajian ini menggunakan tiga data hujan dan satu data aliran sungai mulai tahun 1999 untuk 2014. Parameter yang digunakan bagi kajian ini merangkumi masa penumpuan, koefisien simpanan, dan masa lag. Beberapa kaedah yang digunakan untuk menjalankan analisis ini, yang merupakan kaedah transformasi (Clark Unit Hydrograph), kaedah baseflow (Constant Monthly) dan kaedah kehilangan (SCS Curve Number). Model hidrologi akan dirangsang untuk meramalkan luahan banjir selepas model penentukuran dan pengesahan. Untuk menilai prestasi model hidrologi, RMSE akan digunakan. Model diteliti boleh digunakan untuk ramalan pelepasan banjir. Dengan membandingkan RMSE, ia boleh disimpulkan bahawa RF 4514032 adalah lebih sesuai untuk digunakan bagi meramal aliran sungai bagi kawasan tadahan yang tidak diukur iaitu Sungai Betau, Sungai Jelai Kecil dan Sungai Serau.

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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 Saliran

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Streamflow, or in other words, channel runoff is the movement of water in rivers, streams, ocean and other channels. It is a main element of the water cycle. Streamflow is one of the most critical hydrological variables needed for water resources planning and management, and water resources systems operation together with allocations for environmental flows. Evaporation from the oceans is the dominant way for water from the surface of Earth's to returns to the atmosphere. Water returns to Earth through precipitation that fall to the ground, either it is infiltrate into the soil or the water moving to downhill as surface runoff. . Streamflow normally change from time to time, even minute to minute. The main effect on streamflow is precipitation runoff in watershed.

Hydrological modeling of water balances or extremes (drought and flood) is essential for water management and planning. However, there are limited numbers of consideration of key variables that can affect the hydrological processes limits the applicability of rainfall-runoff models. Discharge will be measured only at a few locations, and precipitation measurements are recorded at some selected points. Therefore, modeling is an important tool to evaluate the water cycle elements.

Catchment models are created to meet one of the two main objectives. The first one is to gain a better perceptive of the hydrologic behaviors in a catchment and how changes in the catchment will affect these behaviors. Next objective is the generation of synthetic hydrologic data for facility design like water resources planning, mitigation of contamination, flood protection, for forecasting, or licensing of abstraction. Catchment models also provide useful information in studying the potential impacts changes in climate or land use.

However, countless river catchments are un-gauged for streamflow data. Referring to Sivapalan et al. (2003), "Un-gauged catchment is the one with inadequate records (in terms of quality and quantity) of hydrological observations to permit computation of hydrological variables of interest (both water quantity and/or quality) at the applicable spatial and temporal scales, and the accurateness acceptable for practical applications. For example, if the variable of interest does not been taken at the required resolution or for period of time required for estimations for model calibration, the catchment will be grouped as un-gauged due to this variable."

Rainfall-runoff modeling is useful in hydrology for several reasons; such as catchment yield studies, design in flood estimation, and assisting in management decisions. Basically, the models are created by inputting the observed rainfall and evapotranspiration, and calibrating model parameters to meet a historical record of runoff.

Rainfall-runoff modeling is a main part of this job. It is used to assume the streamflow in un-gauged catchments. Therefore, rainfall-runoff modeling is chosen as standard tool routinely used today for the investigation and application in catchment hydrology. Generally, rainfall-runoff modeling rely upon streamflow data for calibration and verification. Since this data is not achievable in un-gauged catchments, other ways might need to be applied to in order to get the streamflow data.

1.2 PROBLEM STATEMENT

Nowadays, flood has becoming the most significant natural disaster in Malaysia. Flood has affected many places, and most seriously is Kelantan, Pahang, and Terengganu.

In 11 January 2014, heavy rain non-stop for two days has causes serious flood in Sungai Jelai, Kechau, and Tanum. Water in the rivers are overflow when incessant rainfall that caused the water from the upstream to not reach the confluence. Since the country undergoes rapid development, some problems like environment and drainage will be ignore. Thus, it becomes one of the contributing factors.

Sungai Betau, Sungai Jelai Kecil, and Sungai Serau has been identified as one of the river that causes flood. During heavy rain, the amount of runoff water is higher than the capacity of water the river can cattle. Due to the quantity of runoff increases, the drainage area and the river will not be able to cattle and flood will then occur. Moreover, this river basin area is a well-developed urban area. Population growth, changes in land use, has reduced the foresting land. Water is not use directly, but, they do have consequence on the hydrology as well.

In order to reduce flood in this area, this research was carried out to predict the streamflow in the catchment area. It is been clarified that the area for this basin is un-gauged; therefore, the volume of streamflow is unknown. To calibrate the model parameters, there is an insufficient streamflow data. Along with lacking of data, there are many reasons for it, such as long periods of unseasonable rainfall that producing unrepresentative relationships, or significant modifications to catchment characteristics.

1.3 OBJECTIVES OF STUDY

The main objectives of this research can be outlined as follow:

i. To develop a rainfall-runoff model for un-gauged catchment area using HEC-HMS
ii. To predict the streamflow in un-gauged catchment area
iii. To get appropriate model to predict discharge after calibration and verification model.

1.4 SCOPES OF STUDY

For this study, the rivers involved are Sungai Betau, Sungai Jelai Kecil, and Sungai Serau, whereas these areas are lack of streamflow data. Sungai Jelai Kecil is approximately 39 KM long, and Sungai Serau is around 30 KM long. The main basin for Sungai Jelai Kecil and Sungai Serau is Sungai Jelai, which is approximately 68 KM long.

The scope of this study includes stimulating the river using HEC-HMS software. HEC-HMS model were used to determine the rainfall-runoff relationship and to predict the streamflow data for un-gauged catchment based on the available streamflow data. Hydrological model will be stimulated to predict flood discharge after calibration, validation, and verification.

1.5 EXPECTED OUTCOME

This research helps to predict the streamflow in Sungai Betau, Sungai Jelai Kecil, and Sungai Serau.

1.6 RESEARCH SIGNIFICANCE

This study can provide streamflow data as a reference for related research. Based on this research, the relationship between rainfall and runoff can be determined. As this is an un-gauged catchment, it is important to know the streamflow data and runoff capacity to estimate the potential of flood during raining time. The research can be a guideline to improve the drainage system for river basin and human activities can be controlled to prevent flood. Hydrological model created can be used for the design of drainage of basin based on the hydrological pattern.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Hydrology is the study of distribution, movement, and water quality on Earth. Hydrology deals with the occurrence, distribution and water disposal on earth. It is a science which that involved different phases of the hydrologic cycle. The study includes the water resources, water cycle, and environmental watershed sustainability. Hydrology is from Greek work; Hydrologia, the study of water. Hydrological study is important to control the uses of water, floods, water quality and so on. Water used for drinking, washing, agriculture and also industrial purposes. There are two important aspects of water resources; quantity and quality. World's water supply definition that being interpreted and defined by (Graham, 2011) are as follow:

> "Our Earth's is covered by water almost 70%. But in that 70%, almost 97.5% of all water on Earth is salt water, leaving only 2.5% as fresh water."

2.1.1 Hydrologic Cycle

Hydrologic cycle, or also known as water cycle is the most important natural phenomenon on Earth. It is a process of constant movement and the water is recycling endlessly between the atmospheres, land surface and also under the ground. The three important phase in hydrologic cycle are evaporation and evapotranspiration, precipitation and surface runoff. One-third on earth consists of land, while two-thirds of it is ocean. The hydrological cycle supplied the force that required for most natural processes. Hydrological cycle is the continuous, unsteady circulation of water from the atmosphere to and under the land, and back to the atmosphere by various processes (Walesh, 1989). **Figure 2.1** presets an illustration of hydrological cycle.

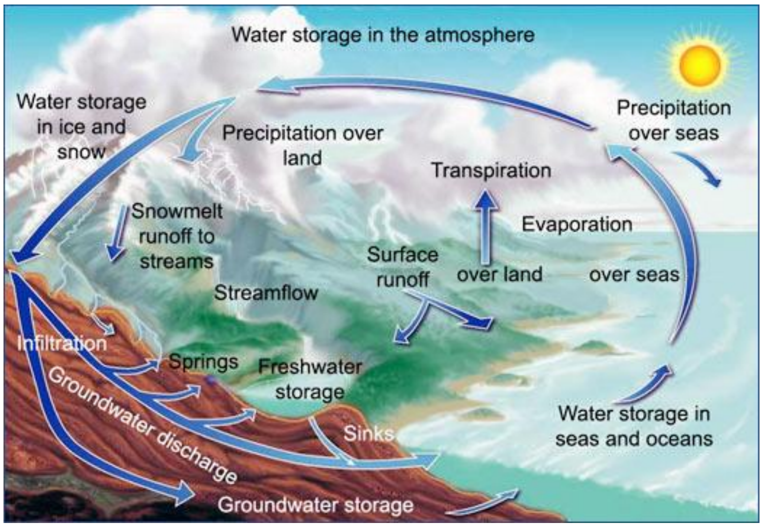

Figure 2.1: Hydrologic cycle

The quantity and quality of water may vary at particular location with time. In hydrologic cycle, water can be in three conditions; solid, liquid and gas. The water in ponds, lakes, ocean, reservoir surfaces etc, will be evaporated, and the transpiration process from surface vegetation such as plants, trees, and forest will take place. These vapours will rise to the sky, condensed and form clouds, thus, resulting droplet growth. The clouds melt and burst, and form precipitation.

2.2 HYDROLOGICAL CHARACTERISTICS

Hydrology is the continuous movement of water, on and under the surface of the earth, between the land surface and atmosphere. Water exists in many forms and circulates within the water cycle. The water that under the ground surface is called ground water, while the water vapour is known as atmospheric water. Waters from rainfall will infiltrates into the soil surface, initially become ground water, collection as surface runoff that move towards downstream. The waters from surface runoff will accumulate in lakes, wetlands or oceans, thus, when the water surface being heated, evaporation process will occur.

2.2.1 Rainfall

Rainfalls or precipitation can be any form of water that falls from the sky, and act as a part of weather to the ground. It can be in terms of rain, snow, sleet, hail and mist. In Malaysia, precipitations occur primarily as rain. The annual precipitation is unpredictable and range approximately 2000mm to 4000mm for various locations. It is the most important process in hydrologic cycle, as it is the driving force providing water that must be accommodated in the urban environment. The precipitation may be due to thermal convection, conflict between two air masses, orographic lifting, and cyclonic. There are two types of catchment, that is gauged catchment and un-gauged catchment. For un-gauged catchment, there is no or less available rainfall data for that particular area.

Thermal convection, or also known as conventional precipitation, is a type of precipitation in the form of local whirling thunder storms. The air is close to the earth, being heated and rises to the atmosphere, due to its low density, cools and form cauliflower shaped cloud, which will burst into thunder storm at the end. Tornados will happened when it is accompanied by destructive winds.

Conflict between two air masses, of frontal precipitation, is when two air masses with different density and temperature clash with each other, condensation and precipitation will occur at the surface contact, called as front or frontal surface. Orographic precipitation is the mechanical lifting of moist air at mountain barriers, and causes the heavy precipitation on the windward side.

Cyclonic precipitation happens due to lifting of moist air that converges into a low pressure belt. The winds will blow spirally inward counterclockwise in the northern hemisphere, and in the southern hemisphere, it will blows in clockwise direction. There are two types of cyclonic precipitation; tropical cyclone (also known as typhoon or hurricane). **Figure 2.2** and **Figure 2.3** presents an illustration for frontal precipitation and orographic precipitation.

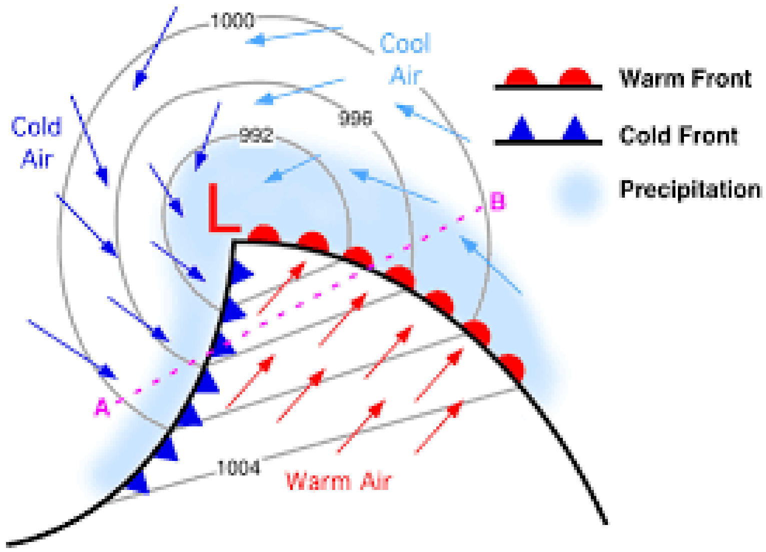

Figure 2.2: Frontal precipitation

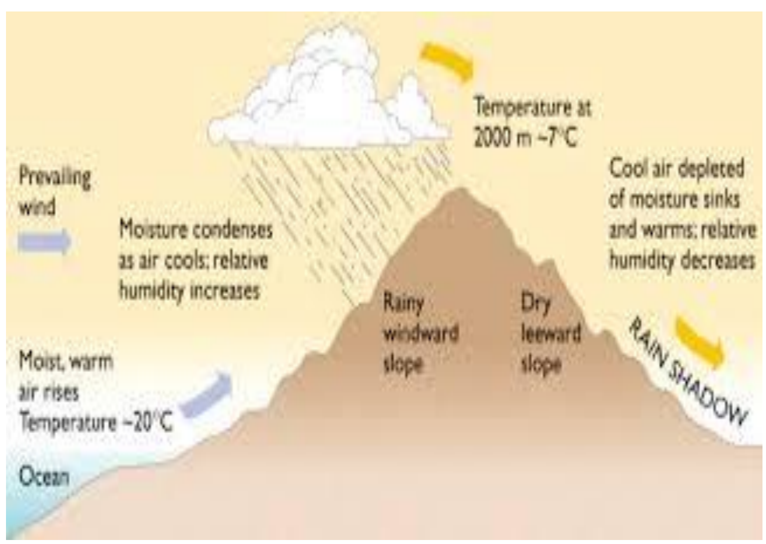

Figure 2.3: Orographic precipitation

2.2.2 Evaporation and Evapotranspiration

Evaporation is a process where the water will transform from liquid or solid state into gaseous state. The water will evaporates from water surfaces such as lakes, reservoirs and oceans. Water vapour can also form from snow and ice through sublimation process and transpiration process by plants. Few factors that will affect evaporation process are temperature of water and air, wind velocity, relative humidity, surface area that exposed to sunlight, and barometric pressure.

Evapotranspiration is a part of water cycle that removes liquid water from vegetation into the atmospheric surface by both transpiration and evapotranspiration process. Evapotranspiration rates will be affected by temperatures, vapour pressure, wind, characteristics of plant, and soil moisture. It is a process that evaporates the water from leaves through plant transpiration during the photosynthesis process. Evapotranspiration is a combination of evaporation and transpiration process. Transpiration takes place when plants release water vapour from stomata. Plants will undergoes photosynthesis and converts carbon dioxide to oxygen. **Figure 2.4** presents an illustration for the process of evaporation and evapotranspiration.

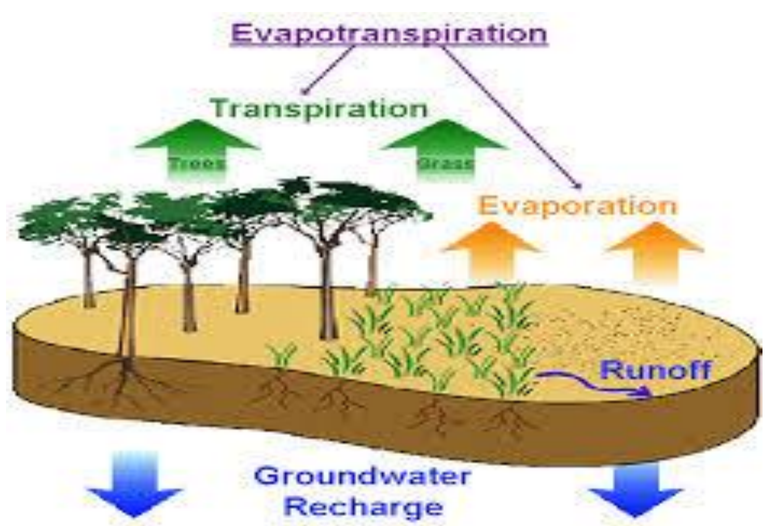

Figure 2.4: Process of evaporation and evapotranspiration

2.3 Runoff

When the amount of precipitation is greater than the infiltration rate of the ground surface, runoff or overland flow will take place. Water leaving an area of drainage, flowing on the land surface to downhill are mostly refers as runoff. Process of water entering the soil is called as infiltration. The water begins to move downslopes because of the earth gravity when the water accumulates at the ground surface. Runoff will be used to describe the rainfall that is not infiltrated into the ground surface. Surface runoff helps to determine the quantity of storm water that affects the quantity of potential pollutants transported to the receiving waters (Walesh, 1989).

Infiltration is defined as the water passage through the air void in the soil interface. Infiltration rates are affected by time, soil permeability and porosity, antecedent soil moisture conditions, and the presence of the vegetation. It is an important process in urban storm water management. Urbanization normally will decrease the rate of infiltration, thus increasing the runoff and discharge volume. Infiltration divides rainfall into two parts. One part goes via overland flow and stream channels as surface runoff, while another part goes initially into the soil (Keith, 2004).

During rainfall or snowmelt, there are two types of surface runoff will occur. Infiltration excess overland flow happens when the soil is not saturated. In fact, the soil can be in dry conditions, but the soil properties or the surface lands do not allow infiltration of rainfall or snowmelt. The water that cannot infiltrates into the soil will become surface runoff. Infiltration excess normally can be observed in short duration of rainfall. Saturation excess overland flow happens when the soil is fully saturated, and there is no void in the soil for the water to infiltrates. This shows that the soil properties allow for large quantity of waters to infiltrate in sub-saturated conditions. Saturation excess can be observed during long duration of rainfall or gentle to moderate rainfall. **Figure 2.5** presents an illustration for the type surface runoff.

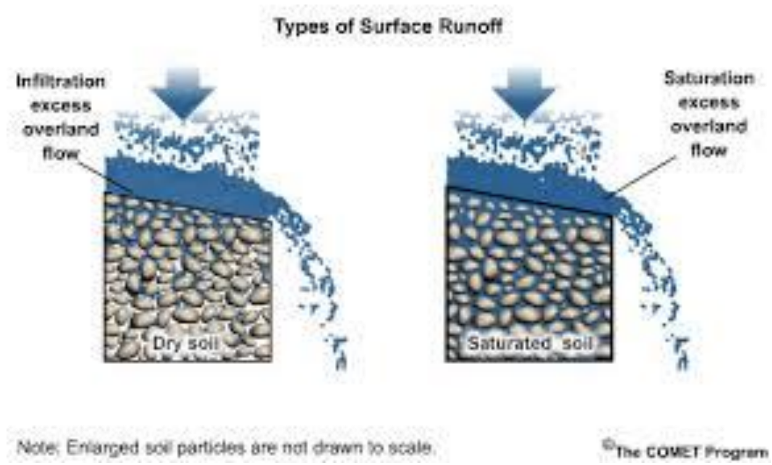

Figure 2.5: Types of surface runoff

2.2.4 Water Balance Equation

In watershed, the water that falling as precipitation or rainfall will be either stored in the soil as groundwater, or return to the atmosphere as water vapour. Water balance equation consists of the input and output of components in the hydrological cycle. The water balance of a watershed can be expressed as in Eq. (2.1)

$$P = ET + R + \Delta S + \Delta G \tag{2.1}$$

Where,

P = Precipitation

ET = Evapotranspiration

R = Runoff/Steamflow

ΔS = Change in storage

ΔG = Change in groundwater flow

2.3 PHYSICAL CHARACTERISTICS OF THE BASIN

The area of land, which the surface runoff will accumulate, is known as drainage basin, watershed or catchment area of the river. As the water will run downhill, a watershed usually begins at the top of the hill or mountain. There are few characteristics that will directly affect the runoff such as size, shape, slope, land use or vegetation, and altitude. Understanding the characteristics of stream habitats is important in drainage basins (Frissell et al. 1986).

2.3.1 Size, Shape, and Slope

Basin can comes in many sizes, shapes, and can be from large to smaller size. A typical watershed is like a vein of smaller rivers, known as tributaries. Tributaries will link to each other and form a bigger river. For a long narrow shape watershed, the rate of runoff will be lower compare with the rate of runoff in fan-shaped watershed. The slopes of the watershed will influence its drainage pattern. The rainwater will be difficult to infiltrate into the ground when the slopes is very steep. Thus, water runoff will occur and eventually will increase the percentage of erosion. This is because there is less vegetation that helps to trap the excess sediments and runoff water. When the slope is very steep, plant cover is difficult to establish. Steep slope area tends to generate more runoff than lowland areas. Precipitation tends to be received more in mountainous area because air will be force to lifted and cooled. When the steep is gentle, the water runoff will pond on the surface, and seep in the ground later. Alternately, for steep slope, the water tends to move faster downwards the hill.

2.3.2 Land Use

Human activities have a great effect on affecting the surface runoff. When development and organization occurs more rapidly, more of the natural landscape is replaced by buildings, houses, roads, and parking lots. This has reduced the infiltration rate of water into the soil. Removal of surface vegetation and soil increase the runoff capacity, thus shorten the time runoff time into the streams. In many studies, it has been proved that infiltration will be higher for forest, medium for agriculture crops, and low for fallow or bare soil that under the same condition and same soil. Forest has low runoff capacity because the rain will slow down when it hit the leaves and trees, providing the plant roots longer time to absorb the water. When the forest is being clear for development, the vegetation will be removed and replaced with blacktop of concrete. There will be no more vegetation that can slow down the rain. Since he top of the ground is covered with buildings, no water can be seep into the soil. Instead, the water runs over the surface, causing soil erosion and flooding to occur.

2.3.3 Elevation of the Basin

In high elevation basins where amount of snow is higher than rain, the timing of the runoff will change due to higher temperature, although the amounts of precipitation remain the same. Alternately, in basins which rain is the main supplier of the water throughout the year, the seasonal pattern of runoff will be affected by increases in precipitation into the rivers. When the elevation is higher, the amount of losses will be lower.

2.4 FLOOD

Flood happens when water overflows or accumulates on the lands that normally dry. Most of the floods take hours or days to develop. Floods have become regular natural disasters in Malaysia that will happen every year during the monsoon season. The most serious flash flood happens in December 2014, which hits Kelantan, Terengganu, Pahang, Perak and Perlis (Bernama, Astro Awani, 2004). Flood happens due to continuous rain and inadequate drainage in urban areas. However, floods are not only caused by heavy rains. It can also cause by dam failure, triggered by earthquake (tsunami), and topography.

2.4.1 Factors Affecting Flood

When the precipitation are not infiltrated into the soil, and runoff flows rapidly into the water catchment, the catchment are not able to accommodate the amount of precipitation causes the water to overflow. As a result, flood happens when the water in the stream overflow. Global warming has increased the frequency of flooding that causes the polar ice caps to melt. One of the major consequences is the sea level will rise, therefore, the area nearby has higher potency of flooding.

2.5 RAINFALL-RUNOFF RELATIONSHIP

Since the 1960s, hundreds of alternatives conceptual model have been developed for the stimulation of rainfall-runoff relationship as hydrological research prime focus including the Stanford Watershed Model. (Teemu et. al. 2001). Rainfall-runoff is an important component of hydrological cycles. Many of the characteristics of a landscape and occurrence and size of floods can be determined (Nano et. al. 2014). **Figure 2.6** presents a schematic diagram that shows the relationship between rainfall, infiltration and runoff.

As the rain continues to fall, the ground will infiltrates until the soil approach a stage where the amount of rainfall (intensity) are more than the infiltration capacity for the soil. Thus, runoff will be generated after the depression storage is filled. Infiltration capacity of the soil will be different based on its texture, structure and also soil moisture content. Before rain start to fall, the initial capacity for the dry soil is high, but, when the rain continues to fall for a period of time, the infiltration rates will decreases until it reaches final infiltration rate. Thereafter, the process of runoff continues as the rainfall has exceeded the infiltration capacity of the soil. At the same time, the runoff process will stops when the rate of precipitation falls below the actual rate of infiltration.

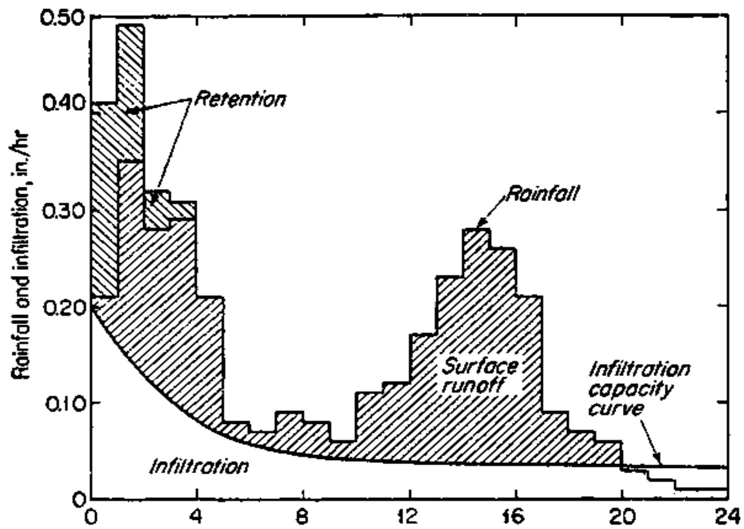

Figure 2.6: Relationship between rainfall infiltration and runoff

2.6 HYDROGRAPH

Hydrograph is a plot of stream flow over duration of time. Discharge is the quantity of water that flows in the river per second. Discharge patterns for drainage basin can be predicted by plotting hydrograph. Moreover, it can help to predict flood. River's hydrograph for circular drainage basins are describes as "flashy". This is because circular hydrograph will have quite steep rising limb with a high peak discharge. **Figure 2.7** below shows the streamflow hydrograph.

Referring figure below, there are few things to be note, which are time lag or basin lag, rising limb, and falling limb. The difference among the peak discharge and peak precipitation is known as time lag. When the time lag is long, it shows that longer time is needed for the precipitation to enter the stream. Alternately, a short lag time shows that the time for the precipitation to enter the stream is much shorter. From the hydrograph, the steep part of the discharge line with positive gradient, showing that the discharge of the stream is increasing. This line is known as rising limb. Falling limb is the contrast of rising limb, which indicates the falling of discharge.

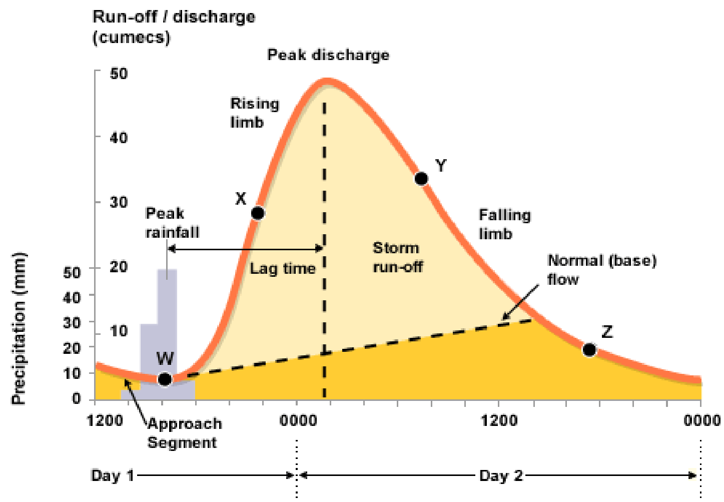

Figure 2.7: Streamflow of the Hydrograph

2.6.1 Unit Hydrograph

Unit hydrograph can be explain as the direct runoff hydrograph that produced by rain in unit duration, uniformly distributed rainfall, with effective depth of 1cm that spread uniformly in watershed area (Sherman 1932). Generally for various purposes, unit hydrograph theory will be used to compute the flood or runoff volume. It is also use to predict the impact of precipitation on streamflow. The duration of the unit volume of excess rainfall, referred as the effective duration (Jorge, 2000). Unit hydrographs can be used in determine for un-gauged catchments with soils, geomorphology, land cover, and climate same with that for gaged basins. In many areas, some of the drainage basins do not have stream flow data. For un-gauged catchment, hydrographs will be synthesized from other catchments directly, or through the empirical relationship indirectly from other catchments.

There are few methods of developing unit hydrograph. These method are synthetically, fitted distributions, and geomorphologic. For synthetic hydrograph, there are three categories, which are Snyder’s Synthetic unit hydrograph, Soil Conservation unit hydrograph, and Time-Area or Clark unit hydrograph.

2.6.1.1 Synder's UH

First synthetic unit hydrograph was developed in 1938 by Synder's. All the features for the unit hydrograph will be retained, and no rainfall-runoff data will be required for synthetic unit hydrograph. By estimating the basin lag, the basin diffusion can be stimulated using certain formula or procedure. Two important parameters in Synder's hydrograph are time parameter C_t and peak parameterC_p. For greater basin lag, the value of C_t will be larger, hence diffusion will be greater. Synder's relations can be expressed as in Eq. (2.2)

$$t_p = C_t(LL_C)^{0.3} \tag{2.2}$$

Where;

t_p = basin lag (hr)

L = length of the main stream from the outlet to the divide (m)

L_C = length along the main stream to nearest centroid of watershed (m)

C_t = time parameter coefficient, range usually from 1.8 t0 2.2

2.6.1.2 Soil Conservation Service Unit Hydrograph

SCS dimensionless hydrograph is which the discharge is indicate by the ratio of discharge to peak discharge, also the time by the ratio of time to the time of peak UH. Unit hydrograph for the given basin can be determine based on the given lag time duration and peak discharge of the excess rainfall. SCS equations for peak flow, time to peak, lag time and time base can be expressed as in Eq. (2.3), Eq. (2.4), Eq. (2.5) and Eq. (2.6).

Peak flow: $$q_P = \frac{CA}{t_p} \tag{2.3}$$

Time to peak: $$T_p = \frac{T_r}{2} + t_P \tag{2.4}$$

Lag time: $$t_p = \frac{L^{0.8}(\frac{1000}{CN} - 9)^{0.7}}{19000y^{0.5}} \tag{2.5}$$

Time base: t_b = 2.67 t_p (2.6)

Where,

q_P = peak discharge

A = basin area

t_p = lag time

t_b = time base

T_r = excess duration

C = 2.08 (SI unit)

For un-gauged watershed, the SCS suggest that UR lag time may be related to time of concentration, t_c and can be expressed as in Eq. (2.7)

$$t_{lag} = 0.67t_c \quad (2.7)$$

The earliest method of SCS is assuming a hydrograph as a simple triangle as shown in figure 2.8 below. The **Figure 2.8** below shows the SCS triangular unit hydrograph and **Figure 2.9** shows the SCS dimensionless unit hydrograph.

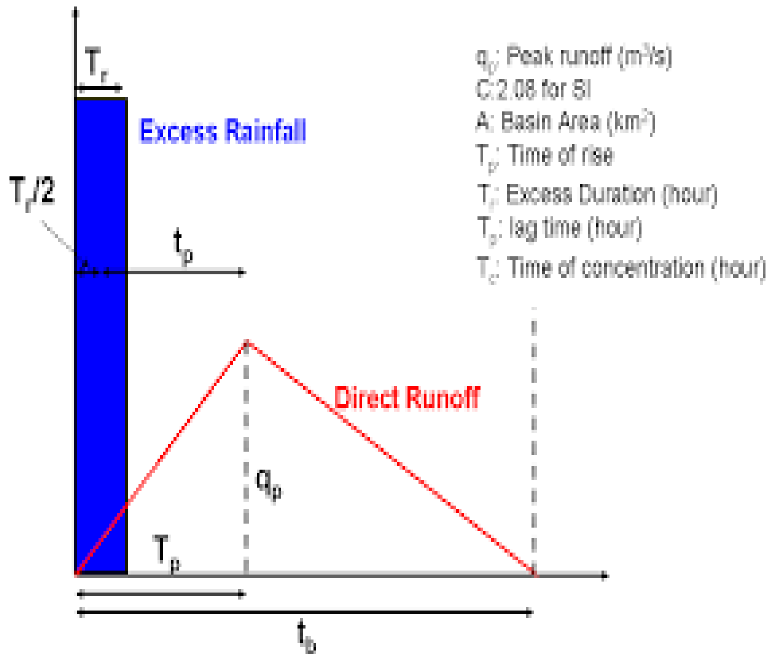

Figure 2.8: SCS Triangular UH

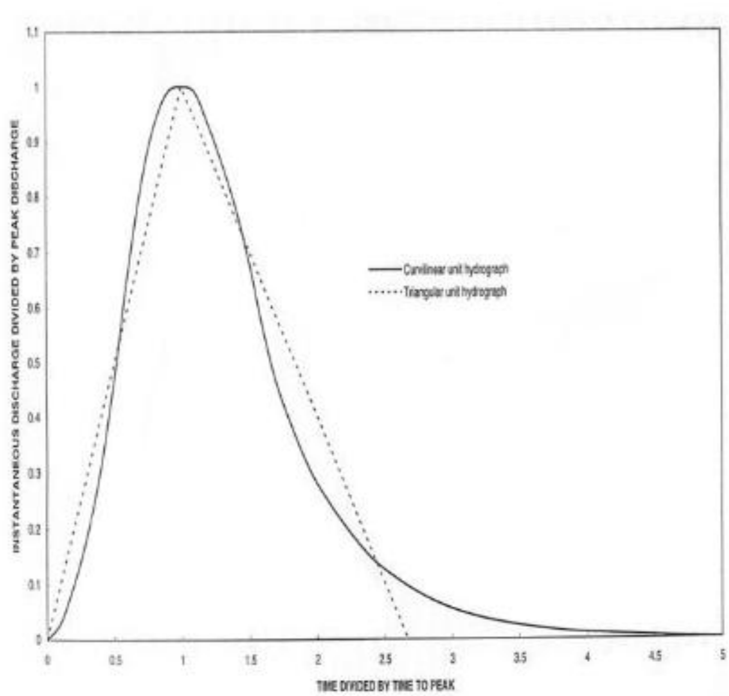

Figure 2.9: SCS Dimension UH

2.6.1.3 Clark's Unit Hydrograph

Clark's (1943) unit hydrograph has no duration, slightly different compare with other synthetic unit hydrograph. It is an instantaneous unit hydrograph. Clark unit hydrograph is unique in derivation, from the parameters and theories of Muskingum hydrograph application and routing. Although later this method has been done some suggestion for un-gauged sites, but it is only develop for gaged sites. Some advantages of Clark's UH are as follows:

i. Based on the observed hydrographs, mathematically method is used to define parameters. The experiment is repeated by two people with same data.
ii. Spatial runoff distribution knowledge is not required for this method.
iii. Clark's UH is the output of an instantaneous rainfall.

Two processes that dominate the movement of flow in watershed are translation and attenuation. Translation is the movement of the excess down gradient through the watershed in response to gravity. Attenuation or the reduction of the magnitude of the discharge as the excess is stored throughout the watershed. Equation 2.8 shows the continuity equation for linear reservoir model. Linear reservoir model is the effects of short term storage throughout the watershed. It can be expressed as in Eq. (2.8)

$$\frac{dS}{dt} = I_t - O_t \qquad (2.8)$$

Where,

I_t = average inflow to storage at time, t

O_t = outflow to storage at time, t

2.7 SOFTWARE FOR ANALYZING RAINFALL AND RUNOFF RELATIONSHIP

Although many mathematical models have been developed for the purpose of stimulating hydrological phenomena and system, Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) is chosen as a tool for this research. These tools are used in various types of studies such as flood inundation models and building flood forecasting. Also, it is use to analyze different flood control alternatives and developing a system for early flood warning.

2.7.1 HEC-HMS

HEC-HMS is developed by US Army Corps of Engineers-Hydrologic Engineering Center (HEC) in 1992 to replace HEC-1 as a standard stimulation for hydrologic. It is one of the hydrologic modeling to stimulate rainfall-runoff processes. HEC-HMS stimulates the rainfall-runoff processes by physically based and conceptual semi distributed model. Losses, open-channel routing, rainfall-runoff stimulation, runoff transform analysis of meteorological data and parameter estimation can be done by the system. HEC-HMS can be used for solving the problems in a wide range of geographic area. The results from HEC-HMS system are hydrograph and flow volume. From HEC-HMS system, hydrograph provided can be used directly with other software for the other kind of study such as water availability and floodplain regulation. Hydrographs can also be combined together representing for two streams. HEC-HMS required three main parameters, that is losses, transform method and stream flow routing. HEC-HMS model has been also used to simulate rainfall-runoff process with geo-informatics and atmospheric models for flood forecasting and early warnings in different regions of the world (Choudhari et al., 2004)

2.7.1.1 Modeling Basin Components

Physical description of the watershed describes in basin model. Such components of basin model are sub-basin, reservoir, junction, diversion, source, sink, and also reach. Sub-basin refers to the watershed catchment at which rain has falls. Reservoir can be dams or lakes. Runoff will flow downhill and reach rivers and streams. Computation proceeds from upstream element in a downstream direction.

2.7.1.2 Losses

Precipitation loss method for overland flow considers the infiltration losses. Methods available in HEC-HMS are Deficit and Constant, Initial and Constant, SCS Curve Number, Soil Moisture Accounting, Green-Ampt, Exponential, and Smith Parlage. For simple continuous modeling, one layer-deficit and constant model can be used.

2.7.1.3 Runoff Transform

Transform method will be specified after the precipitation losses been considered for transforming to surface runoff from overland flow. There is multiple method to choose for transform method in HEC-HMS, including SCS, Synder UH, Clark, ModClark, Kinematic Wave and User specific unit hydrograph. Two parameters required for both Clark and Synder methods, but only one parameter required for SCS method by assuming the hydrograph shape. Although Clark and Synder methods are more flexible in determining the hydrograph shape, the parameters needed are difficult to estimate.

2.7.1.4 Rainfall-runoff Simulation

For simulation run, it consists of three parameters. Such parameters are meteorological model, control specifications and one basin model. For simulation run option, it consists of outflow or precipitation ratio option, save and start states option. Global summary table from menu or toolbar option shows the results for the current stimulation run. For viewing the one element results for the current stimulation run, menu, toolbar, or basin map option can be used. It will shows time-series and summary table, together with graph. Custom graphs and time-series tables for different simulation can be viewed using Watershed Explorer.

2.8 ADVANTAGES OF HEC-HMS

Numerous mathematical models have been developed for simulating various hydrological systems that has their own advantages. From the research, HEC-HMS model is suitable to be used for flood estimation. Advantages of HEC-HMS include:

i. HEC-HMS has more than 30 years of experience for the stimulation of hydrologic.
ii. HEC-HMS has an optimize feature for the calibration purpose.
iii. HEC-HMS provides a graphical user interface to make it easier to use the e software.
iv. HEC-HMS are widely used and accepted for many research.
v. HEC-HMS can be done fast and result produced can be applied.
vi. Users have various options in choosing the parameters to be used.

2.9 ROOT MEAN SQUARE ERROR

The commonly used method for measuring the differences between the values predicted by a model is known as root mean square error. RMSE is an estimator and the values observed. RMSE has high measure of accuracy; therefore, it is ideal if it is small. Moreover, RMSE value should be used also to distinguish model performance in a calibration and validation process. The equation of RMSE can be expressed as in Eq. (2.9)

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \quad (2.9)$$

Where,

X_{obs} = Observed value

$X_{model,i}$ = Stimulated value at time or place

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter provides a detailed methodology to determine the rainfall-runoff relationship for un-gauged catchment area. The method used for determining the relationship is Hydrologic Engineering Centre-Hydraulic Modeling System (HEC-HMS). For un-gauged catchment, there is lack of rainfall and streamflow data for that particular catchment area. For this study, rainfall data is very important for the stimulation of rainfall-runoff model. Furthermore, this research is aim to predict the streamflow data and to get appropriate model to predict discharge after calibration, validation and verification model. At the same time, the selection of the rainfall data and discharge data for validation and calibration process were based on the availability and the best quality of data sets as the rainfall and discharge station.

3.2 FLOW CHART OF METHODOLOGY

This flow chart indicates the methodology used for throughout this research as shown in **Figure 3.1.**

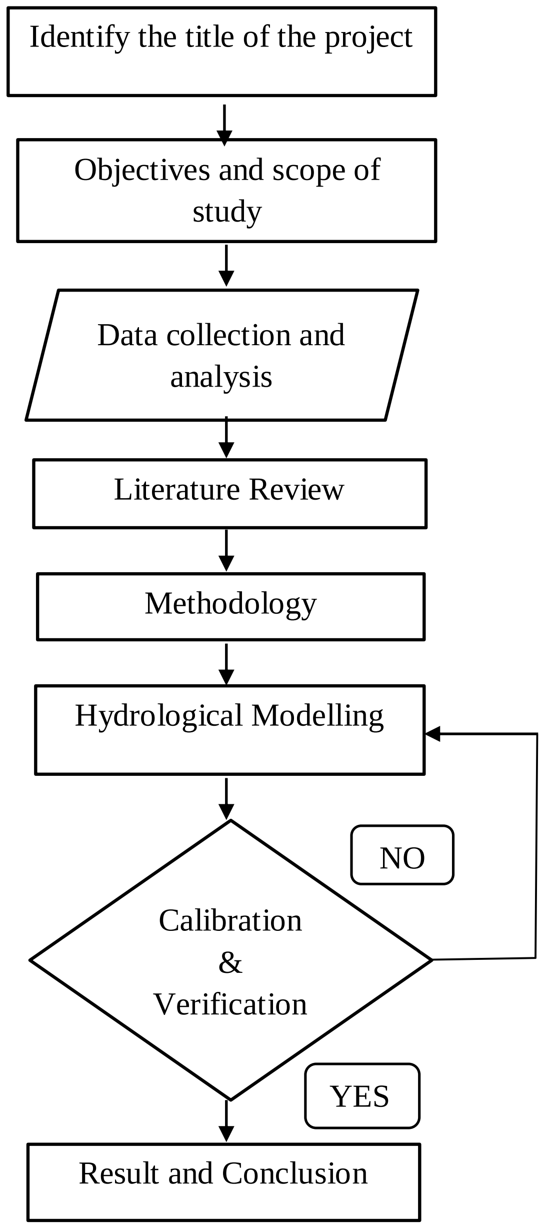

Figure 3.1: Flow chart of methodology

3.3 DATA COLLECTION

For this research, three rainfall data and one streamflow data are available. Although this is un-gauged catchment, data collection is still needed for the determination of rainfall-runoff relationship using HEC-HMS Model and also to predict the streamflow for the catchment area. In addition, HEC-HMS is used as a tool for creating hydrologic modeling of Sungai Betau, Sungai Jelai Kecil, and Sungai Serau. The data use for HEC-HMS and it souce are shown in Table 3.1.

Table 3.1: Data for HEC-HMS and the sources

	Data	**Source**
a.	Rainfall Data	The Department of Irrigation and Drainage (JPS)
b.	Streamflow Data	The Department of Irrigation and Drainage (JPS)
b.	Topography Data	The Department of Survey and Mapping Malaysia (JUPEM)

3.3.1 Rainfall Data

The rainfall data for this study are obtained from The Department of Irrigation and Drainage (JPS). The rainfall data is available from year 1999 to 2014. For this study, three rainfall data is being used. **Table 3.2** shows the name and rainfall station use in HEC-HMS Model. Rainfall data can be refer at **Appendix A.**

Table 3.2: Rainfall Station use in HEC-HMS Model

Station No	**Station Name**	**Increment**
RF 4218043	Paya Tepuai	Daily
RF 4514032	Ladang Teh Sungai Palas	Daily
RF 4620046	Merapoh at Pahang	Daily

3.3.2 Streamflow Data

The streamflow data for this study are obtained from The Department of Irrigation and Drainage (JPS). Only one streamflow data is being used in this study. The streamflow data is used to compare with the simulated data. **Table 3.3** shows the name and streamflow station use in HEC-HMS Model. Streamflow data can be refer at **Appendix A.**

Table 3.3: Streamflow Station use in HEC-HMS Model

Station No	**Station Name**	**Increment**
SF 4218416	Sungai Jelai at Kuala Medang	Daily

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

The Hydrological Modeling System (HMS) is designed for presenting many different watersheds. By separating the hydrologic cycle, watershed model can be constructed. HMS is widely used in solving the problems in a a wide range of geographic area. Problems that can be solve using HMS are including water supply in large river basin and flood hydrology, also for small urban runoff or runoff in natural watershed. Hydrographs obtained from HMS can be used directly with other software for other kind of studies. For this research, Clark Unit Hydrograph method will be used in HEC-HMS.

3.4.1 Clark's Unit Hydrograph Method

Clarks's UH are slightly different than other synthetic unit hydrograph methods in that it has no duration. Clark's UH is an instantaneous unit hydrograph. This method was developed for gaged sites only, but has produced some suggestions for transfer of Clark parameters to un-gaged sites. Clark's model derives a watershed UH by explicitly representing two critical processes in the transformation of excess precipitation to runoff. Two critical processes are translation or movement of the excess from its origin throughout the drainage to the watershed outlet and attenuation or reduction of the magnitude of the discharge as the excess is stored throughout the watershed.

Short term storage of water throughout the watershed in the soil, on the surface and in the channels is an important role in the transformation of precipitation excess to runoff in Clark's. The linear reservoir model is a common representation of the effects of the storage which begins with a continuity equation:

$$\frac{dS}{dt} = I_t - O_t \tag{2.8}$$

Where,

I_t = average inflow to storage at time, t

O_t = outflow to storage at time, t

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the data collected was analyzed in order to predict the streamflow in un-gauged catchment area in Sungai Jelai Basin using HEC-HMS computer software. The method used to in this HEC-HMS software are Clark Unit Hydrograph. Few hydrology parameters were used to predict the streamflow such as rainfall data and streamflow data. These parameters are obtained from JPS. In this study, the models stimulate the rainfall data and streamflow data starting from year 1999 to 2014.

However, the selection of rainfall data and discharge data for verification and calibration were based on the availability and the best quality of data sets at the rainfall and discharge stations. The coefficient of determination RMSE value is used to evaluate the performance of hydrological model. The lower the value of RMSE, the better the result.

4.2 MODEL SETUP

In this study, AutoCAD software and HEC-HMS software were used. AutoCAD software were used to outline the catchment area, sub-catchments, and also to find the area, length of river, slope and others.

4.2.1 AutoCAD

For this study, AutoCAD software is needed to outline the river catchment. Topography map are needed for this process. From the topography map, the catchment area can be determined and the sub-catchment area can be outlined. Besides, the length of river, area of sub-catchment, elevation, and slope can also be obtained. The catchment area are based on the three rivers, which are Sungai Betau, Sungai Jelai Kecil and Sungai Serau. Topography map and catchment area of Sungai Jelai is shown in **Figure 4.1.**

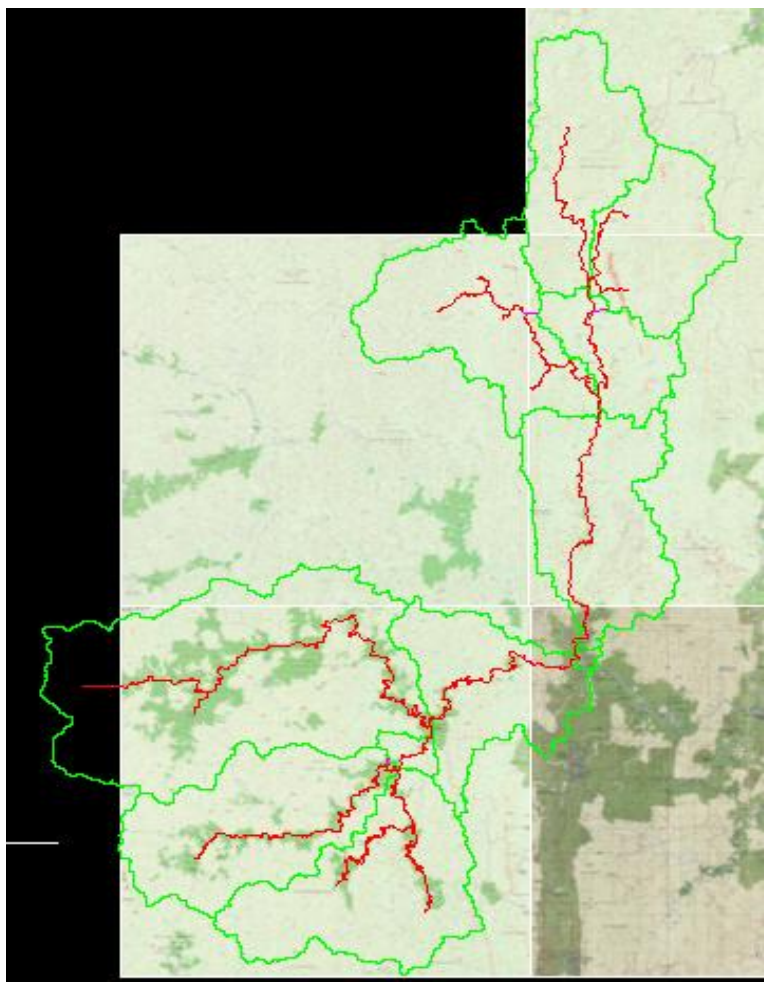

Figure 4.1: Sungai Jelai basin

After the topography map of Sungai Jelai basin are added in AutoCAD, the next step is to determine the sub-catchment area for Sungai Jelai basin. The sub-catchment is shown in **Figure 4.2.**

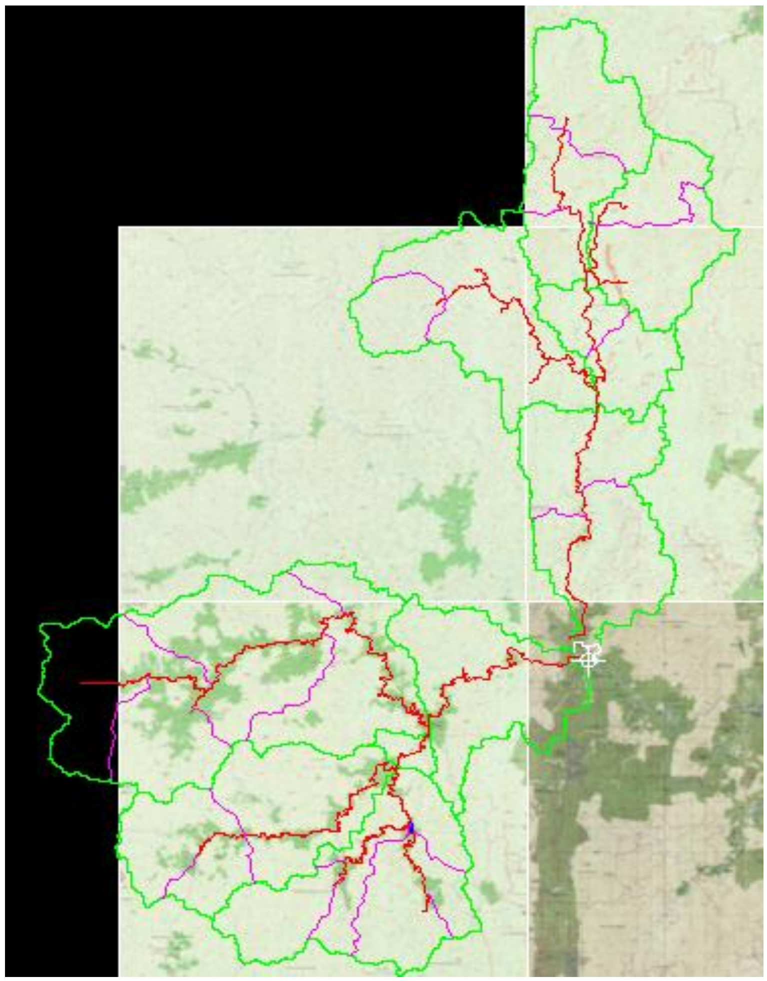

Figure 4.2: Sub-catchment area

4.2.2 HEC-HMS Model Setup

The configuration for HEC-HMS for Sungai Jelai basin model is shown in **Figure 4.3.** There are 35 sub-catchment used to represent the hydrological model in Sungai Jelai. The observed rainfall station used are RF 4218042, RF 4514032 and RF 4620046 and the observed streamflow station are SF 4218416.

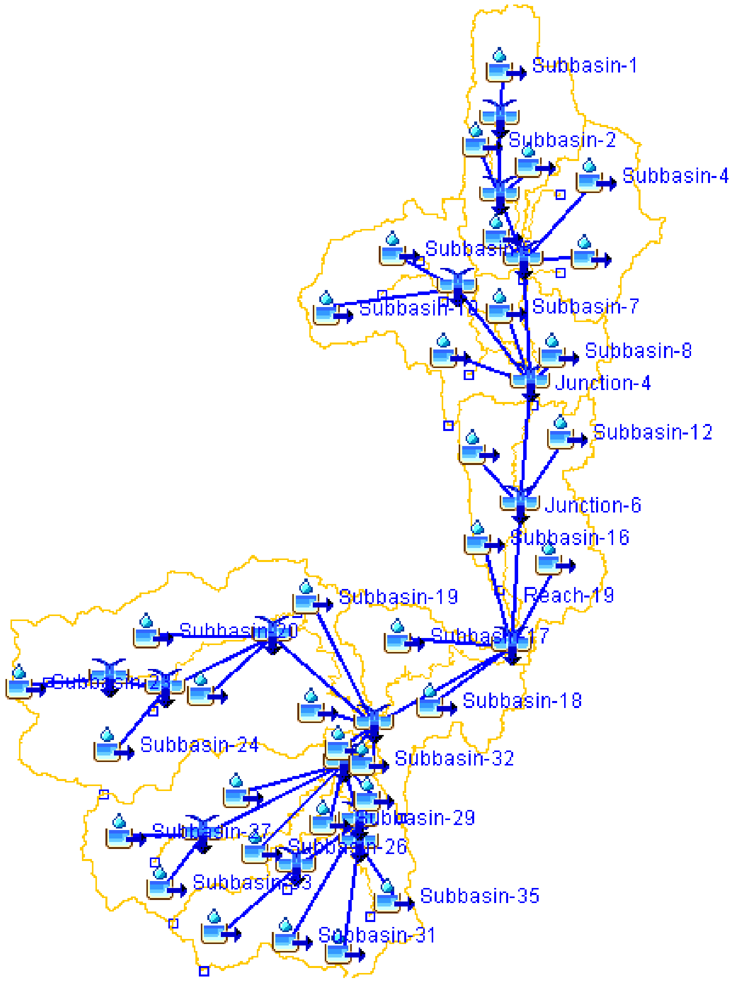

Figure 4.3: HEC-HMS layout model

4.3 SIMULATION WITH HEC-HMS

For the simulation of runoff hydrographs, few parameters are required as inputs in HEC-HMS model. The parameters needed are varies depends on the method used. Some of the parameters can be estimated through the observation and measurements of stream and basin characteristics. In this study, the method used is Clark Unit Hydrograph. Parameters needed for this simulation are shown in **Table 4.1.**

Table 4.1: Parameters used for Clark's Unit Hydrograph

Element	Method	Parameter
Sub-basin	Loss Rate- SCS Curve Number	Initial abstraction Curve Number Impervious
	Transform- Clark Unit Hydrograph	Storage coefficient Time of concentration
	Baseflow- Constant Monthly	Discharge baseflow
Reach	Routing	Lag

4.3.1 Analysis

In this study, the hydrological model simulated the rainfall data and streamflow data starting from April 1999 to February 2014 which is 15 years. These data are obtain from JPS. The rainfall data and streamflow data were taken from 8:00am until 8:00am the next day, which is 24 hours. The data used for analysis must available for all the rainfall station and streamflow station. For this study, two analysis will be done for two different rainfall station. The result of each analysis will be combined with the analysis from Cameron Highland. After analyzed and simulate the data, the result of the analysis can used to determine the peak discharge between simulated and observed hydrograph. The simulated hydrograph will have the same characteristic with the observed hydrograph.

The computed results of HEC-HMS after calibration are shows below. The comparison between the simulated and observed hydrograph can be obtained as shown in **Figure 4.4** until **Figure 4.41**

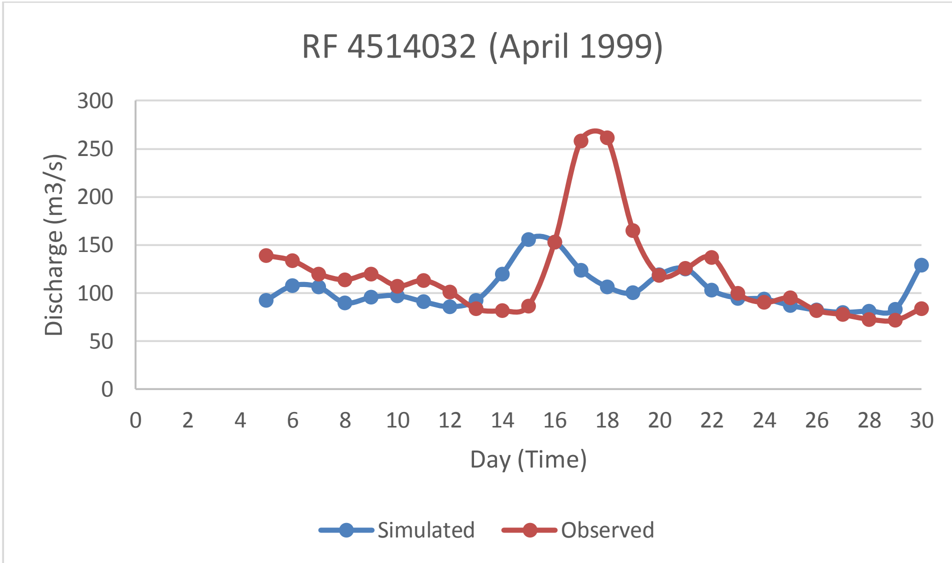

Figure 4.4: Runoff hydrograph for RF 4514032 discharge station

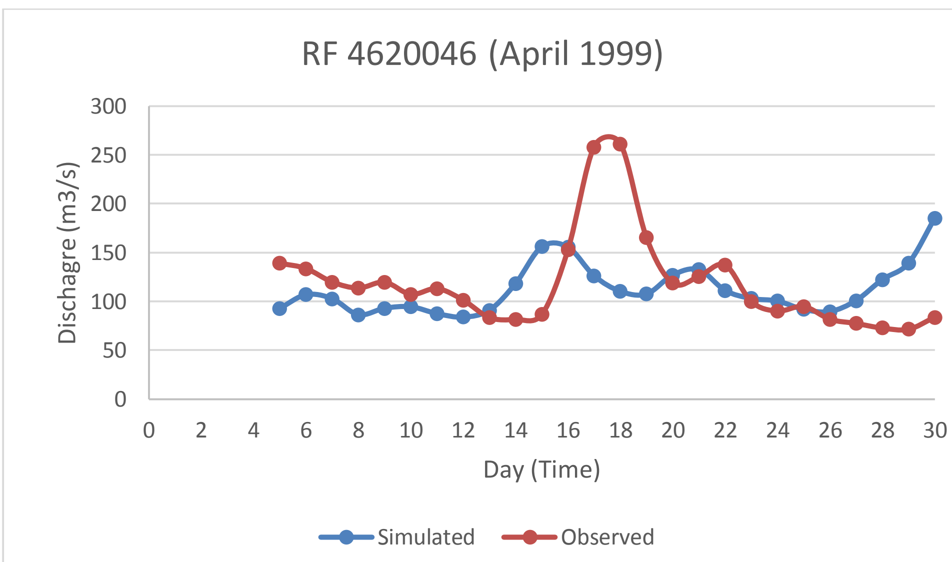

Figure 4.5: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in April 1999, the RMSE for RF 4514032 was 67.03 m^3/s while the RMSE for RF 4620046 was 70.66 m^3/s.

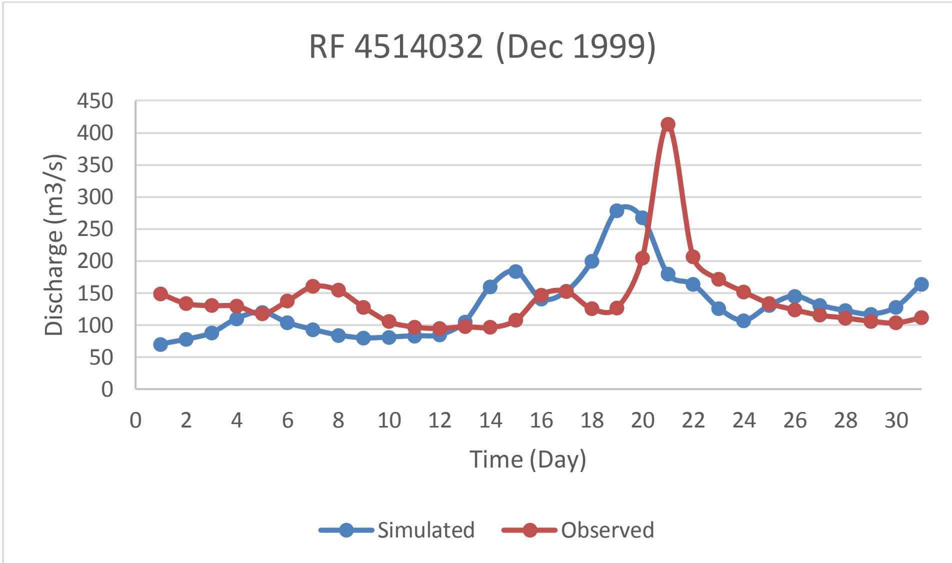

Figure 4.6: Runoff hydrograph for RF 4514032 discharge station

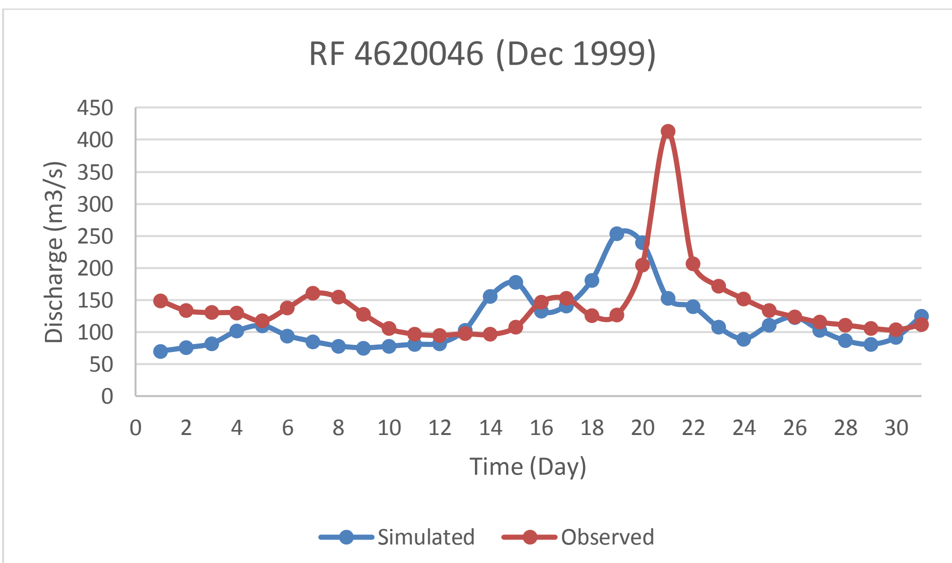

Figure 4.7: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in December 1999, the RMSE for RF 4514032 was 65.36 m^3/s while the RMSE for RF 4620046 was 67.68 m^3/s.

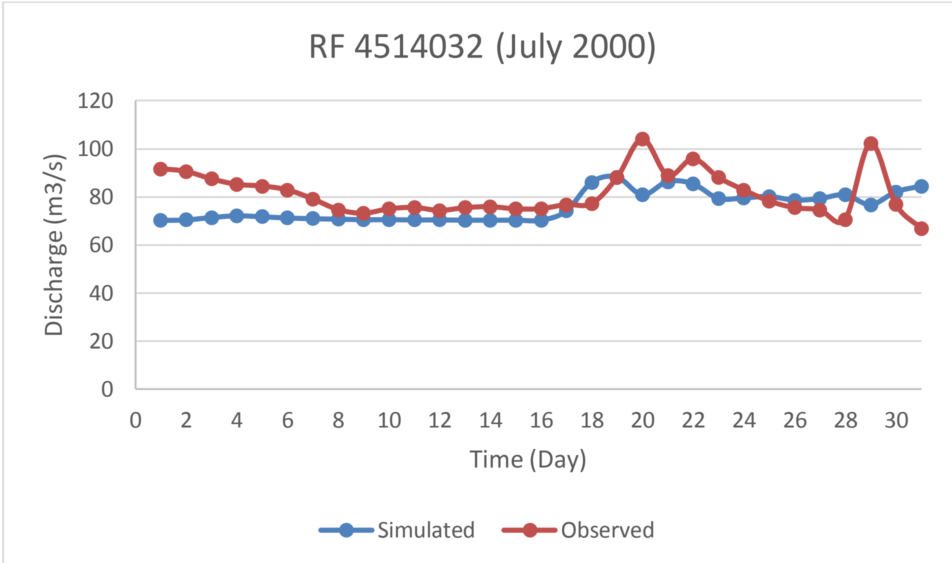

Figure 4.8: Runoff hydrograph for RF 4514032 discharge station

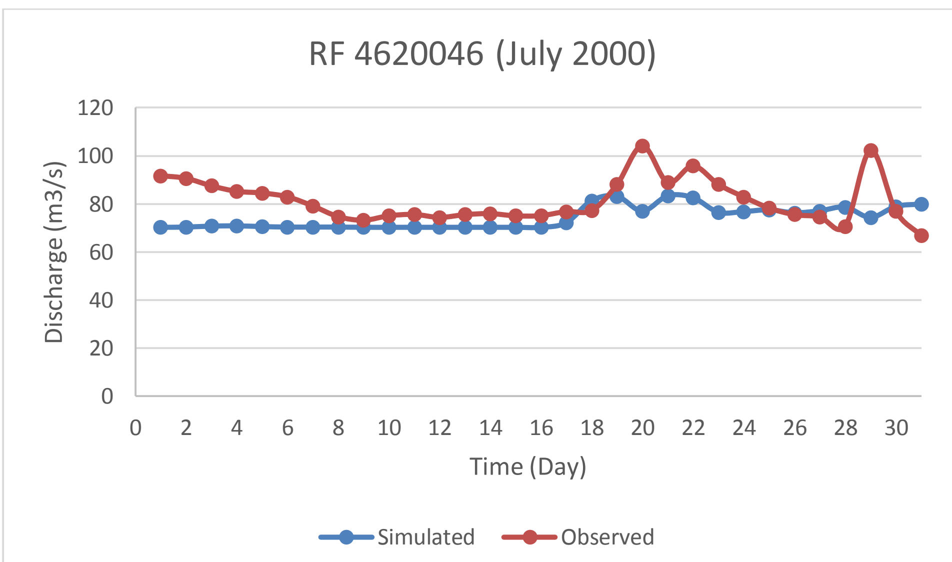

Figure 4.9: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in July 2000, the RMSE for RF 4514032 was 11.07 m^3/s while the RMSE for RF 4620046 was 11.62 m^3/s.

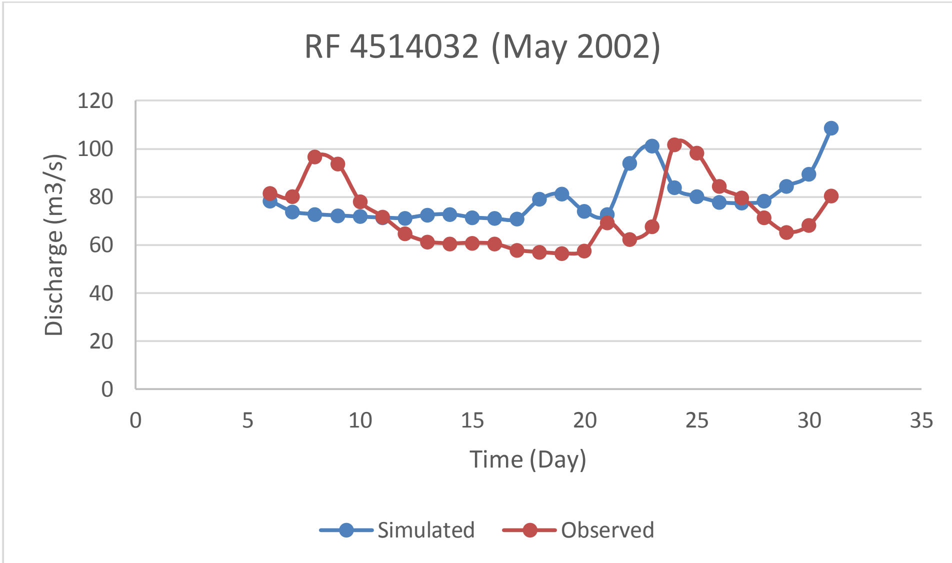

Figure 4.10: Runoff hydrograph for RF 4514032 discharge station

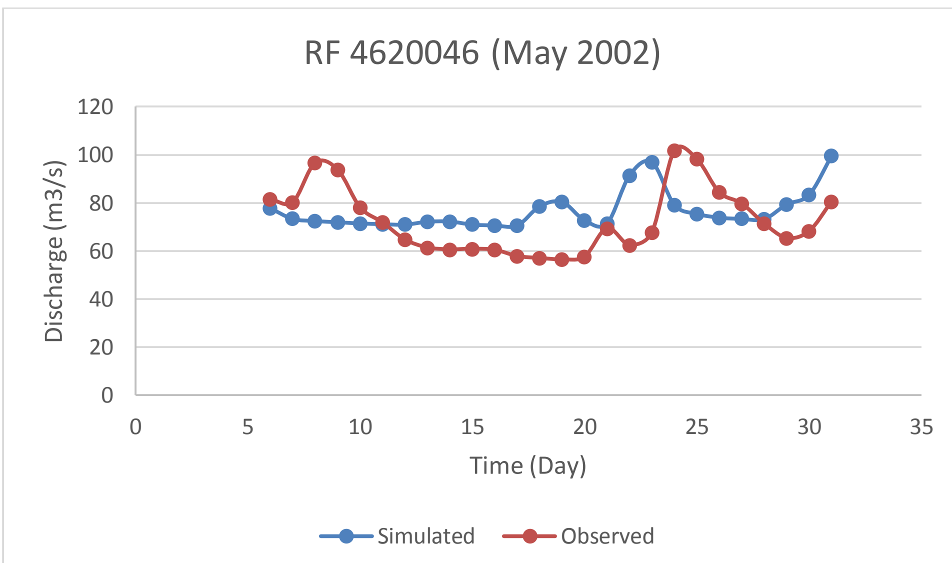

Figure 4.11: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in May 2002, the RMSE for RF 4514032 was 26.54 m^3/s while the RMSE for RF 4620046 was 26.07 m^3/s.

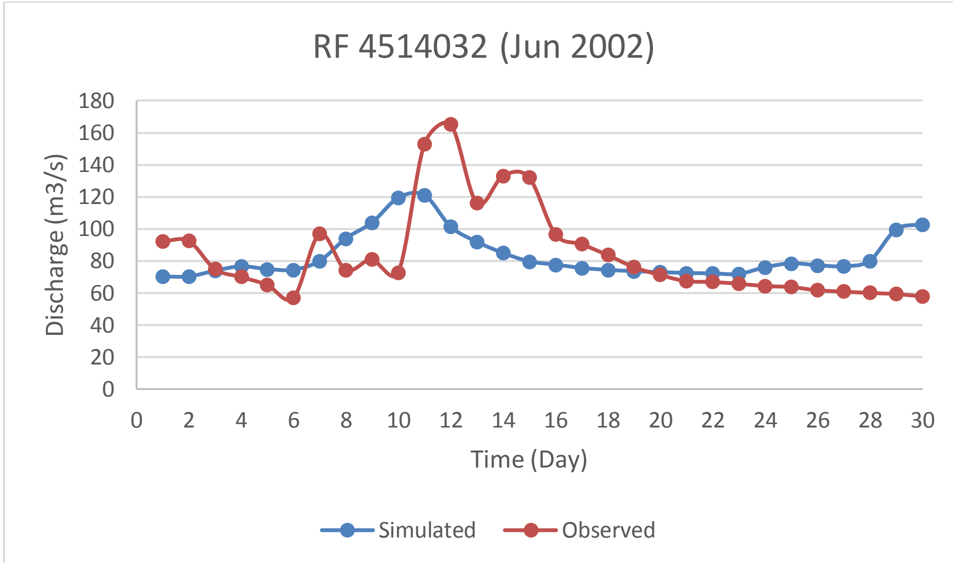

Figure 4.12: Runoff hydrograph for RF 4514032 discharge station

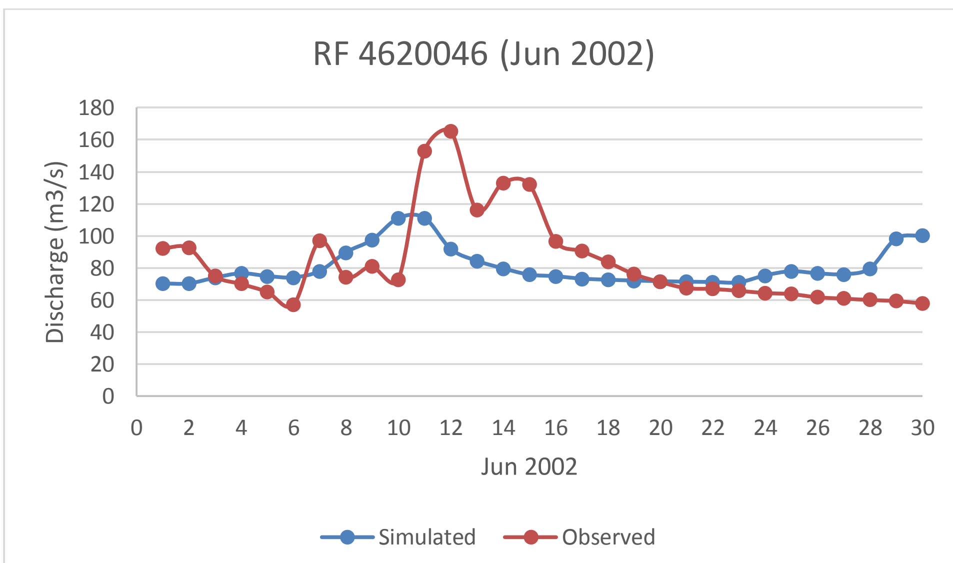

Figure 4.13: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in June 2002, the RMSE for RF 4514032 was 26.56 m^3/s while the RMSE for RF 4620046 was 27.88 m^3/s.

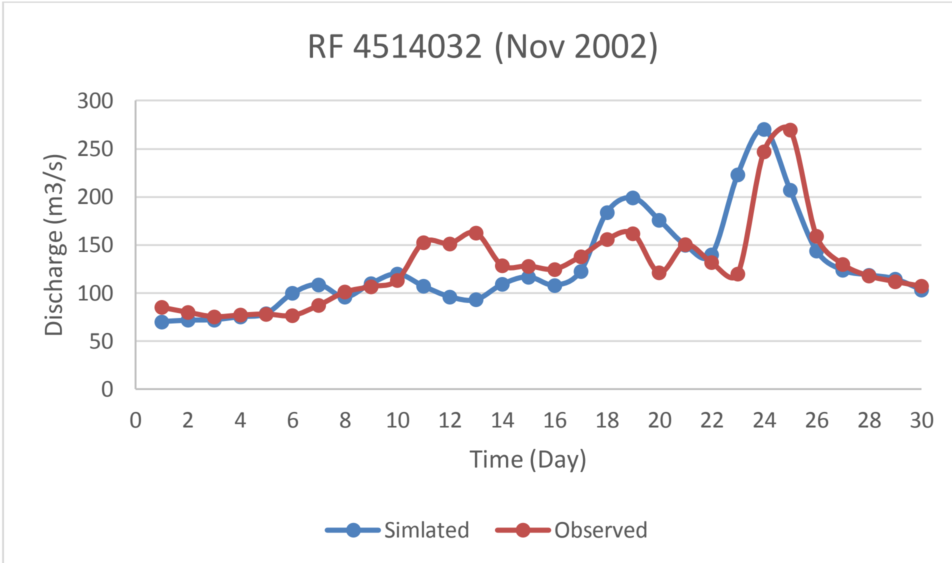

Figure 4.14: Runoff hydrograph for RF 4514032 discharge station

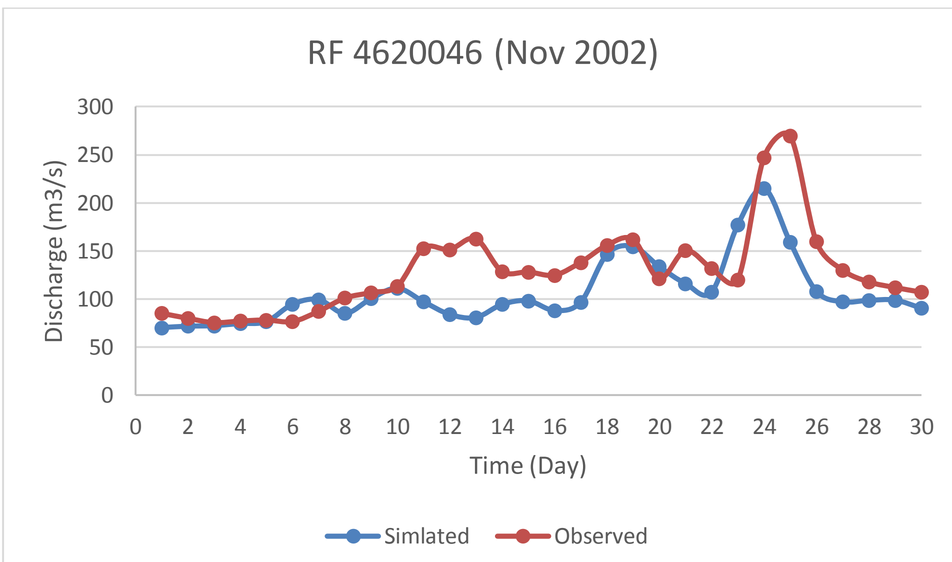

Figure 4.15: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in November 2002, the RMSE for RF 4514032 was 33.15 m^3/s while the RMSE for RF 4620046 was 38.16 m^3/s.

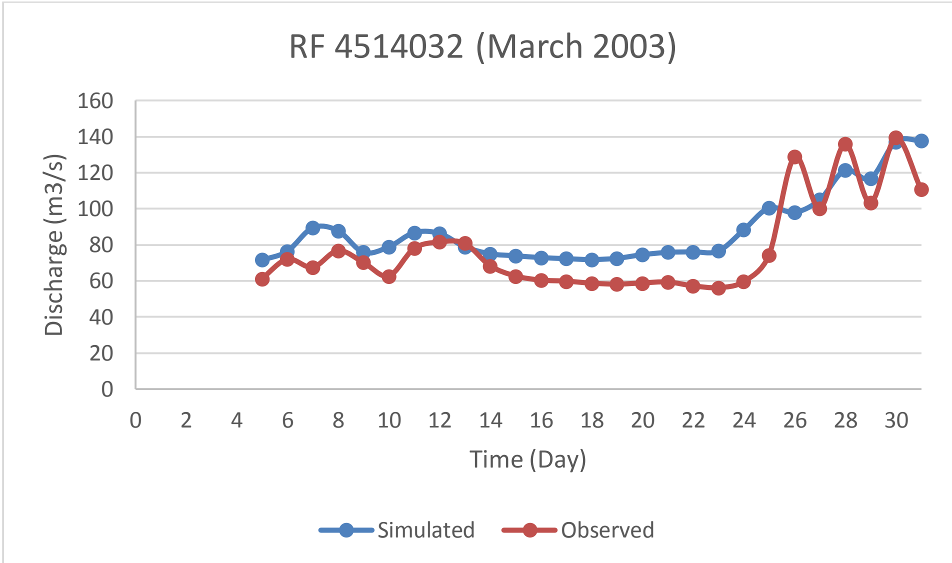

Figure 4.16: Runoff hydrograph for RF 4514032 discharge station

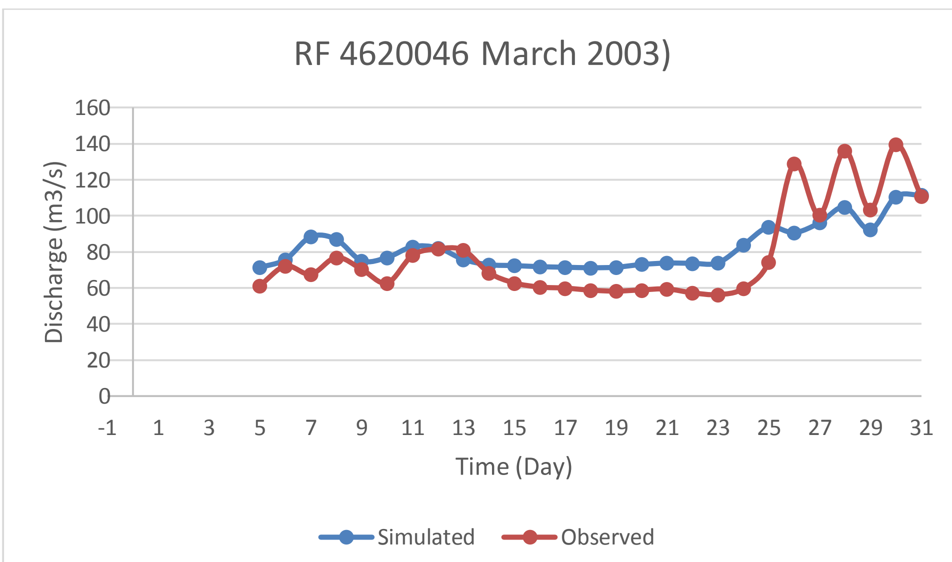

Figure 4.17: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in March 2003, the RMSE for RF 4514032 was 39.39 m^3/s while the RMSE for RF 4620046 was 39.43 m^3/s.

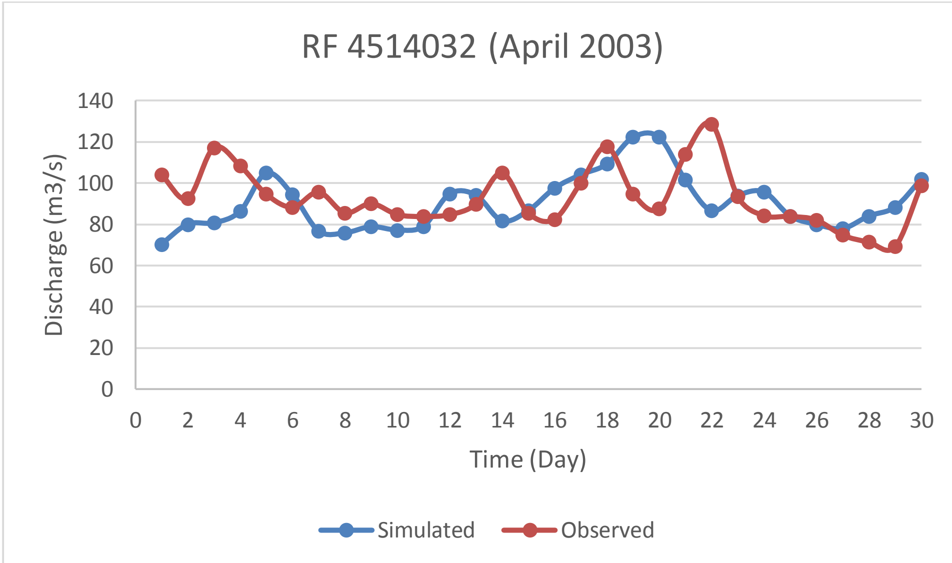

Figure 4.18: Runoff hydrograph for RF 4514032 discharge station

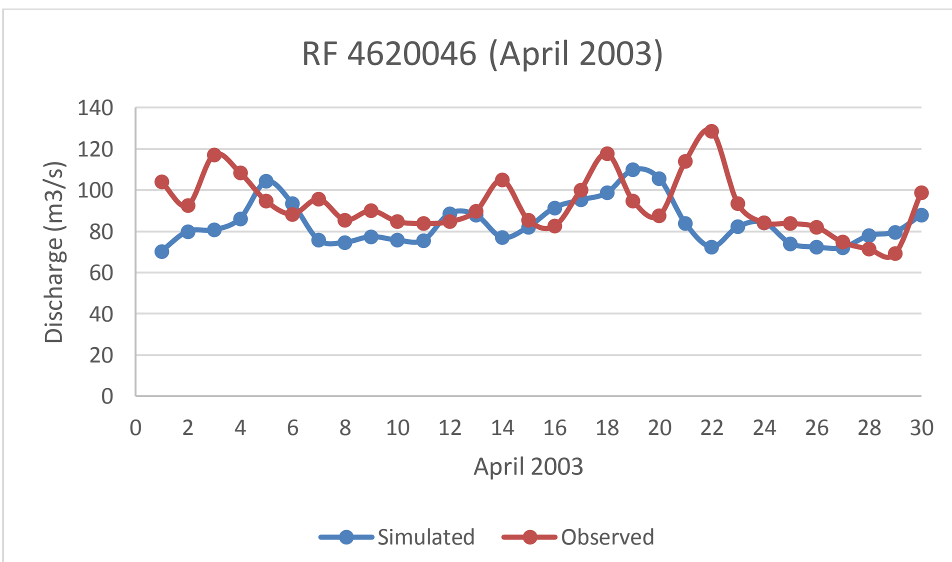

Figure 4.19: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in April 2003, the RMSE for RF 4514032 was 17.75 m^3/s while the RMSE for RF 4620046 was 18.78 m^3/s.

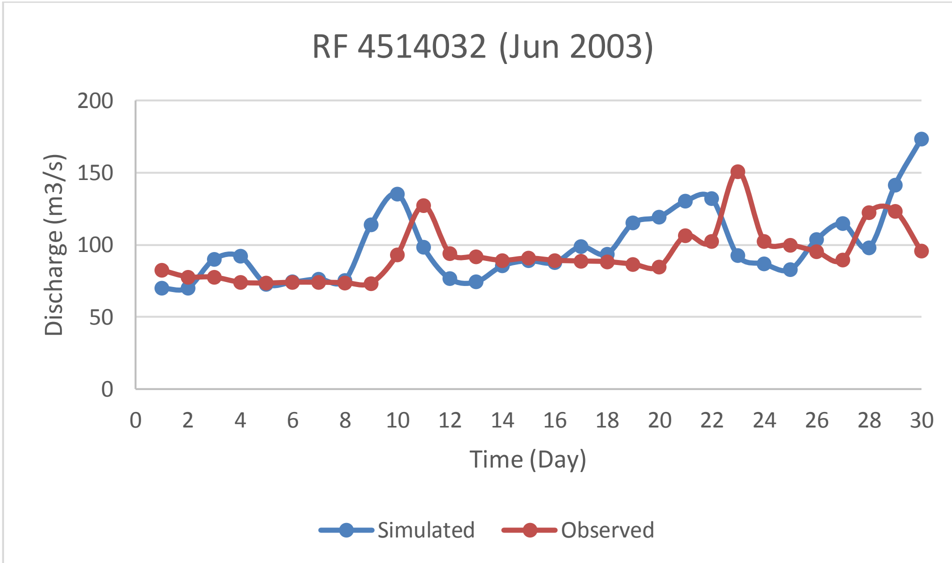

Figure 4.20: Runoff hydrograph for RF 4514032 discharge station

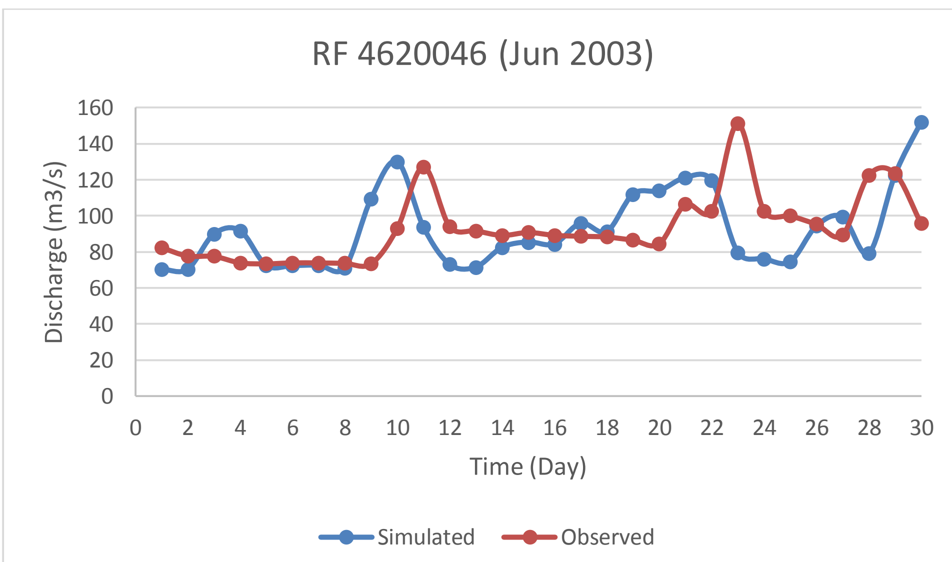

Figure 4.21: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in June 2003, the RMSE for RF 4514032 was 26.37 m^3/s while the RMSE for RF 4620046 was 25.25 m^3/s.

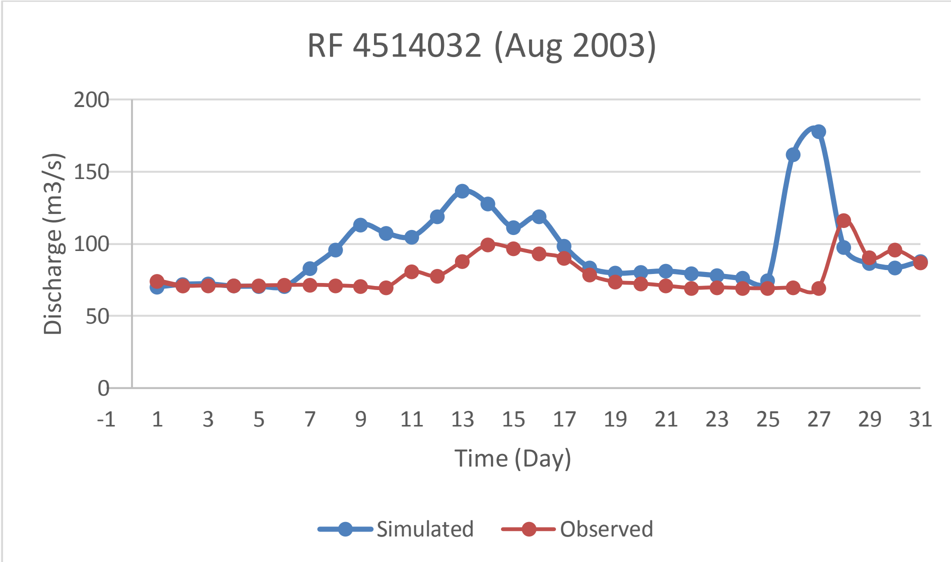

Figure 4.22: Runoff hydrograph for RF 4514032 discharge station

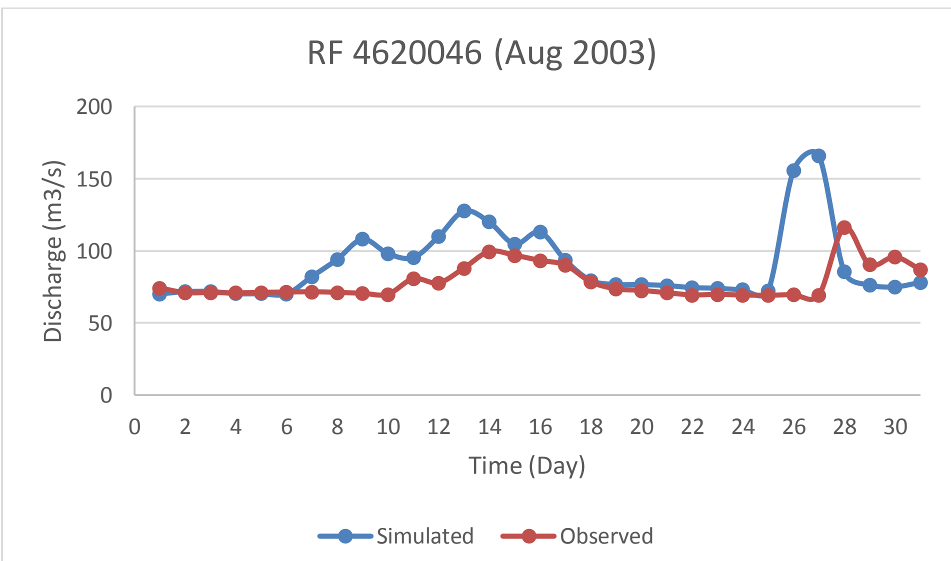

Figure 4.23: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in August 2003, the RMSE for RF 4514032 was 32.0 m^3/s while the RMSE for RF 4620046 was 28.49 m^3/s.

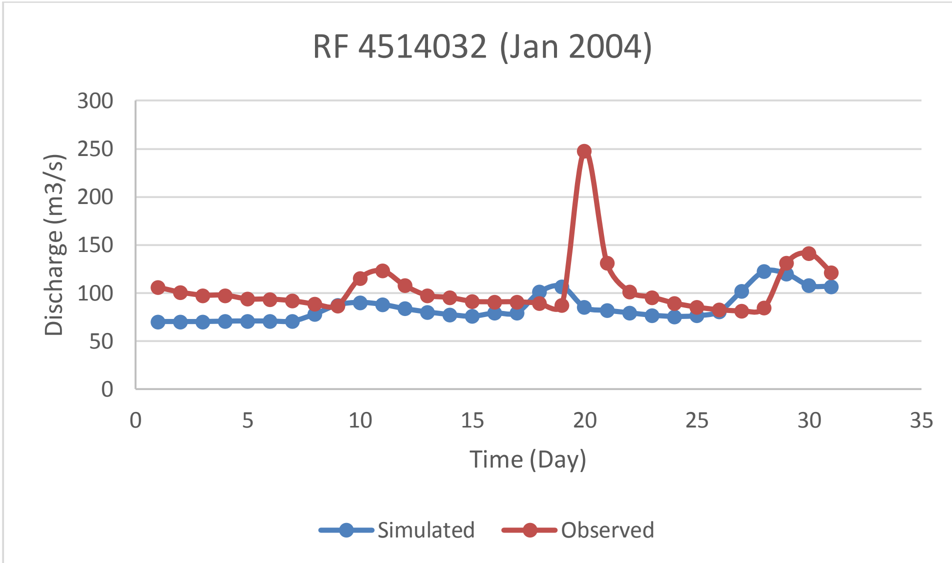

Figure 4.24: Runoff hydrograph for RF 4514032 discharge station

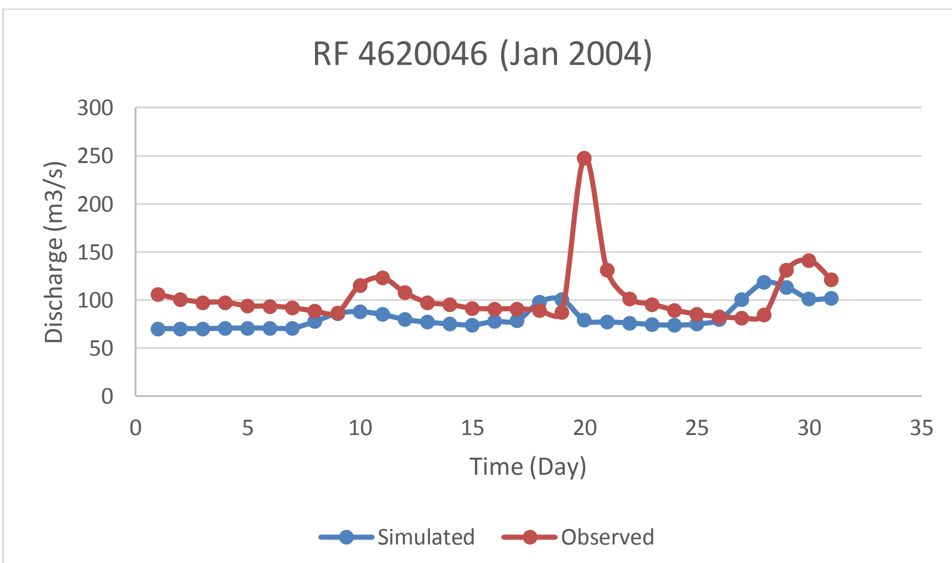

Figure 4.25: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in January 2004, the RMSE for RF 4514032 was 37.07 m^3/s while the RMSE for RF 4620046 was 38.71 m^3/s.

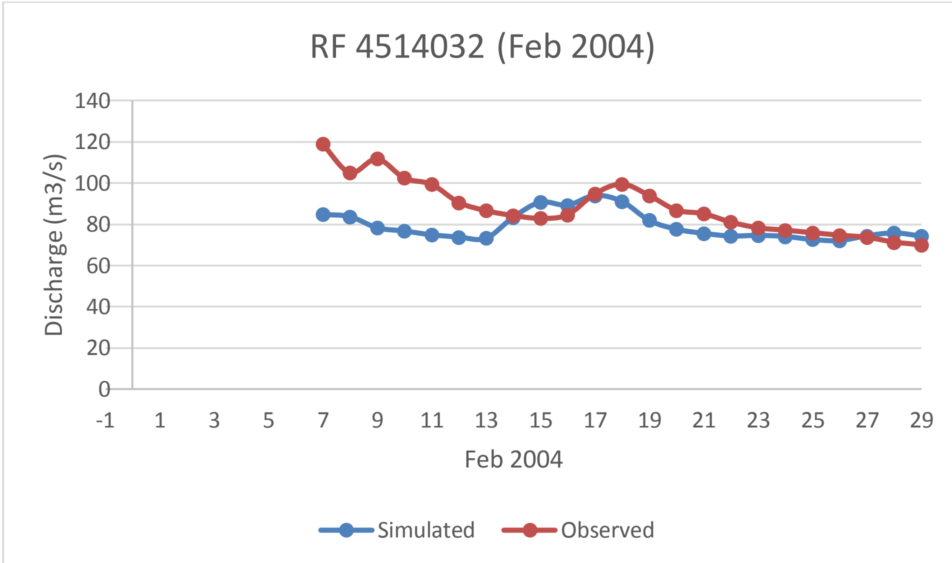

Figure 4.26: Runoff hydrograph for RF 4514032 discharge station

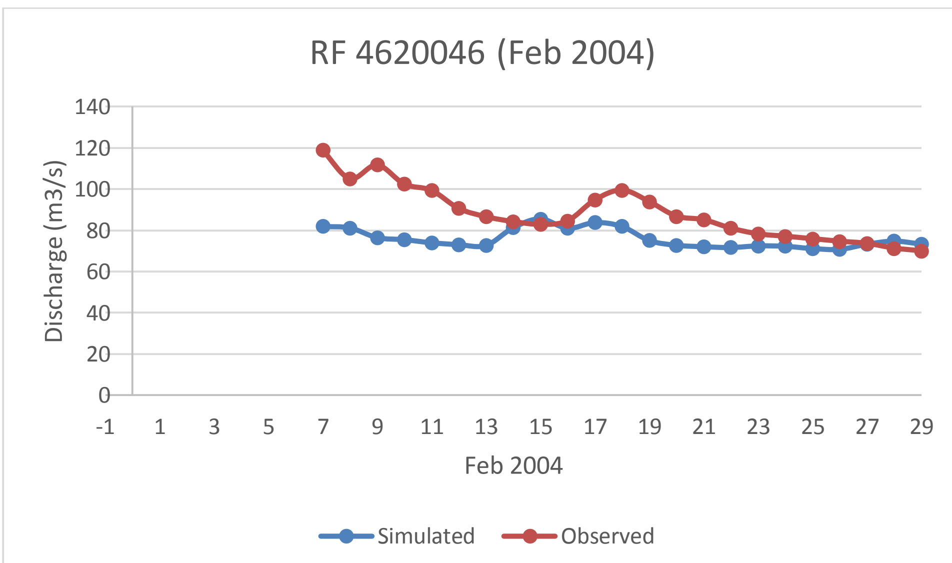

Figure 4.27: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in February 2004, the RMSE for RF 4514032 was 26.41 m^3/s while the RMSE for RF 4620046 was 27.63 m^3/s.

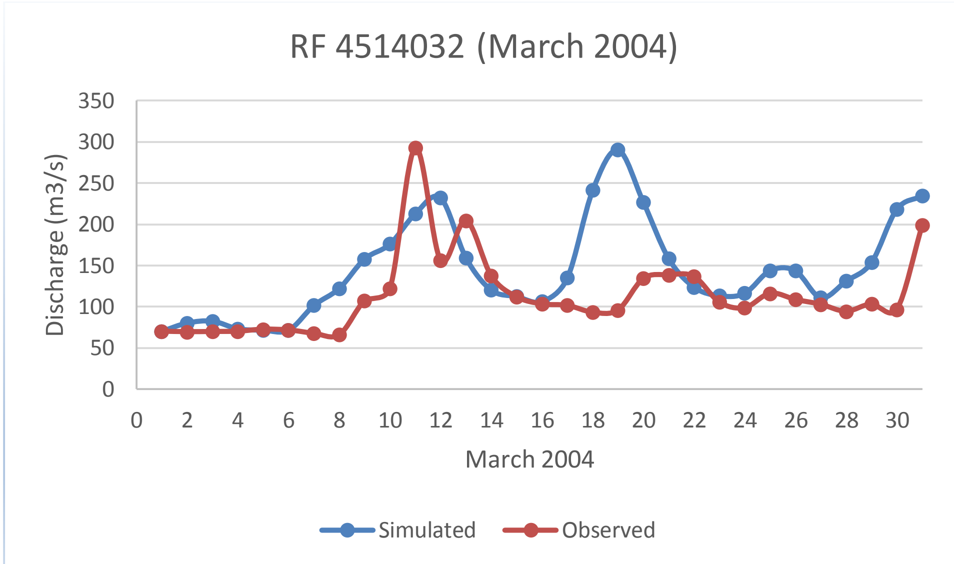

Figure 4.28: Runoff hydrograph for RF 4514032 discharge station

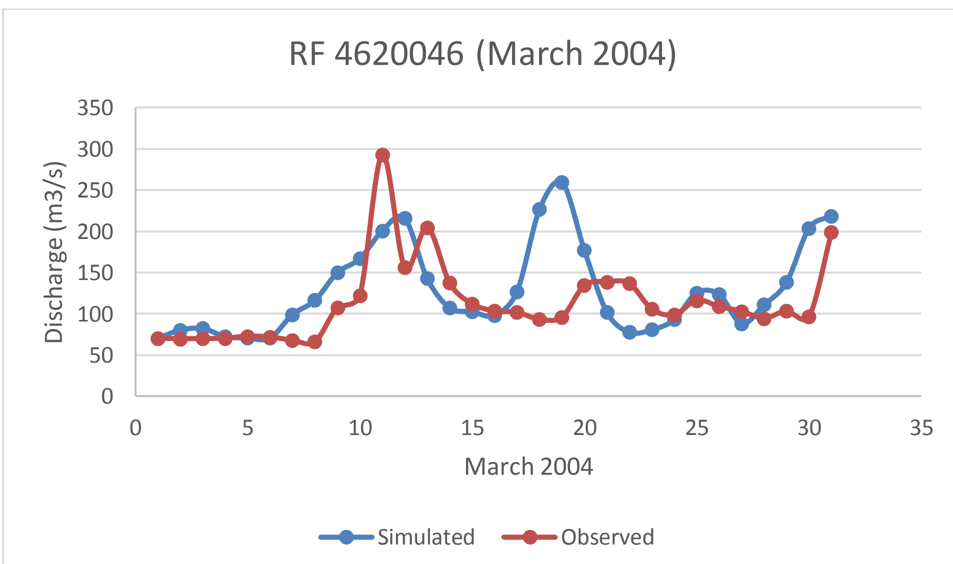

Figure 4.29: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in March 2004, the RMSE for RF 4514032 was 61.48 m^3/s while the RMSE for RF 4620046 was 54.10 m^3/s.

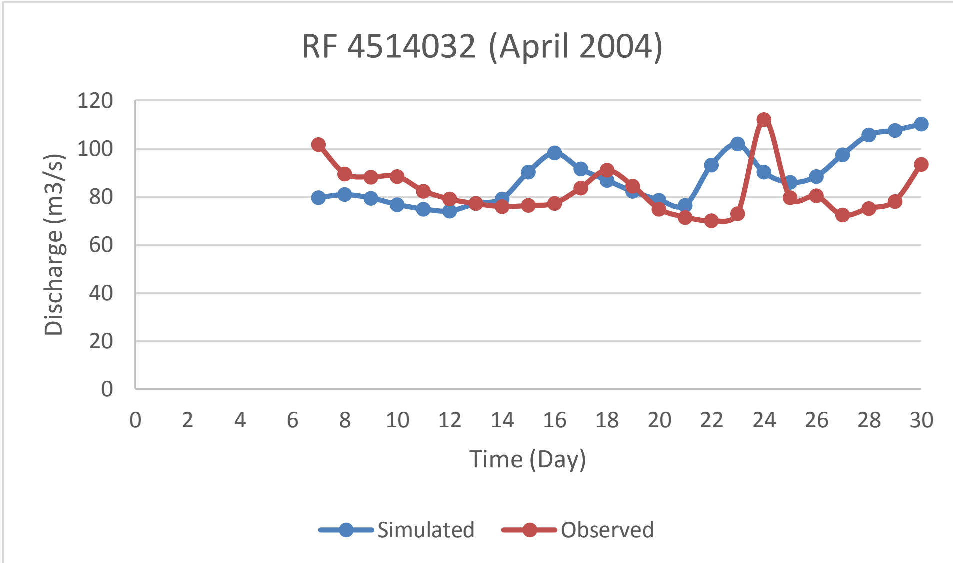

Figure 4.30: Runoff hydrograph for RF 4514032 discharge station

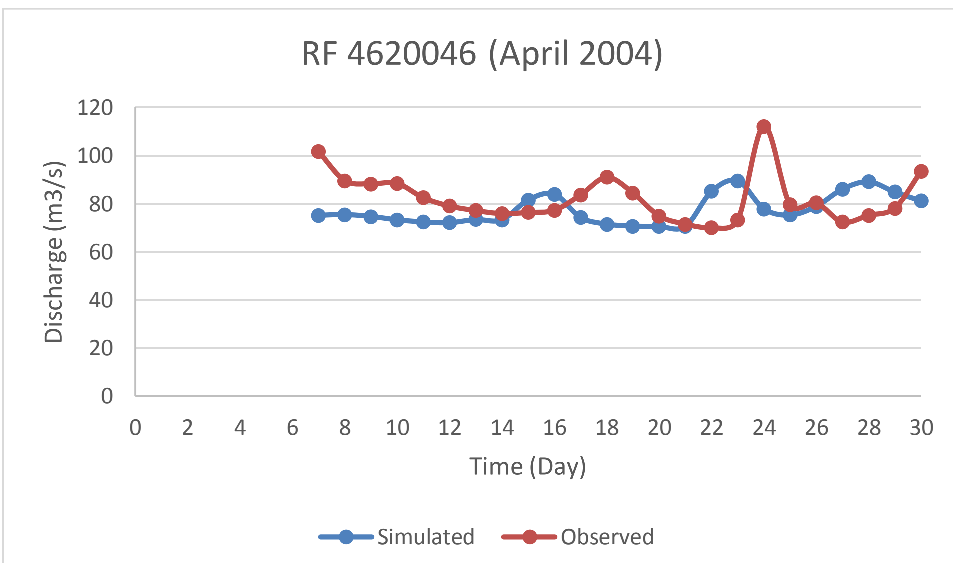

Figure 4.31: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in April 2004, the RMSE for RF 4514032 was 21.42 m^3/s while the RMSE for RF 4620046 was 20.55 m^3/s.

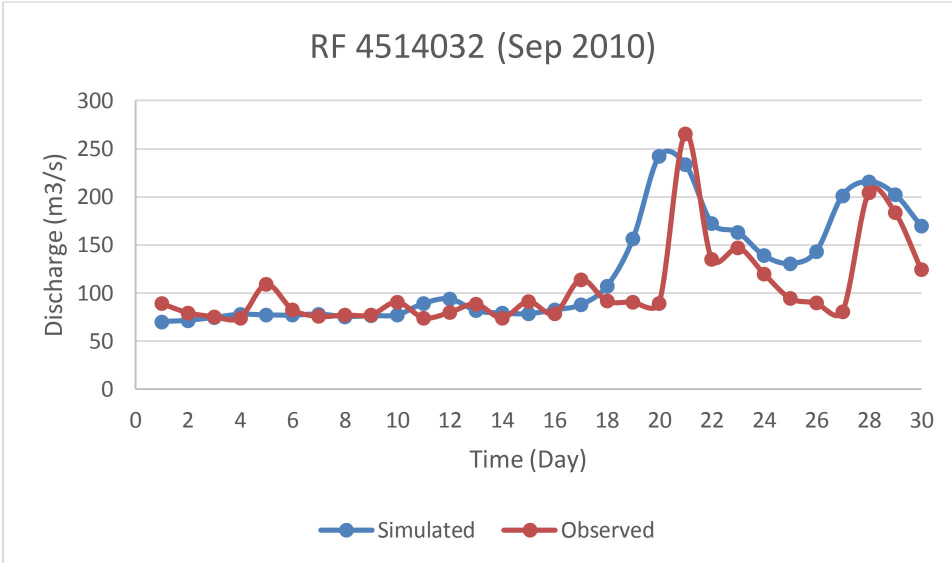

Figure 4.32: Runoff hydrograph for RF 4514032 discharge station

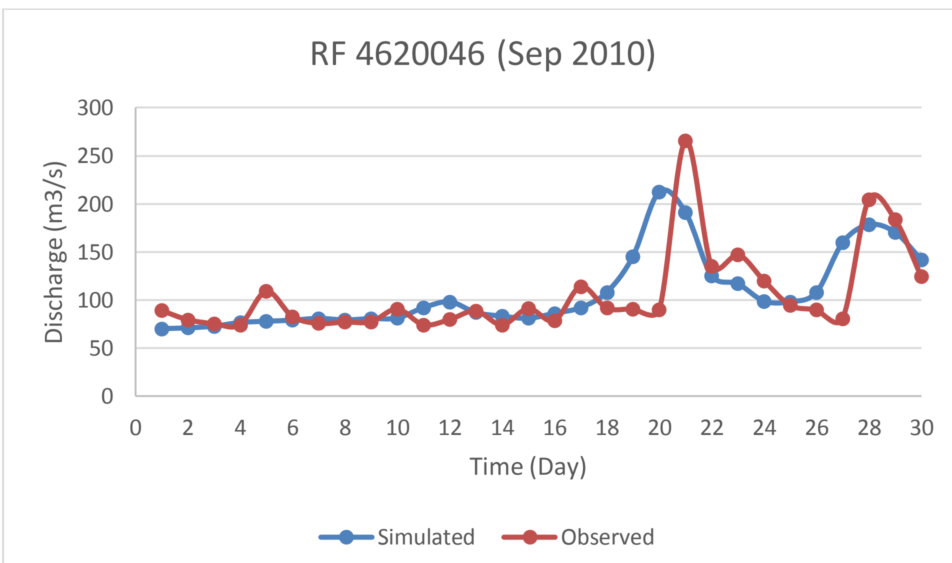

Figure 4.33: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in September 2010, the RMSE for RF 4514032 was 42.85 m^3/s while the RMSE for RF 4620046 was 34.63 m^3/s.

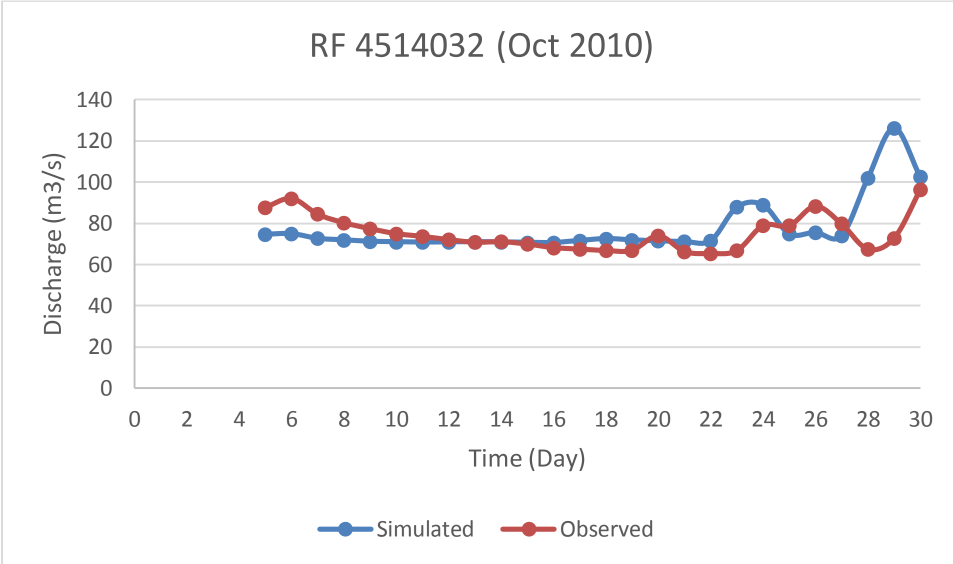

Figure 4.34: Runoff hydrograph for RF 4514032 discharge station

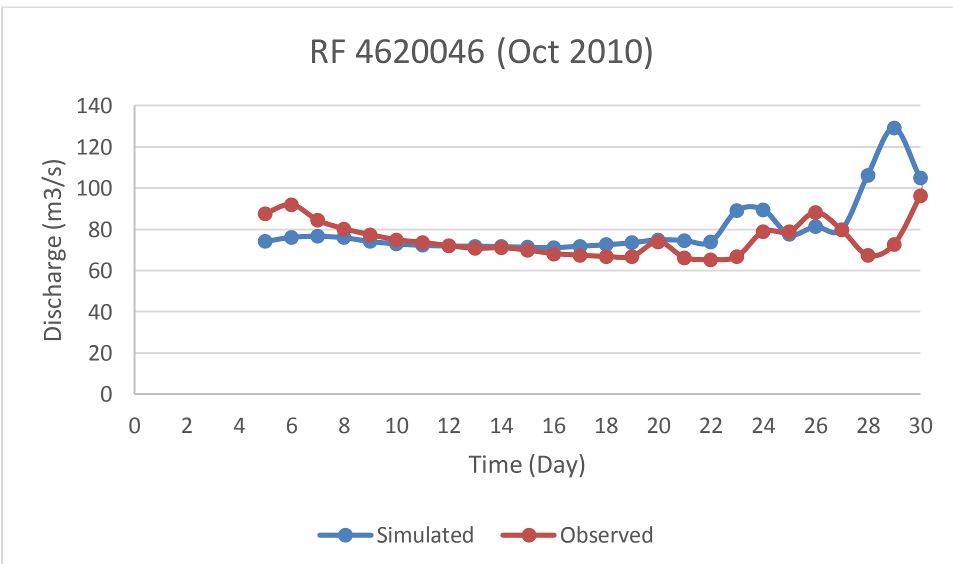

Figure 4.35: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in October 2010, the RMSE for RF 4514032 was 20.51 m^3/s while the RMSE for RF 4620046 was 20.68 m^3/s.

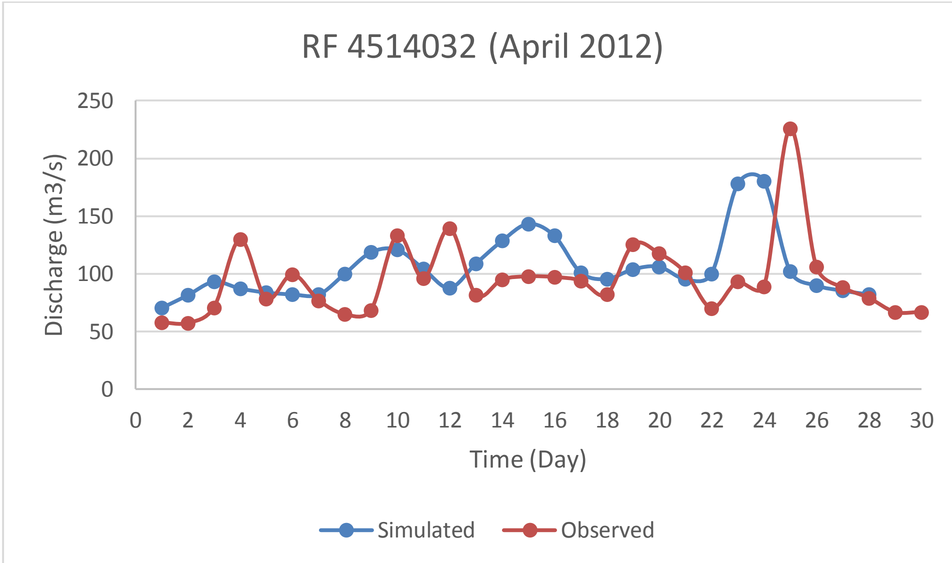

Figure 4.36: Runoff hydrograph for RF 4514032 discharge station

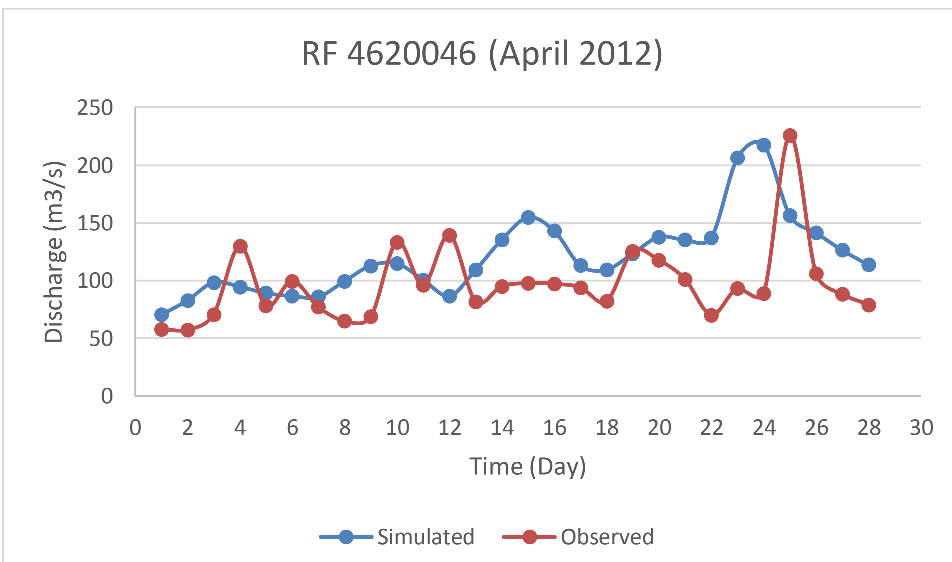

Figure 4.37: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in April 2012, the RMSE for RF 4514032 was 41.76 m^3/s while the RMSE for RF 4620046 was 51.57 m^3/s.

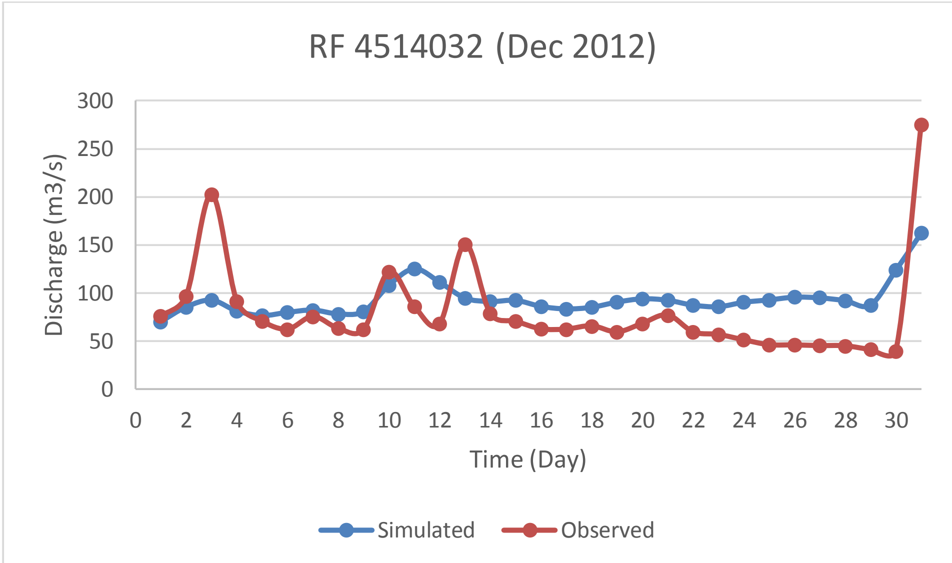

Figure 4.38: Runoff hydrograph for RF 4514032 discharge station

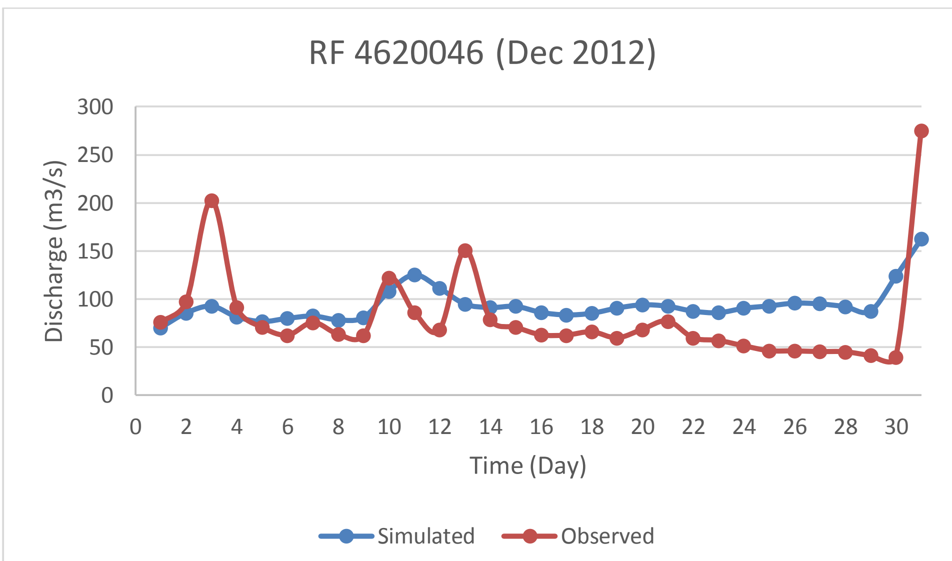

Figure 4.39: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in December 2012, the RMSE for RF 4514032 was 43.45 m^3/s while the RMSE for RF 4620046 was 43.27 m^3/s.

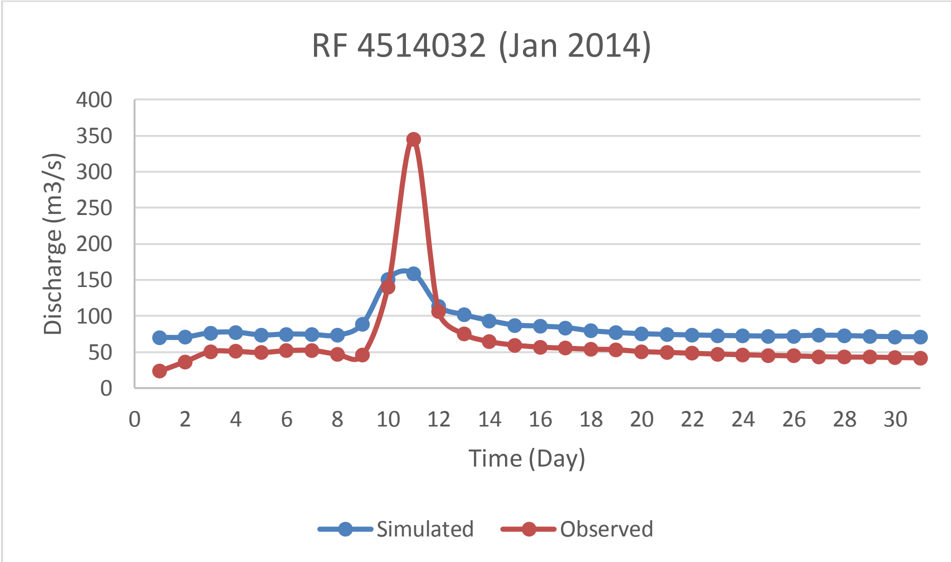

Figure 4.40: Runoff hydrograph for RF 4514032 discharge station

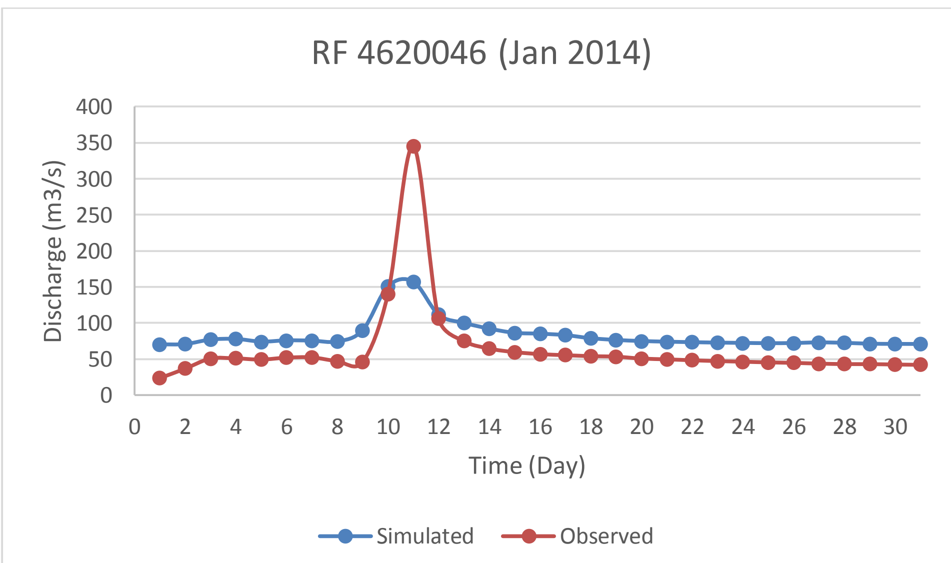

Figure 4.41: Runoff hydrograph for RF 4620046 discharge station

Based on the computed result in January 2014, the RMSE for RF 4514032 was 43.10 m^3/s while the RMSE for RF 4620046 was 43.18 m^3/s.

4.4 Model Calibration

After obtaining the hydrograph model, calibration process has been carried out. Model calibration is a process of adjusting the model parameters value until the model result obtained are match with the observed model. For this process, discharge baseflow value (Q_b) value are determined using trial and error method. The equation that being used before calibration are expressed in Eq. (4.1).

$$Q_b = 0.11\ A^{0.85889} \tag{4.1}$$

As the result obtain are not so fit with the observed model, therefore, the equation are calibrated. The equation after calibration are expressed in Eq. (4.2). The value of discharge base before and after calibration are shown in **Table 4.2.**

$$Q_b = 0.0473\ A^{0.85889} \tag{4.2}$$

Table 4.2: The value of discharge before and after calibration

SUB-BASIN	Q_b (Actual)	Q_b (Calibrated)
1	3.9811	1.7119
2	1.1828	0.5086
3	1.3368	0.5748
4	2.4172	1.0394
5	4.1473	1.7833
6	1.9261	0.8282
7	1.7509	0.7529
8	2.4272	1.0437
9	3.6564	1.5723
10	2.1917	0.9424
11	4.0079	1.7234
12	2.1191	0.9112
13	2.5290	1.0875
14	4.2771	1.8391
15	0.5198	0.2235

16	1.3968	0.6006
17	3.3007	1.4193
18	4.2761	1.8387
19	2.4149	1.0384
20	4.0464	1.7400
21	4.0403	1.7373
22	3.0176	1.2976
23	4.8105	2.0685
24	3.7388	1.6077
25	4.2136	1.8118
26	2.0086	0.8637
27	3.0876	1.3277
28	2.5802	1.1095
29	1.0927	0.4699
30	1.9882	0.8549
31	2.5448	1.0943
32	0.4080	0.1755
33	1.7725	0.7622
34	2.7387	1.1776
35	1.9785	0.8508

4.5 Model Verification

After the calibration process, all the parameters will be used for other rainfall and flowrate event. For the verification process, the hygrograph model generated will be used to compare with other hydrograph model in different month and year.

The hydrograph model is verified for August 2003 and October 2010. The model calibration results are shown in **Figure 4.42** and **Figure 4.43**.

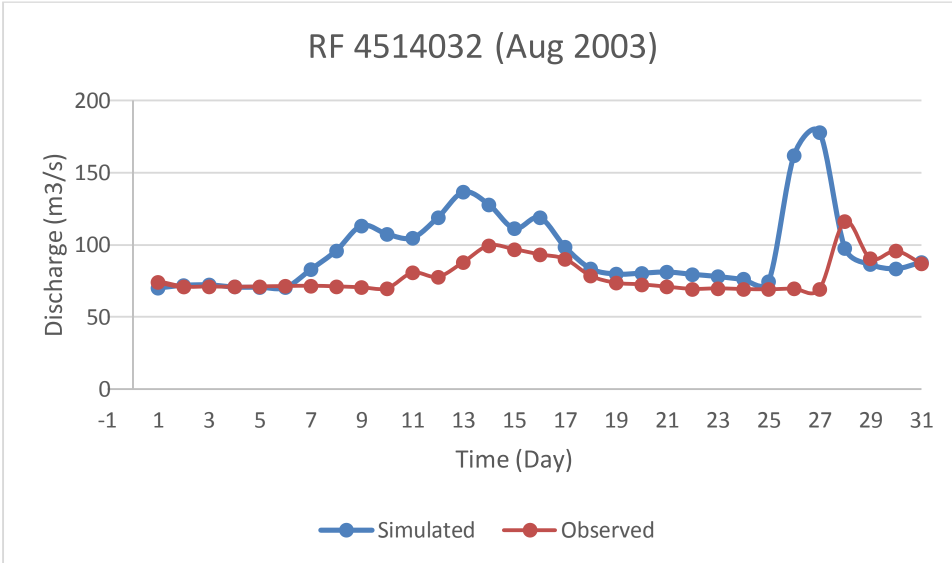

Figure 4.42: Runoff hydrograph for RF 4514032 discharge station

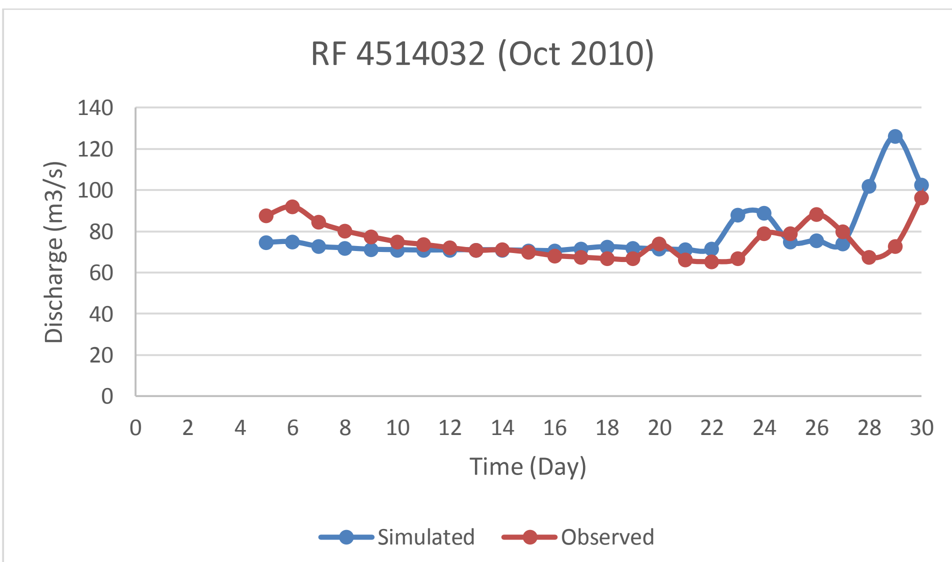

Figure 4.43: Runoff hydrograph for RF 4514032 discharge station

From the verification result, the RMSE value for RF 4514032 station on August 2003 and October 2010 are 32.0 m^3/s and 20.51 m^3/s. For RMSE, the lower the value, the result will be better. There is no limitation value for RMSE. The characteristic of simulated hydrograph are almost same with the observed hydrograph.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

After the simulation process is done for calibration and verification by using HEC-HMS software, the simulated discharge hydrograph generated are not fitted satisfactory with the observed hydrograph. This may due to non-uniform distributions and the parameter value used are not so suitable. Therefore, some adjustments of parameters value is required to obtain more fitted simulated hydrograph.

Due to time constraint, there is only one method been done for this analysis. To get more accurate result, at least two methods are needed to analyze the data. The value for curve number also need to be calibrated.

From the calibrated result, the RMSE value for RF 4514032 July 2000 and April 2003 are 11.07 m^3/s and 17.75 m^3/s. For another rainfall station, that is RF 4620046, the RMSE value for July 2000 and April 2003 are 11.62 m^3/s and 18.78 m^3/s. By comparing the RMSE value for both rainfall station, it can be conclude that RF 4514032 are more suitable to be used to predict the discharge for un-gauged catchment area at Sungai Betau, Sungai Jelai Kecil, and Sungai Serau.

In conclusion, based on the results and data confirmation, HEC-HMS can be a reliable tool to predict flood levels, flowrate as well as for design purpose. HEC-HMS is the suitable model to predict the discharge for un-gauged catchment area.

5.2 RECOMMENDATION

The hydrological data obtained from The Department of Irrigation and Drainage (JPS) are not so accurate as it is manual rain gauges. Thus, in future, automatic rainfall stations with hourly increment data should be used for more accurate results.

From the hydrological data, there are some missing data, which means that analysis cannot be done for that particular month. It is recommend that the data collection should be upgraded to effective real time data which is more effective in terms of minimizing the error,

Therefore, to obtain more accurate result, a few rainfall station should be proposed evenly throughout the basin. There should be more rainfall station for Sungai Jelai catchment area. For better accuracy, two or more method are used in the analysis and consider some other parameters in HEC-HMS modelling.

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APPENDIX A

RAINFALL AND STREAMFLOW DATA

TABLE 6.1: April 1999

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	40	14	0	210.08
2	25	29.5	15.5	119
3	0	24.5	6	314.53
4	0	1	32.5	198.86
5	0	17	12.5	139.16
6	0	30.5	0	133.74
7	11.5	0.5	0	119.99
8	30	0	0	113.87
9	21	0	0	119.86
10	6	20	0	107.41
11	0	5.5	14.1	113.25
12	0	11	25.6	101.55
13	4	18	17.5	83.71
14	48	15	29	81.8
15	19	0.5	9.7	86.81
16	35	0	0	152.93
17	5	0	0	258.3
18	0	0	18.1	261.41
19	6	0.5	6.9	165.34
20	0	2	0	118.88
21	0	3	12.6	125.69
22	0	0	4.9	137.39
23	0	0	0	100.02
24	8	0	0	90.33
25	0	0	0	95.03
26	0	0	21.3	81.99
27	0	0	42.9	77.68
28	10	0	35	72.96
29	0	0	26.4	71.69
30	30	18.5	6.9	83.95

TABLE 6.2: December 1999

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	10	30.5	0	149.06
2	0	40.5	0	133.8
3	0	15	0	130.55
4	15	32.5	0	129.89
5	6	11	0	117.65
6	11	4.5	0	137.84
7	7	5	0	160.41
8	0	0	0	154.57
9	10	0	0	128.26
10	21	0	0	105.51
11	20	0	0	97.25
12	0	2.5	0	95.03
13	33	4	0	97.67
14	9.5	25.5	0	96.55
15	3	8	0	107.68
16	6.5	12	0	147.25
17	40.5	21.5	0	152.83
18	9.5	30.5	0	125.91
19	20.5	11	0	127.2
20	5.5	16.5	0	205.05
21	4.5	5	0	412.98
22	3	2.5	0	206.76
23	0	1	0	172.03
24	0	15	0	151.99
25	0	5.5	0	134.4
26	1.5	12.5	0	124.2
27	0	25	0	115.7
28	0	11	0	111.46
29	1.5	5.5	0	106.43
30	18	20.5	0	103.8
31	34	10	0	111.55

TABLE 6.3: July 2000

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	0	0	91.75
2	0	2	0	90.63
3	0	8	0	87.5
4	1	0	0	85.23
5	0	0	0	84.54
6	0	0	0	82.93
7	0	0	0	79.14
8	0	0	0	74.71
9	0	0	0	73.21
10	0	0	0	75.06
11	0	0	0	75.61
12	0	0	0	74.39
13	0	0	0	75.52
14	0	0	0	75.95
15	0	0	0	75.03
16	0	0	0	75.12
17	0	35	0	76.83
18	26.5	5	0	77.24
19	7.5	1	0	88.06
20	3	0.5	0	104.15
21	0	6	0	88.97
22	0.5	3.5	0	95.83
23	0	4.5	0	88.13
24	10	2.5	0	82.91
25	0	4	0	78.3
26	0	0	0	75.52
27	5	5	0	74.58
28	3	3	0	70.68
29	0	3.5	0	102.3
30	4	18.5	0	77
31	0	8	0	66.85

TABLE 6.4: May 2002

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	4	0	113.97
2	5.5	4	0	174.17
3	3	0.5	0	106.73
4	4	0	0	95.92
5	14	2	0	88.26
6	0	0	0	81.46
7	0	0	0	80.23
8	0	0.5	0	96.59
9	0	0	0	93.76
10	0	0	0	78.07
11	0	0	0	71.79
12	0	0	0	64.68
13	1	3.5	0	61.36
14	0	0	0	60.59
15	0	0	0	60.82
16	0	0	0	60.38
17	0	0	0	57.79
18	0	3	0	56.96
19	5.5	5.5	0	56.45
20	0	0	0	57.59
21	0	2.5	0	69.38
22	17	26	0	62.43
23	5	0.5	0	67.7
24	3	14.5	0	101.78
25	2	2	0	98.17
26	0	0	0	84.32
27	0	20	0	79.67
28	0	7	0	71.33
29	15	2	0	65.36
30	3.5	33.5	0	68.18
31	0	20.5	0	80.49

TABLE 6.5: June 2002

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	1	0.5	0	92.35
2	0	0	0	92.65
3	27.5	0	0	75.1
4	3	0	0	70.19
5	1.5	0	0	65.21
6	0	7.5	0	57.25
7	22.5	18.5	0	96.96
8	0	20	0	74.51
9	36.5	18.5	0	81.24
10	5	25.5	0	72.89
11	16.5	20	0	153.04
12	0	0	0	165.49
13	3	0	0	116.27
14	0	0	0	133.22
15	2	0	0	132.09
16	0	0	0	96.81
17	0	0	0	90.66
18	0	0	0	83.8
19	0	0	0	76.3
20	0	0	0	71.37
21	0	0	0	67.59
22	0	0	0	67.05
23	0	0	0	65.92
24	24.5	0	0	64.54
25	0	0	0	63.88
26	6	0	0	61.88
27	0	0	0	61.04
28	18	0	0	60.19
29	8.5	17	0	59.54
30	0	0.5	0	58.05

TABLE 6.6: November 2002

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	31	2	0	85.21
2	6.5	0	0	80.03
3	0	0	0	75.52
4	9.5	15.5	0	77.1
5	0	3.5	0	78.22
6	11	50.5	0	76.64
7	4.5	20.5	0	87.27
8	15	8.5	0	100.95
9	68	12.5	0	106.73
10	0	10	0	113.28
11	0	30	0	152.78
12	0	6.5	0	151.46
13	5	6.5	0	162.55
14	4	30	0	128.67
15	3	5	0	128.15
16	1.5	15	0	124.88
17	8.5	35	0	138.05
18	5.5	25.5	0	155.8
19	24	15	0	161.85
20	3	3	0	121.29
21	0	0	0	150.31
22	40	30	0	131.83
23	47.5	35	0	119.99
24	7	2	0	247.12
25	0	1	0	269.34
26	0	0.5	0	159.51
27	0	0	0	130.15
28	13	0	0	117.81
29	0	0	0	111.96
30	0	0	0	107.21

TABLE 6.7: March 2003

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	3	0	181.51
2	0	0	0	186.45
3	0	0	0	150.09
4	0	0.5	0	165.07
5	4	2	0	61.23
6	7.5	6	0	72.01
7	0.5	0	0	67.51
8	0	0	0	76.77
9	8.5	2	0	70.23
10	13	24	0	62.64
11	0	6	0	77.99
12	3	0	0	81.54
13	0	0	0	80.82
14	2	0	0	68.36
15	0	0	0	62.67
16	0	0	0	60.38
17	0	0	0	59.79
18	0	0	0	58.65
19	0	9	0	58.13
20	11.5	0	0	58.79
21	0	10	0	59.32
22	6.5	0.5	0	57.18
23	1.5	10	0	56.2
24	10	31	0	59.53
25	5.5	5	0	74.37
26	18.5	19	0	128.83
27	6.5	21	0	100.33
28	8	51	0	136.04
29	3.5	5	0	103.43
30	0	20	0	139.4
31	3	5	0	110.78

TABLE 6.8: April 2003

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	10	0	0	104
2	0	0	0	92.52
3	0	0	0	117.13
4	21	3	0	108.47
5	0	5	0	94.65
6	0	0	0	88.36
7	0	1	0	95.65
8	12	7	0	85.61
9	0	0	0	90.11
10	0	5	0	84.78
11	5	34	0	83.84
12	17.5	8.5	0	84.72
13	0	0	0	89.75
14	14.5	0	0	104.96
15	0	22	0	85.57
16	3.5	17	0	82.51
17	0	35	0	100.02
18	0	1	0	117.68
19	0	30	0	94.86
20	0	17	0	87.64
21	0	0	0	113.94
22	0	0	0	128.72
23	15.5	10	0	93.47
24	0	2	0	84.26
25	0	0	0	83.89
26	0	0	0	82.17
27	0	1	0	74.8
28	2.5	7	0	71.43
29	0	10	0	69.17
30	23	20	0	98.9

TABLE 6.9: June 2003

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	0	0	82.45
2	0	0	0	77.83
3	0	5	0	77.62
4	0	0	0	74.04
5	0	0	0	73.51
6	0	30	0	74.04
7	0	0	0	74.01
8	0	10	0	73.78
9	7	15	0	73.49
10	0	5.5	0	93.11
11	0	0.5	0	127.27
12	0	1.5	0	94.2
13	3.5	1	0	91.79
14	10	15.5	0	89.27
15	14.5	0.5	0	90.87
16	60	3	0	89.29
17	5	2	0	88.8
18	0	0	0	88.34
19	0	25	0	86.63
20	0	15	0	84.61
21	0	30.5	0	106.5
22	0	7	0	102.53
23	0	5	0	151.12
24	9	0	0	102.75
25	0	2	0	100.05
26	6	20	0	95.38
27	4	21	0	89.58
28	0	0	0	122.56
29	0	15	0	123.6
30	14	15	0	95.75

TABLE 6.10: August 2003

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	10	0	74.19
2	0	3	0	71.04
3	0	0	0	71.09
4	0	1	0	70.87
5	0	0	0	71.18
6	0	0	0	71.4
7	0	11	0	71.61
8	0	4	0	71.19
9	0	60	0	70.54
10	0	1	0	69.91
11	0	15	0	80.65
12	16	17	0	77.8
13	1.5	10	0	88.1
14	13.5	1	0	99.59
15	69	6	0	96.96
16	0	4	0	93.39
17	0	0	0	90.18
18	0	0	0	78.53
19	0	0	0	73.66
20	0	15	0	72.57
21	0	1	0	70.95
22	6.5	1	0	69.43
23	0	0	0	69.79
24	0	0	0	69.34
25	0	0	0	69.15
26	12.5	35	0	69.64
27	14.5	0	0	69.3
28	0	5	0	116.11
29	2	0	0	90.54
30	0	5	0	95.78

TABLE 6.11: January 2004

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	5.5	0	0	105.84
2	0	0	0	100.71
3	0	0	0	97.6
4	3	0	0	97.5
5	0	0	0	93.64
6	1	0	0	93.53
7	0	0	0	91.71
8	50	7.5	0	88.36
9	10.5	8	0	86.8
10	17	5	0	115.37
11	0	15	0	122.95
12	4.5	2	0	107.63
13	0	0	0	97.35
14	0	0	0	95.16
15	0	0.5	0	91.17
16	6	0.5	0	90.64
17	0	0	0	90.66
18	17	40	0	89.34
19	0	4	0	87.3
20	13.5	0	0	247.88
21	7	0	0	131.1
22	0	0	0	101.26
23	0	0	0	95.58
24	2	0	0	89.36
25	8	0	0	85.09
26	16.5	0	0	82.38
27	39	15	0	81.4
28	9	27	0	84.39
29	11	5	0	131.1
30	3	0	0	141.05
31	19	5	0	121.13

TABLE 6.12: February 2004

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	8.5	3	0	110
2	0	0	0	109.77
3	57.5	0	0	105.12
4	1.5	13	0	93.13
5	0	1	0	100.65
6	2.5	13	0	187.43
7	15	0	0	118.9
8	0	0	0	105.12
9	6.5	0	0	111.77
10	0	0	0	102.42
11	0	0	0	99.38
12	0	0	0	90.59
13	1.5	0	0	86.58
14	0	30	0	84.2
15	4	18	0	82.84
16	5	35	0	84.54
17	9	9	0	94.74
18	3	0	0	99.53
19	0	0	0	93.98
20	0	0	0	86.85
21	0	0	0	85.12
22	0	0	0	81.01
23	0	0	0	78.23
24	0	0	0	77.07
25	0	0	0	75.87
26	0	0	0	74.63
27	19	0	0	73.62
28	0	0	0	71.29
29	0.5	0.5	0	69.97

TABLE 6.13: March 2004

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	1	6	0	133.83
2	13	10	0	105.41
3	0	16	0	99.29
4	22.5	0	0	110.11
5	0	14	0	109.89
6	0	0	0	124.62
7	0	25	0	101.62
8	11	1	0	89.6
9	0	0	0	88.29
10	0	0	0	88.46
11	0	0	0	82.44
12	0	3	0	79.02
13	0	35	0	77.12
14	0	0	0	75.88
15	0	45	0	76.34
16	0	23	0	77.25
17	0	6	0	83.61
18	0	0	0	90.99
19	0	0	0	84.49
20	0	0	0	74.94
21	0	0	0	71.5
22	41	24	0	70.04
23	2.5	0	0	73.12
24	0	5	0	112.25
25	0	1	0	79.72
26	0.5	5	0	80.38
27	3	15	0	72.38
28	10	14	0	75.18
29	0	20	0	78.16
30	11	15.5	0	93.37

TABLE 6.14: April 2004

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	0	0	70.12
2	0	0	0	69.52
3	0	5	0	69.74
4	0	2	0	70.1
5	0	2	0	72.54
6	0	0	0	71.63
7	7	35	0	67.63
8	20	19	0	65.83
9	171.5	18	0	107.28
10	0	25.5	0	122.06
11	19	43	0	293.05
12	1	15	0	156.39
13	11.5	0.5	0	204.66
14	0	0	0	137.35
15	3	5.5	0	111.93
16	0	0	0	103.26
17	0	10	0	101.51
18	0	40	0	93.18
19	2	42	0	95.9
20	0	38	0	134.27
21	0	0	0	138.58
22	0	0	0	136.59
23	11.5	0	0	105.43
24	0	0	0	98.78
25	10.5	5	0	116.18
26	0	15	0	108.67
27	0	0	0	102.78
28	50	0	0	94.36
29	1.5	0	0	103.21
30	66	10	0	96.61
31	3	0	0	198.6

TABLE 6.15: September 2010

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	0.5	21	89.08
2	0	11	1	79.57
3	0	16	6	75.46
4	0	0	22.8	74.27
5	0	6	5.7	109.06
6	10.5	8	21.1	82.85
7	0	0	3.4	75.66
8	0	0	18.4	77.13
9	0	4	4.5	77.33
10	0	0	0.5	90.64
11	0	1	4.5	74.27
12	0	0	32.5	79.74
13	0	22	8	88.64
14	0	0	3.5	74.13
15	0	8	0	91.12
16	0	4	27.4	78.53
17	0	52	7.6	113.9
18	0	4	0	91.69
19	0	75	0	90.84
20	0	31	1	89.62
21	0	36	20.5	265.66
22	0	34	19.5	135.25
23	0	6	2.5	147.49
24	0	8	0	120.11
25	0	0	0	94.47
26	0	38	0.5	89.65
27	0	11	25.5	80.64
28	0	9	0.8	204.57
29	0	4	0.2	183.98
30	0	1	0	124.63

TABLE 6.16: October 2010

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	8	0	129.88
2	0	0	3	110.39
3	0	2	0	100.58
4	0	3	0	93.95
5	0	2	0	87.78
6	0	0	36	92.07
7	4.5	0	0	84.4
8	0	0	0	80.31
9	0	0	0	77.41
10	0	0	0	74.99
11	0	0	1.5	73.66
12	0	2	0.5	72.09
13	0	0	2	70.78
14	0	0	0	71.1
15	0	0	0	69.92
16	0	0	0	68.22
17	0	11	8.2	67.48
18	0	0	2.3	66.84
19	0	0	26	66.89
20	0	0	0.5	74.03
21	0	0	0	66.33
22	0	4	0	65.39
23	0	0	0	66.74
24	0	1	0.5	78.91
25	0	14	52	78.87
26	0	0	2.2	88.33
27	0	2	2.8	79.75
28	0	42	22	67.49
29	0	6	0	72.78
30	0	1	7.5	96.37
31	0	1	0.4	122.63

TABLE 6.17: April 2012

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	14	20.5	57.81
2	2.5	22	48.5	57.23
3	14	4	42.2	70.66
4	0	17	1.4	129.62
5	12.5	4	8.2	78.14
6	0	0	12.2	99.45
7	0.5	4	0	76.9
8	2.5	65	2	64.86
9	61	0	3.8	68.58
10	4.5	6	0.7	133.4
11	2.5	0	13.7	95.96
12	0	7	4.8	139.38
13	5	12	16.8	81.85
14	0	8	44.7	94.92
15	4.5	28	4	97.64
16	5.5	17	30	97.03
17	0	10	16.3	93.97
18	0.5	4	7.2	81.92
19	3.5	7	34.5	125.24
20	24	0	24	117.54
21	0	0	11	101.02
22	7.5	3	1	70.14
23	4	14	11	93.36
24	15	2	57.5	88.75
25	0	1	0	225.96
26	2	0	5.8	105.88
27	0	0	2.1	88.14
28	0	1	0	79.03
29	10.5	0	42	66.74
30	0	1	0	66.78

TABLE 6.18: December 2012

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	24	33	8	75.82
2	21	17	1	96.94
3	18.5	1	0.5	202.58
4	0	0	0	91.2
5	0	0	0	70.44
6	33	0	0.4	62.24
7	0	1	9.1	75.4
8	0	0	0	63.1
9	32.5	2.5	0.5	62.01
10	0	31	1.5	122.05
11	0.5	22.5	3	85.89
12	15.5	12.5	0.5	67.89
13	4	0	1	150.81
14	2	7.5	1.8	78.47
15	0.5	6	21.7	70.41
16	3.5	2	1.5	62.53
17	1	2	13.3	62.22
18	19	4	3.5	65.67
19	5.5	3.5	6.9	59.38
20	0	8	4.8	68.26
21	0	4.5	13.5	76.95
22	1.5	9.5	10.5	59.38
23	0.5	8.5	0	56.68
24	8	5	23.2	51.09
25	3.5	4	13.8	46.02
26	8	3	4	45.77
27	0.5	8	1.9	45.08
28	0	5.5	1.1	44.88
29	0	0	0.5	41.11
30	66	19.5	3.9	39.66
31	10.5	10	64.9	275

TABLE 6.19: January 2014

DAY	RF 4218042	RF 4514032	RF 4620046	SF 4218416
1	0	2.5	0	23.92
2	0	0	0	36.98
3	0	0	2.5	51
4	0	0	0.5	51.23
5	11	2	5.5	49.63
6	10	1.5	4.5	52.26
7	0	0	0	52.62
8	0	0.5	3	47.47
9	30	20.5	20	46.14
10	115	66.5	50.5	140.51
11	3	1.5	1	345.33
12	4.5	3	0.5	106.42
13	0	2.5	0	75.36
14	1.5	0	0	64.87
15	0	0.5	0	59.92
16	0	0.5	0	57.16
17	0	1.5	0	55.67
18	0	0.5	0	54.37
19	0	0	0	53.6
20	0	0	0	51.02
21	0	0	0	49.94
22	0	0	0	48.63
23	0	0	0	47.51
24	0	0	0	46.65
25	0	0	0	45.71
26	0	0	0	45.03
27	0	3	0	44.04
28	0	0.5	0	43.35
29	0	0	0	43.28
30	0	0	0	42.77
31	0	0	0	42.3