DETERMINATION OF STREAMFLOW DISCHARGE HYDROGRAPH IN THE ROMPIN RIVER BASIN

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ABSTRAK

Malaysia terjejas oleh dua masalah utama yang berkaitan dengan air iaitu banjir dan kemarau. Terdapat dua jenis banjir yang berlaku di negara ini iaitu banjir monsoon dan banjir kilat. Banjir monsun biasanya berlaku pada akhir tahun semasa monsun timur laut. Sebaliknya, kemarau berlaku semasa musim kering dari Mei hingga September. Oleh kerana air terlalu banyak atau terlalu kurang selalu menjadi masalah di Malaysia, ia penting untuk memahami proses hidrologi yang terlibat dalam lembangan sungai. Kajian ini bertujuan untuk menganggarkan pelepasan aliran sungai yang terdapat di sistem sungai semasa tempoh aliran tinggi dan rendah untuk Sungai Rompin. Model hidrologi yang digunakan untuk kajian ini adalah HEC-HMS. Model ini dipilih kerana ia mudah untuk digunakan dan tidak memerlukan pelesenan. Data 6 stesen hujan dan 2 stesen aliran sungai di Sungai Rompin Basin dari tahun 1990 hingga 2013 akan digunakan sebagai data input, proses penentukuran dan pengesahan. Untuk kaedah transformasi larian permukaan, kaedah SCS dipilih untuk mengubah taburan hujan ke hidrograf pelepasan. Dalam kajian ini, hipotesis bahawa model HEC-HMS dapat mensimulasikan aliran sungai di Sungai Rompin dengan kecekapan yang mencukupi untuk tempoh kering dan basah. Temuan ini penting sebagai alat sokongan keputusan yang boleh digunakan dalam operasi dan pengurusan kawasan Rompin, untuk bekalan air dan kawalan banjir.

ABSTRACT

Generally, the Rompin River Basin is affected by two major water-related problems, floods and droughts. There are two types of floods occur in this country which are the monsoon flood and flash flood. Monsoon floods normally took place at the end of the year during the north-east monsoon. Oppositely, drought occurs during the dry period from May to September causing insufficient water supply especially for irrigation purpose. Thus, it is important to understand the hydrological process involved in the river basins. This study aims to estimate the streamfow for the Rompin River Basin using HEC-HMS hydrological model, and calibrate and validate the transformed rainfall-runoff model. HEC-HMS model is chosen because it is simple to apply and require no licensing. Data of 6 rainfall and 2 streamflow stations in the Rompin River Basin from the year 1990 to 2013 were used in the input, calibration and validation processes. For the surface runoff transformation method, SCS method was selected. In this study, results indicate that the HEC-HMS model is able to simulate the streamflow in the Rompin River Basin with sufficient efficiency for both the dry and wet periods. This finding is important as a decision support tool that can be used in the operation and management of Rompin area, for both water supply and flood control.

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LIST OF SYMBOLS

t_c	Time of concentration, min
L	Travel length, m
S	Slope
t_L	Lag time, min
Obs	Observed discharge, m/s^3
Sim	Simulated discharge, m/s^3
Omean	Mean observed discharge, m/s^3

LIST OF ABBREVIATIONS

RRB	Rompin River Basin
DID	Department of Irrigation and Drainage
JUPEM	Department of Survey and Mapping Malaysia
HEC-HMS	Hydrologic Modeling System
CN	Curve Number
RMSE	Root Mean Square Error
NSE	Nash-Sutcliffe Efficiency

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is rich in water resources, receiving an abundant amount of rain every year. Malaysia's climate is categorised as equatorial and is hot and humid throughout the year. The average rainfall is 2500mm a year with average temperature of 27 °C (De Silva, Samat, Zakaria, and Agbayani, 1992). Malaysia has only two seasons – wet and dry. The wet season lasts from October to March, with November being the wettest month with a total rainfall of around 305mm. The dry season occurs from May to September, with the driest month being June – with a rainfall of around 102mm.

During the wet, Malaysia is prone to flood problem. Flood in this country can be categorised into two, monsoon flood and flash flood (Diya, Gasim, Toriman, & Abdullahi, 2014). Monsoon flood generally occurs between November to February on the monsoon season and hit badly on the east coast of Peninsular Malaysia. Flash flood is a sudden local flood that typically due to heavy rain in short duration and often occurs at the urban areas. Flood is one of the natural disasters that bring impact to the Malaysian community and economy system.

Rompin River Basin (RRB) which is located at the southeastern corner of the Pahang state in Malaysia is one of the region that is affected by the monsoon flood. It receives heavy rainfall during the north east monsoon which leads to severe flooding in the areas almost every year. The December 2013 flood event was the worst ever recorded in decades with 3615 victims (Zaidi, Akbari and Ishak, 2014). This has caused millions of ringgits property damage with thousands of people affected and loss of life.

Agriculture is one of the important sector of Malaysia's economy, accounting for 12% of the national GDP and providing employment opportunities for 16% of the population (British, Asia, Malaysian, and Council, 2015). Food and agriculture are the biggest consumers of water and require one hundred times more than the domestic demand (Lenntech, 2011). As the population continues to increase, more food and livestock feed will be needed to be produced in the future and more water will be used for this purpose. The amount of water involved in agriculture is significant and most of it is provided directly by rainfall. In Malaysia, Rompin is one of the state in which the economy mostly depending on agriculture activities. Agriculture lands in the Rompin River Basin cover near to 50% of the landuse including several paddy schemes which require large amount of water usage. Therefore, there is a need to study the streamflow discharge in Rompin area for effective water management to cater for future development especially in the dry season.

There are numbers of software developed to analyse the rainfall-runoff processes. One of the commonly used is the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS). This modelling program is able to simulate the rainfall-runoff processes of dendritic watershed system (Razi, Ariffin, Tahir, and Arish, 2010). Furthermore, the software is an open source application that can be downloaded from the U.S. Army Corporation website without charges. Therefore, it is a very popular modelling tool worldwide including in Malaysia (Halwatura and Najim, 2013). Another advantages of this software are its ability to stimulate short-term events, easy to use and it applies the common hydrologic basic.

In HEC-HMS model, several methods can be applied to simulate the surface runoff of the model and different methods may produce different results. For example, the rainfall runoff losses in the HEC-HMS model can be estimated by using Conservation Service (SCS), Green and Ampt, Initial Constant, Deficit Constant, Constant Fraction, exponential and Soil Moisture Accounting (SMA) (Razmkhah, 2016). The outcome generated by using the HEC-HMS model is the hydrograph for the basin and river system. From the hydrograph, the flood and dry peak can be identified (Feldman, 2000). This finding is important as a decision support tool that can be used in the operation and management of the RRB, for both water supply and flood control.

1.2 Problem Statement

Flood is one of the regular natural disasters and has become a common phenomenon in Malaysia especially on the east coast including RRB (Basarudin, Adnan, Wardah, and Syafiqah, 2014). Basically, river flooding occurs because of the heavy rainfall which resultant in large concentration of runoff that exceeded the capacity of the river. The peak discharge and volume of runoff increase with increasing rainfall intensity for a given infiltration rate. Apart from flood problem, RRB also receive low rainfall during the dry period. This sometimes affect the agriculture needs especially for the paddy plantations. Hence, it is crucial to develop a rainfall-runoff model for RRB using HEC-HMS to analyse the hydrological processes and determine the rainfall-runoff processes in the basin.

1.3 Objectives

The purpose of this study is to stimulate streamflow estimation for water management applying HEC-HMS model with SCS unit hydrograph method in the Rompin River Basin. The objectives of the study are:

1. To determine streamflow discharge
2. To calibrate and validate transformation model

1.4 Scope of Study

Rompin River Basin is selected as the study area in this research mainly for the flood control, agriculture and domestic water supply. Streamflow hydrographs were simulated for several events on the wet and dry periods using HEC-HMS model with SCS unit hydrograph transformation method. For the calibration process, the basin characteristics parameters were calibrated using the streamflow data collected from the streamflow station for year 1990 to 2013. The simulated results were then validated using another set of data to ensure the reliability of the calibrated parameters.

1.5 Significant of Study

Streamflow is always changing, every day or even every minute. Of course, the main impact on streamflow is precipitation runoff in the basin. Since the hydrological information for watershed in Rompin is still lacking, it is important to understand the hydrological process involved in the Rompin River Basin. In this study, it shows that the HEC-HMS model is able to simulate the streamflow in the Rompin River Basin. The streamflow discharge was estimated by using HEC-HMS adopting SCS method by which eventually produced streamflow hydrographs. This finding is important as a decision support tool that can be used in the operation and management of the Rompin area, for both water supply and development of flood forecasting and warning systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Water is an essential element in maintaining life and for the survival of all organisms (Martino, 2003). There would be no life if there is no water. Water comes from the environment and flows through the natural water cycle. For water supply, the source mainly comes from rivers and streams. Although water seems to be important for human and living organisms, it can also be a disaster when there is too much of it and not properly managed.

Hydrology is the study of water. Hydrology deals with part of the water cycle, from precipitation of surface water to precipitation to the ultimate loss from the ground, or to the atmosphere through evaporation or transpiration, or through the surface and underground to the ocean. It is thus primarily concerned with waters close to the land surface (Beven, 2018).

2.2 Hydrological Cycle

The hydrologic cycle is a continuous process without any beginning or end – a loop (Patra, 2003). Water is evaporated from water surfaces and the oceans, moves inland as moist air masses and produces precipitation. The precipitation that falls from clouds onto the land Earth’s surface spreads through several paths into the hydrological cycle. A portion of the precipitation or rainfall is remained in the soil near where it falls and is returned to the atmosphere by evaporation. Evaporation is where the water is converted from water to water vapour and transpiration is the water vapour is lost through plant tissue and leaves. The combined loss called evapotranspiration, is a maximum value if the water supply in the soil is always sufficient.

Apart from being evaporated, some water enters the soil system as infiltration which is a function of soil moisture conditions and soil type (Gray and Norum, 2009). The water that seeps into the ground maybe stored as groundwater recharge or later re-enter the channels as a stream. Ground water flows into the subsurface porous media of shallow (eventually enters the stream) or deeper aquifer system (groundwater storage). In arid or semi-arid regions where surface water is very low or unavailable, groundwater pumping is a common practice to supply water for agricultural and urban water systems.

After deducting the losses, the remaining portion of precipitation becomes overland flow or direct runoff, which typically flows in a downward gradient to accumulate in local streams that subsequently flows to rivers. Surface water and groundwater flows from higher elevations towards lower elevations and may eventually be discharged into the ocean, especially after heavy rainfall events. However, a large amount of surface water and part of ground water are returned to the atmosphere by evaporation, thus completing the natural hydrologic cycle.

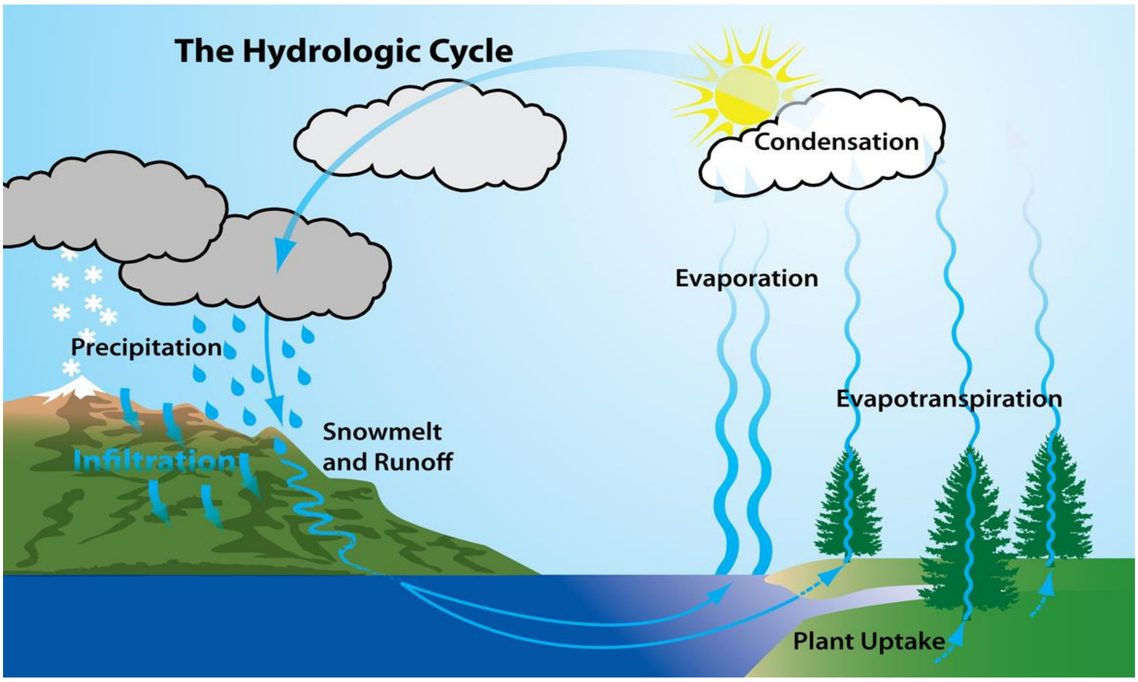


Figure 2.1 The hydrologic cycle

Source: Delaware River Basin Commission (2012).

2.3 Hydrological Characteristics

2.3.1 Rainfall

Malaysia is geographically divided into the Peninsula of Malaysia and the western part of Borneo (Chen, Tsay, Yen and Matsumoto, 2013). The highest rainfall occurred in between October to March, while the lowest rainfall occurred in between April to September. For the tropical climatic region of Malaysia, the country receives an average rainfall of about 2500mm annually. The highest rainfall recorded in a year was 5687mm at Sandakan, Sabah while the lowest rainfall recorded in a year was 1151mm at Tawau, Sabah (Mursid Rahman, 2015).

Rainfall is one form of the precipitation. Another formations of precipitation are hail, dew, frost, snow and fog. If rainfall arrives at the ground surface as droplets, it is classified as liquid precipitation. The size of raindrop varies from 0.5mm to 6mm as drops larger than this size are found to breakup when fall in the air (Xu, Cui, and Ren, 2012). With the intensity less than 2.5 mm/h, rainfall is classified as light rain. Meanwhile, rainfall is classified as heavy rain when its intensity more than 7.5 mm/h.

The increase in the frequency and intensity of extreme rainfall events raises concerns that human activities may cause changes in the climate system. It is believed that the increase in the frequency and intensity of extreme rainfall events are the main impact of global warming (Chou, Chen, Tan and Chen, 2012). Heavy rainfall or long-term continuous rainfall on short-term scales often leads to large-scale flooding, leading to dangerous situations. Peninsular Malaysia suffered unpredictable rainfall events, causing serious damage and losses of millions economically (Weng Chan, 1997). In the past decade, the increase in large-scale floods including mountain torrents and landslides were due to the increase in rainfall intensity (Syafrina, Zalina and Juneng, 2015).

In response to the uncertainty in climate change, simulation of rainfall-runoff relationship is increasingly important, not only for hydrological purposes, but also for inputting crop growth models, urban drainage system design, land management systems and other environments project. Thus, hydrological modelling shall cover both high and low flow simulation. In the study by Wong, Venneker, Uhlenbrook, Jamil and Zhou (2009), the lowest mean monthly rainfall identified in the study is 115 mm which occurred in February, contributes about 5% to the mean annual rainfall. According to Pei, Madihah and Sidik (2011), the subsequent changes in rainfall will affect the agriculture activity and preparations are needed in order to sustain the agricultural products for sustainable development in the economy.

2.3.1.1 Type of Rainfall

Generally, there are three main types of rainfall which are:

1. Relief rainfall

Relief rainfall occurs frequently near the seaside mountains. When the wind blows in from the sea and meets a high mountain, it is forced to rise upward. As it rises up, it is cooled and forms a cloud. Cloud water is saturated with water vapour and begins to settle on the mountain facing the sea. This side of the mountain is called the windward side. Clouds settled most on the windward side of the mountain. When the cloud meets the other side, which is called the leeward side, the cloud has lost most of its moisture, so there is very little rain there. This makes the leeward surface of a mountain very free from rain and hardly get any rain. There is a more humid climate on the windward side while there is a drier climate on the downwind side (Selase, Eunice, Agyimpomaa, Selasi, Melody and Hakii, 2015).

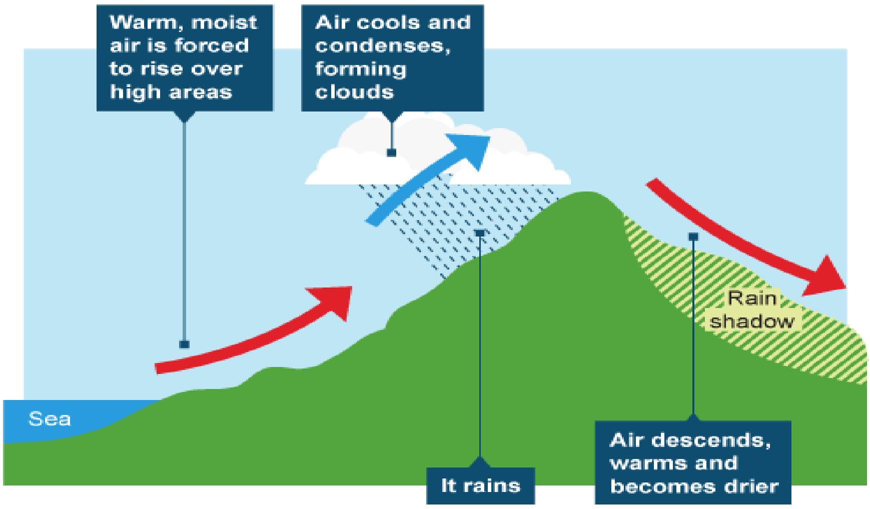


Figure 2.2 Relief rainfall
Source: BBC (2014).

2. Convectional rainfall

Convective rainfall frequently occurs on hot days and usually form cumulus clouds and thunderstorms. The sun heats the earth's ground and cause the air to warm up. It becomes very hot and the air rises upward. The air then cools and condenses to form cumulus clouds. When the saturated cumulus cloud is formed, it begins to precipitate and producing intense thunderstorms. The sun warms the air and it rises, cools and begins to rain (Selase et al., 2015).

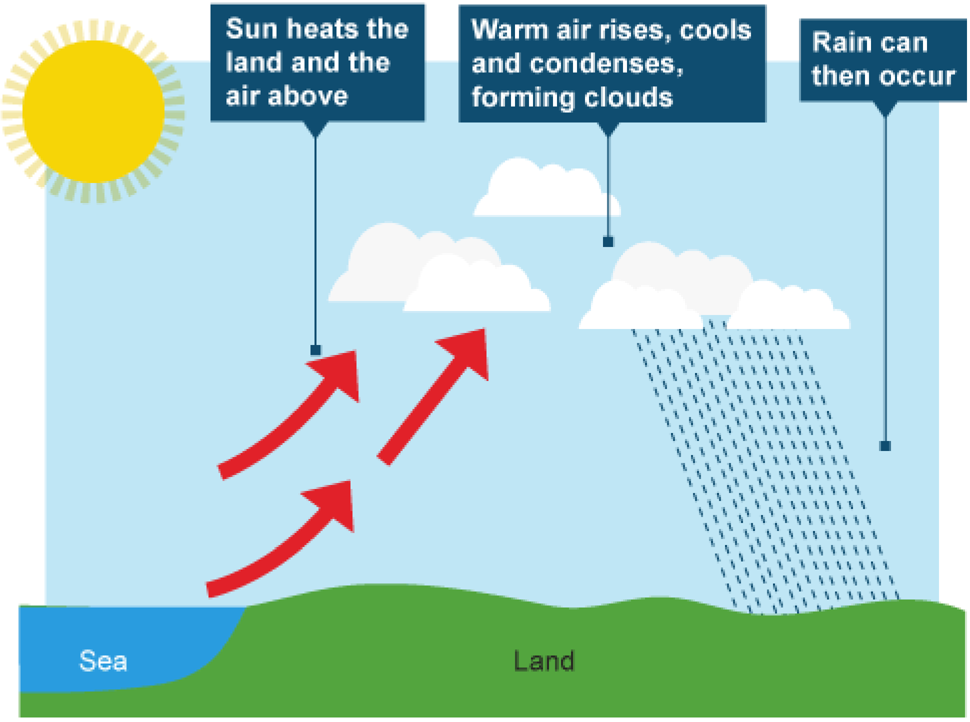


Figure 2.3 Convectional rainfall
Source: BBC (2014).

3. Frontal rainfall

This happened when a warm tropical air mass was in contact with a cold polar air mass, and it was very common in the United Kingdom and Ireland. A warm tropical air mass contact with a cold polar air mass. Because the air in the warm front is good and warm, it rises on the cold front. The air is cooled and condenses to form a cloud. It begins to precipitate when the stratus cloud is saturated (Selase et al., 2015).

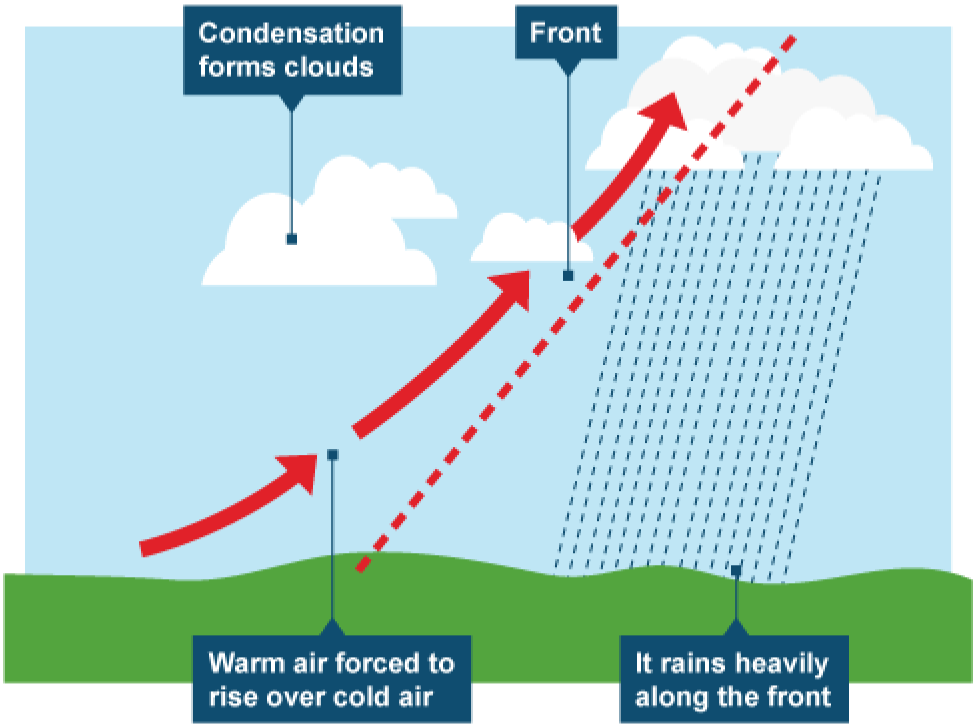


Figure 2.4 Frontal rainfall

Source: BBC (2014).

In overall, Rompin experienced convectional rainfall which the surface is heated by the sun and the warmer air rises. Further rising and cooling causes a large amount of condensation to occur and rain is formed (Badron, Ismail, Asnawi, Nordin and Khan, 2015).

2.3.2 Runoff

According to USGS (2016), Runoff is a flow from a basin into a stream. The flow consists of precipitation directly falling on the river, surface runoff flowing through land surfaces and channels, subsurface runoff and groundwater runoff. Some groundwater flows quickly into the water stream, while the rest may take longer time to enter the stream. As each component flows into the stream, they form a total runoff. The total amount of runoff in a channel is called streamflow, which is usually considered as direct runoff or baseflow.

2.3.2.1 Factor Affecting Runoff

There are many factors affecting runoff such as the duration of rainfall, intensity of rainfall, distribution of rainfall, direction of storm movement, soil moisture and other climate conditions. The intensity of rainfall has a great influence on runoff (Sharpley, 1985). Rainfall with higher intensity will generate more runoff than low intensity rainfall. If rainfalls continue over an extended period, the water table may rise and sometimes even overflow on the ground surface in low lying areas, reducing the infiltration capacity to zero of that area and causes serious flood hazard. The runoff from a drainage basin depends on distribution of rainfall. For a given total rainfall with all other conditions being the same, the greater the distribution coefficient, the greater the peak runoff. However, for the same distribution coefficient, the higher the peak runoff would result in storm falling on the lower part of the basin. The factors affecting runoff in terms of meteorological includes the types of precipitation such as rain, snow and sleet. Apart from that, rainfall intensity, rainfall amount, and rainfall duration play the key roles in affecting runoff (Dunne, Zhang and Aubry, 2011).

2.4 Watershed

According to USGS Water Science School (2016), a watershed is an area of land that drains all the steams and rainfall into a river network converging to an outlet. It divided the river basin or catchment area. A river basin consists smaller sub-basins which are combined into a larger water basin. When rain falls, the water will flow through a river basin before entering the river, lakes, oceans or sea.

2.4.1 Physical Characteristics of Basin

The physical characteristics of basin include land use, slope and elevation. These physical characteristics influenced the basin’s biological habitats and the ways people use the basin’s land and water resources.

1. Land use

Land use can be defined as activities that take place on ground or above ground. Land use or land management has a significant impact on the surface runoff stimulation. In a virgin forest area that accumulate a thick mulch of leaves and grass, the total amount of water even from the heaviest rainfall is absorbed by the trees. This resultant no surface runoff to reach the stream (Mamat, 2015). However, if the forest is removed and the land is cultivated after removing the mulch, the ground will become compacted. Therefore, even mild rainfall can also lead to significant surface runoff.

2. Slope

Previous research studies have shown that runoff from steep slopes is greater than that from milder slope (Sajjan, Yeboah and Sharma, 2013). The pattern of basin drainage depends on the slope as the surface of every soil is different at each location. It is difficult for rainfall or snowmelt to infiltrate steep slopes, while the shallow and permeable surfaces are directly inflow of rainwater. It is observed that the runoff decreases as the slope length increases. If it is a steep basin, the flow rate will be greater, and the runoff will take less time to reach the river, resulting in higher runoff. Therefore, larger slopes in the basin produce more velocity than smaller ones.

3. Elevation

The elevation of the basin is one of the physical characteristics that influences the time distribution and concentration of the basin discharge. The elevation of the basin represents the topography of the land. There are some software in hydrological modelling that can analyse the drainage network (Magesh, Jitheshlal, Chandrasekar and Jini, 2013).

2.5 Rainfall-runoff Relationship

Hydrologists are concerned with the amount of surface runoff generated in a watershed for a given pattern, and attempts have been made to analyse historical rainfall, infiltration, evaporation, and streamflow data to develop predictive relationships (Ian Watson, 1995). When rainfall exceeds the infiltration rate at the surface, excess water begins to accumulate as surface storage in small depressions governed by surface topography. As depression storage begins to fill, overland flow or sheet flow may begin to occur in portions of a watershed, and the flow quickly concentrated into small rivulets or channels., which can then flow into larger streams. Contributions to a stream can also come from the shallow subsurface via interflow or baseflow (from bank storage) and contribute to the overall discharge hydrograph from a rainfall event (Ramana, 2014).

2.5.1 Hydrograph

A hydrograph is a graphical representation of river flow pattern over time for a certain location. It is the results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, and baseflow. The shape of a hydrograph depends on precipitation pattern characteristics and basin properties (Kharagpur, 2018).

The concept of a unit hydrograph was first introduced by Sherman in 1932. A unit hydrograph is the hydrograph of direct runoff for any storm that produces exactly 1.0 inch of net rain (Kharagpur, 2018). To develop a unit hydrograph, it is desirable to acquire as many rainfall data as possible within the study area to ensure that the amount and distribution of rainfall over the watershed are accurately known.

The purposes for which a unit hydrograph can be used are:

1. Computation of flood hydrograph for design of a structure

When the probable maximum precipitation (PMP) or the standard project storm (SPS) for a basin is known, the unit hydrograph is convoluted over the excess rainfall of the histogram blocks of PMP or SPS to obtain the design flood at the project site

2. Extension of flow records at a site

All storm precipitation depths, for example rainfall excess for the entire period under consideration are multiplied successively by unit hydrograph ordinates and added up to compute the runoff volumes.

3. Flood forecasting models

Unit hydrographs developed for a basin are stored in a computer. Knowing the excess rainfall depths from telemeter-gauges, flood can be forecasted for the basin by convoluting the unit hydrograph over the excess storm rainfall and carrying out the channel routing if necessary.

4. Comparing the catchment characteristics

Two unit hydrographs of the same unit durations derived from two adjoining basins can be used to compare the hydro-meteorological characteristics of the basins (Shreyasi, 2016) (Crick, 2018).

2.5.2 Limitations of Unit Hydrograph

The limitations of a unit hydrograph are:

1. The maximum catchment area is up to $5000km^2$. For catchment exceeding this area, the basin assumption of uniform rainfall distribution over the basin due to the storm may be violated.
2. The application of unit hydrograph is not suitable for very long basins.
3. The lower limit on the size of a basin to which the unit hydrograph concept apply should preferably be more than $2km^2$.
4. The duration of rainfall excess should preferably be 1/3 to 1/5 of basin lag.
5. Unit hydrograph should not be derived from a catchment where large storage exists.
6. If there is high variation in the rainfall intensity over the basin, then for such storms unit hydrograph should not be derived.
7. When a large portion of a basin is covered with snow, the unit hydrograph principle should not be applied (Shreyasi, 2016) (Crick, 2018).

2.6 HEC-HMS Model

HEC-HMS is a public domain software, and the most recent version 4.2.1 can be downloaded online without charges (Nordstrom, Thompson and Hartmeister, 2009). This modelling software can be applied to solve most of the hydrological problem encountered in a river valley system. It can be used for flood analysis, streamflow synthesis, reservoir operation, flood mapping and solving variety of other hydrological problems. The hydrologic element options available in HEC-HMS are shown in Table 2.1 The distributed modelling approach in HEC-HMS required four major components: basin model, meteorologic model, control specification and gridded data.

Table 2.1 Hydrologic element options available in HEC-HMS

Hydrologic element	Options in HEC-HMS
Losses	Initial/constant
	Deficit/constant
	Green-Ampt
	SCS curve number
Transformation of rainfall to runoff	Modified Clark
	Kinematic wave gridded
	Snyder unit hydrograph
	Clark unit hydrograph
	SCS dimensionless unit hydrograph
	Input unit hydrograph
Baseflow	Exponential recession
	Constant monthly
Routing	Lag
	Muskingum
	Modified Puls
	Muskingum-Cunge
Precipitation	Average grid-based
	Import hyetograph
	Gauge data with weights
	Inverse distance gauge weighting
	Frequency-based blocked IDF design storm
	Standard project storm

2.6.1 Basin Model

The basin model is the representation of the physical watershed (Feldman, 2000). Hydrological elements such as sub-basins, junctions and river reaches are added and linked to create a basin model. Sub-basin tool is used to represent the sub-catchment in the main basin while the reaches are used to convey streamflow downstream in the basin model. Inflows may come from one or more upstream hydrological elements and they are connected to the downstream elements by junctions. The inflow into the junction can come from one or more upstream elements.

2.6.2 Precipitation Model

The temporal distribution of either historical or design storm is input as either total rain depth and distribution histogram or directly as the desired distribution of the precipitation amounts in each time step. Spatial distribution of the precipitation can be cell-by-cell, subbasin-by-subbasin, by rain gauge location and weighting (such as Thiessen polygon), or by an automated inverse distance-squared weighting method spread among points of known values. The precipitation model also known as meteorological model in HEC-HMS which calculate the precipitation input required by each sub-basin element.

2.6.3 Control Specifications

This component set the time span of a simulation run. The control information such as time and date of the rainfall, actual hydrographs for comparisons with simulated graphs, time interval for computation, and input or output specifications are required in this component. If measured hydrographs are available, the parameter optimisation routine can be selected to generate best-fit estimates of the sub-basin and routing-reach parameters.

2.6.4 Runoff Curve Number

Each sub-catchment uses a Curve Number (CN) to characterise the runoff properties for a particular soil and ground cover. The runoff curve number is widely sued and efficient method for predicting direct runoff from rainfall excess. As shown in Appendix A, there are some important matters in the selection of CN should be taken, most notably are hydrologic soil group, landuse, treatment and hydrologic condition. Selection of lower CN shoes that runoff potential is low while high CN indicate a high runoff potential.

2.6.5 SCS Transform Method

Soil Conservation Service (SCS), now Natural Resources Conservation Service (NRCS) developed a Dimensionless Unit Hydrograph (DUH) based on the analysis of large number of watersheds. The parameter that needed in SCS transform method is lag time. According to Kirpich formula and National Resources Conservation Service formula,

$$t_c = 0.0078 \frac{L^{0.77}}{S^{0.385}} \tag{2.1}$$

$$t_L = \frac{t_c}{1.67} \tag{2.2}$$

Where, t_c = Time of concentration

L = Travel length

S = Slope

t_L = Lag time

2.6.6 Advantages of HEC-HMS

According to Scharffenberg, Ely, Daly, Fleming, and Pak (2010), the HEC-HMS software is very adaptable, and the advantages are:

- HEC-HMS is public domain software tools. The documentation and the latest version of the software can be downloaded.
- Allow the user to choose from a number of methodologies to model rainfall-runoff processes.
- Can be used in a variety of geographic areas with distinct physical conditions.
- Developed to stimulate the rainfall-runoff processes of dendritic watershed systems.
- To solve widest possible range of problems including large river basin water supply, flood hydrographs and small urban or natural watershed runoff (Dhami and Pandey, 2013).
- Less data needed in the model which can be applied in conditions where limited numbers of data of a selected basin are available.
- It has also been used in ungauged catchment after calibration and validation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides a detailed methodology to determine the streamflow discharge in the Rompin River Basin. The method used for simulating the river discharge is the Hydrologic Engineering Centre-Hydraulic Modelling System (HEC-HMS). In this study, the hydrology parameters such as rainfall and stream-flow data are important in the setting up of the rainfall-runoff model. This study aims to calibrate and validate the hydrological transformation model. The selections of the rainfall and discharge data for calibration and validation processes were based on the availability and the quality of the data-sets captured by the rainfall and discharge gauging devices.

3.2 Flow Chart

Processes involved in the methodology adopted in this study is presented in Figure 3.1. The procedures began with the selection of study area, followed by site survey, data collection, data analysis, hydrological modelling, calibration and validation.

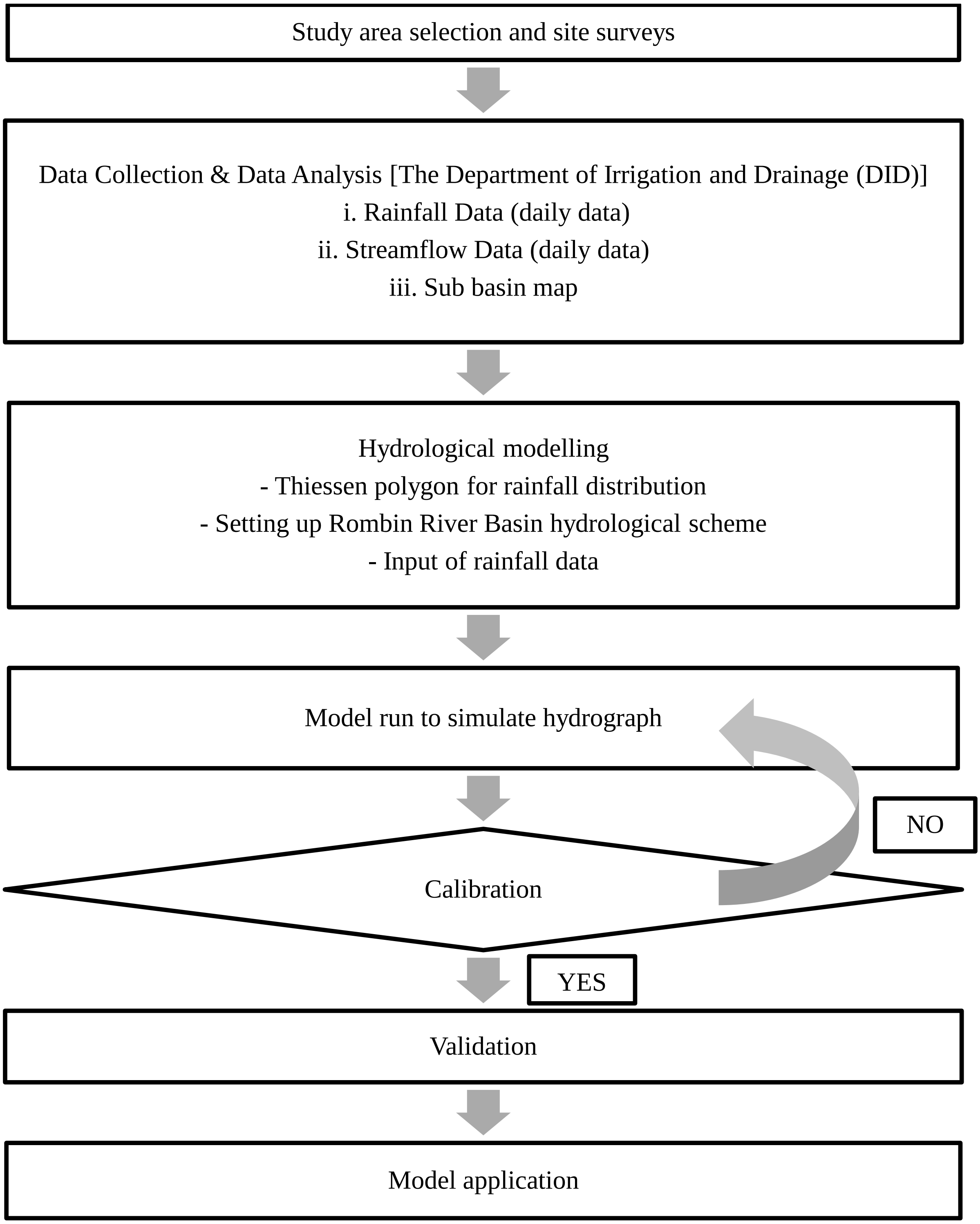


Figure 3.1 Flow chart of methodology

3.3 Study Area

The study area selected in this study is the Rompin River Basin. Rompin River as shown in Figure 3.2 is a river in state of Pahang, Malaysia situated on the east coast of the peninsula. The river flows through the southeastern part of the Pahang state before emptying into South China Sea. Rompin Rivers Basin is located between the coordinate of 102°40'20" to 103°30'05"E and 2°30'05" to 3°20'20"N. this basin covers a total area of about 4208 km^2 and the Rompin River is 83 km in length. Rompin River Basin receives heavy rainfall during the North East Monsoon that occurs between October and March Rompin is one of the district in which the economy is partly depending on agriculture activities.

3.4 Site Survey

Before any analysis works were done for the Rompin River Basin, a site survey was conducted on 24 November 2017 to capture the surrounding condition of the basin. From the survey activity, it is found that there are not much developments existed in the basin except from the town near the estuary namely Kuala Rompin. Furthermore, almost half of the landuses in the Rompin River Basin are agriculture and the other half are reserved forest. For agriculture activities, palm oil plantation as displayed in Figure 3.3 is dominated. There are also several small scale paddy schemes at the downstream part of the basin. It is important to identify the different types of landuse in the basin because this influence the lose parameter, curve number in the hydrological modelling.

Figure 3.2 Rompin River

Figure 3.3 Palm oil plantation in Rompin

3.5 Data

3.5.1 Data Collection

Data required for the hydrological modelling in this study are the rainfall and streamflow data. The data collected are important as the input and observation in the simulating, calibrating and validating processes of the study using HEC-HMS model. The rainfall and streamflow data were obtained from The Department of Irrigation and Drainage (DID) for the daily data. All the data were collected from the DID for 6 rainfall and 2 streamflow stations. Table 3.1 and Table 3.2 show the name and the station number of the gauging stations considered and used in HEC-HMS modelling.

Table 3.1 Rainfall station used in HEC-HMS

Station No	**Station Name**
2828173	Kg. Gambir
2829001	Ulu Sg. Chanis
2831179	Kg. Kedaik
2834001	Stn. Pertanian Rompin-Endau
3028001	Sg. Kepasing
3030178	Pecah Batu Bkt. Raidan

Table 3.2 Streamflow station used in HEC-HMS

Station No	Station Name
2928401	Sg. Keratong di Jam. Bahau Keratong
3030401	Sg. Rompin di Jam. Kuantan/Segamat

Other than hydrological data, topographic maps covering the entire basin are also needed in this study. Topographic map is a map showing the real form of land and elevation represented by contour lines. These maps were obtained from The Department of Survey and Mapping Malaysia (JUPEM). From the topographic maps, the sub-catchments can be determined, as well as the length of river, slope, elevation and landuses information. In this study, the maps were used to calculate the river slope and length to estimate the lag time of the reach.

Figure 3.4 The combined topographic maps covering Rompin River Basin

3.5.2 Data Processing

The hydrological data obtained from DID is not always complete. In some historical years of data, there are plenty of missing data. Thus, selection of data for certain event desired have to be done beforehand. The first steps in the data selection processes is to determine the acceptable percentage of missing data by analysing all the available data. From the analysis, it is found that most of the datasets collected have 80% of data availability. Hence, the allowable missing percentage for selected datasets is restricted to a maximum of 20%. Table 3.3 shows the analysis outcome.

Table 3.3 Missing data analysis

Missing Percentage (%)	**Number**
0 – 5	2502
6 – 10	326
11 – 15	24
16 – 20	48
21 – 25	25
26 – 30	23
31 – 35	15
36 – 40	37
41 – 45	14
46 – 50	15
51 – 55	26
56 – 60	30
61 – 65	27
66 – 70	18
71 – 75	17
76 – 80	23
81 – 85	20
86 – 90	15
91 – 95	31
96 - 100	398

In this study, the rainfall-runoff analyses are to be conducted for 2 different events: high flow (wet or monsoon season), low flow (dry season). Average monthly rainfall for each available year was plotted in Figure 3.5 to determine the high and low flow events. Based on the results obtained, the months selected for the high and low flow in this study are as stated in Table 3.4. The rainfall and streamflow data that were used in the model are tabulated in Appendix B and Appendix C.

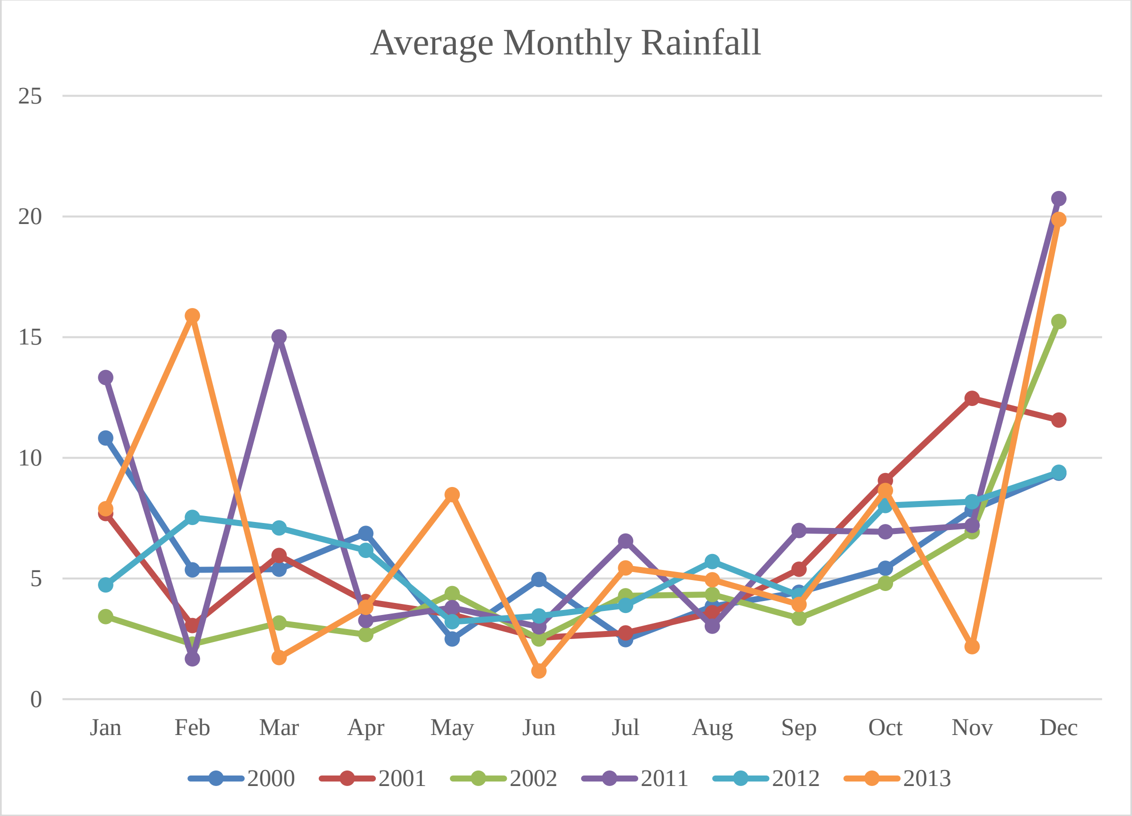


Figure 3.5 Average monthly rainfall

Table 3.4 Months selected for the stimulation

Event	Calibration	Validation
High flow	December 2000	December 2012
Low flow	June 2012	May 2013

3.6 Hydrological Modelling

3.6.1 Thiessen polygon

Thiessen polygon are polygons whose boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points. Thiessen polygon were used to distribution the rainfall depths through the sub-basins in the Rompin River Basin. The fraction of areas generated by the Thiessen polygons were converted into percentage of rainfall depths. Rainfall distributions were then carried out by multiplying the rainfall depths from the stations involved with the contributing percentage for each sub-basin.

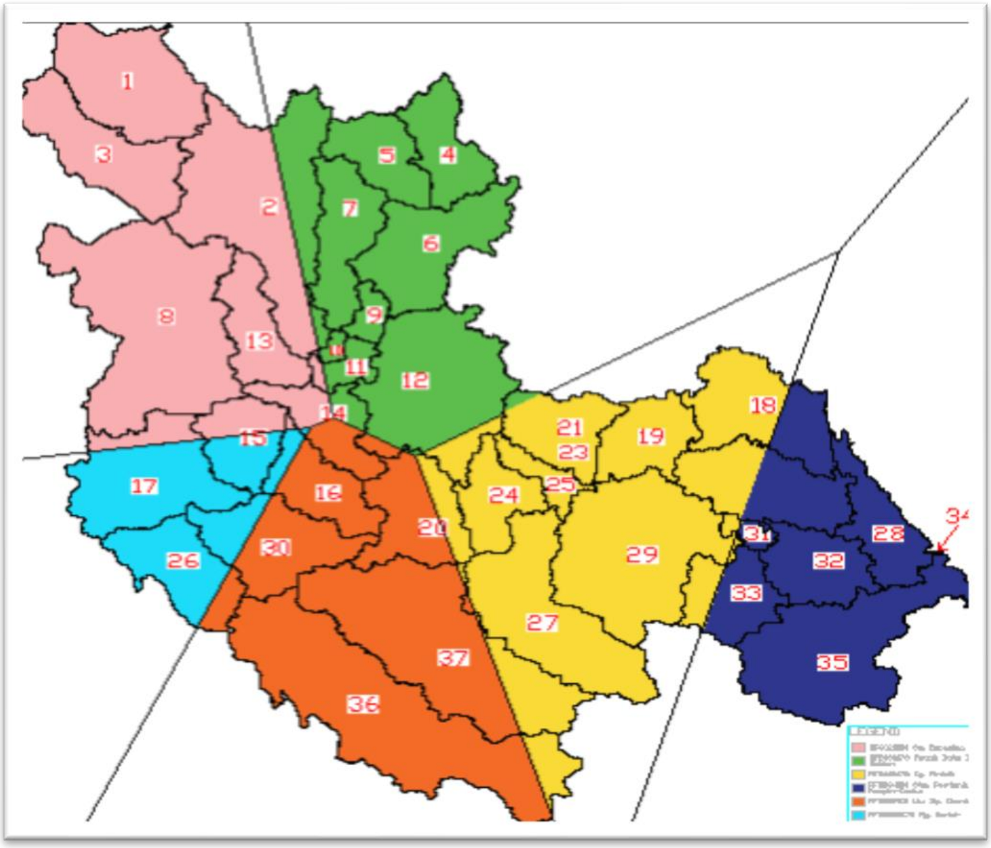


Figure 3.6 Thiessen polygon

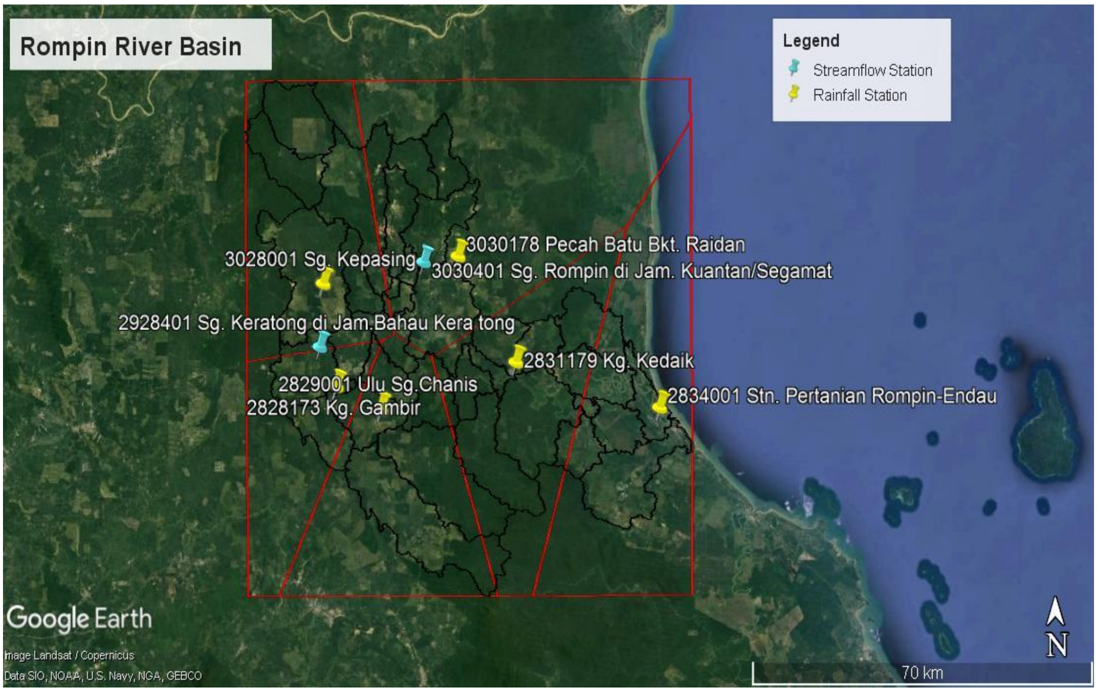


Figure 3.7 Thiessen polygon in Google Earth with sub-basins and stations

3.6.2 Hydrological Modelling Scheme

The hydrological modelling scheme for the Rompin River Basin was developed using the HEC-HMS model. For Rompin River Basin, it was make known that there are 40 sub-basins generated with SRTM DEM 30m resolution using ArcGis application. In HEC-HMS model, the setup started with importing the basemap and sub-basin map of the studied area into the model space. Based on the basemap and digitized river layers, the river network elements such as reach and junction were assigned into the model. For each element, the downstream points were defined accordingly. Table 3.5 shows the number of sub-basins, reaches and junctions developed for the Rompin River Basin hydrological modelling scheme.

Table 3.5 Number of elements developed in HEC-HMS

Elements	Number
Sub-basin	40
Junction	20
Reach	22

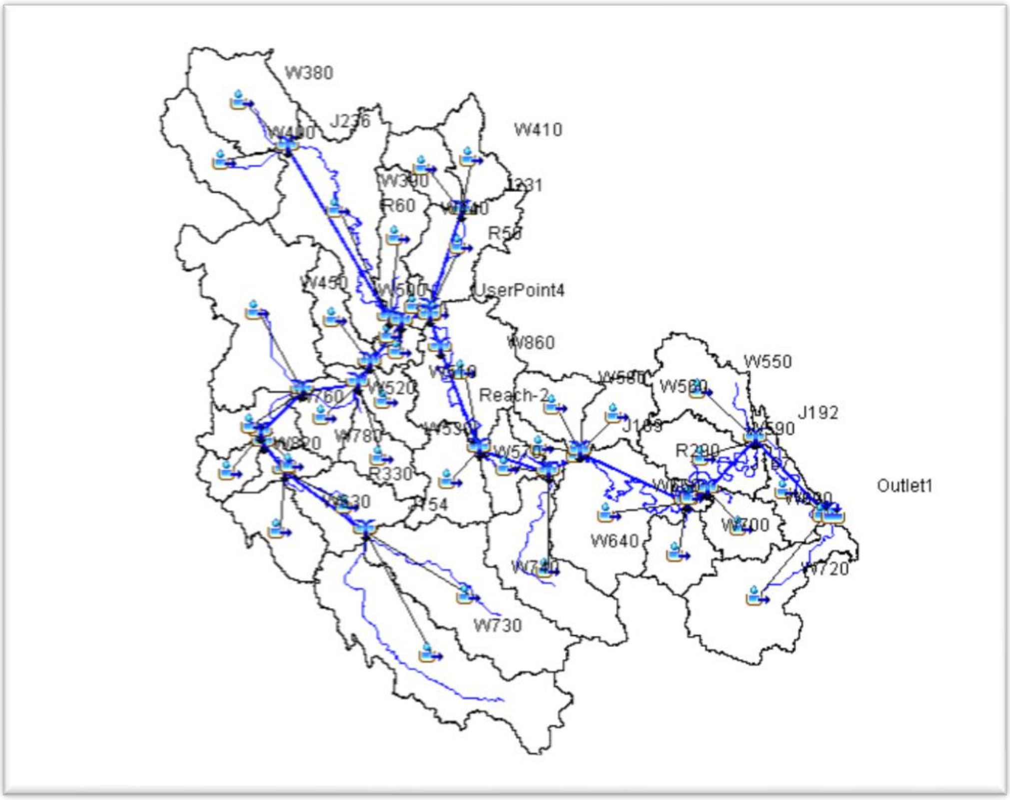


Figure 3.8 HEC-HMS model for RRB

3.6.3 Data Input

Input data used in the hydrological modelling for the Rompin River Basin includes the hydrological daily data of 6 rainfall and 2 streamflow stations. The parameters required for the loss method, transform method, baseflow method and routing method were computed accordingly before applied into HEC-HMS model. In this study, all the calibration and input parameters were estimated priory by applying Equation 2.1 to 2.2.

3.7 Calibration and Validation Processes

3.7.1 Calibration Process

Model calibration is the process of adjusting the model parameter values until the model result matches the observed data. The process can be completed manually using engineering knowledge by repeatedly adjusting parameters, computing and inspecting the goodness of fit between the computed and observed hydrograph. In this study, there are 1 set of low flow and high flow monthly data selected for the calibration processes: June and December. The discharge output from rainfall model was calibrated with observed streamflow by manually adjusting the calibration parameters as listed in Table 3.6. Calibration process was done manually in reference to the estimated values obtained from Equation 2.1 to 2.2.

Table 3.6 Parameters used in HEC-HMS

Method	Parameter
Loss – SCS curve number	Curve number Initial abstraction Imperviousness
Transform – SCS UH	SCS lag
Baseflow – constant monthly	Baseflow
Routing - Lag	Lag time

3.7.2 Validation Process

Validation is the process of testing the model applicability by using another set of data. In this process, the parameters which have been applied during calibration process are kept unchanged. For this Rompin River Basin study, the monthly data selected for validation are May and December. The simulated streamflow for the selected events and observed hydrograph were compared to identify whether the degree of agreement between the two. If the validation result fails, the calibration process was repeated until the validation showed sufficient result.

3.8 Model Performance

The performance of the developed HEC-HMS model was evaluated by conducting the error analysis using the Root Mean Square Error (*RMSE*) and Nash-Sutcliffe Efficiency (*NSE*).

RMSE, also known as root mean square deviation, is the comparison between closeness of the observed value with the simulated one. Lower *RMSE* value indicates desirable closeness of the predicted model to the observed data. *RMSE* is calculated using Equation 3.1:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Obs - Sim)^2} \tag{3.1}$$

where, Obs is the observed discharge and Sim is the simulated discharge.

The *NSE* are used to evaluate the predictive power of this HEC-HMS model. Nash and Sutcliffe (1970) suggested that it is necessary to find R^2 value to determine efficiency of the model where this value can determine the linear agreement or disagreement between observed and measured data. The value of *NSE* ranges from negative infinity to 1, where 1 is perfect match of the measured and observed data. Efficiency of 0 indicates the prediction of model equal to mean of the data observation. Negative value of *NSE* indicates mean observed data is a better predictor than the simulated data. NSE is calculated by Equation 3.2:

$$NSE = 1 - \frac{\sum(Obs - Sim)^2}{\sum(Obs - Omean)^2} \qquad 3.2$$

where Obs is the observed discharge, Sim is the simulated discharge and $Omean$ is the mean observed discharge.

CHAPTER 4

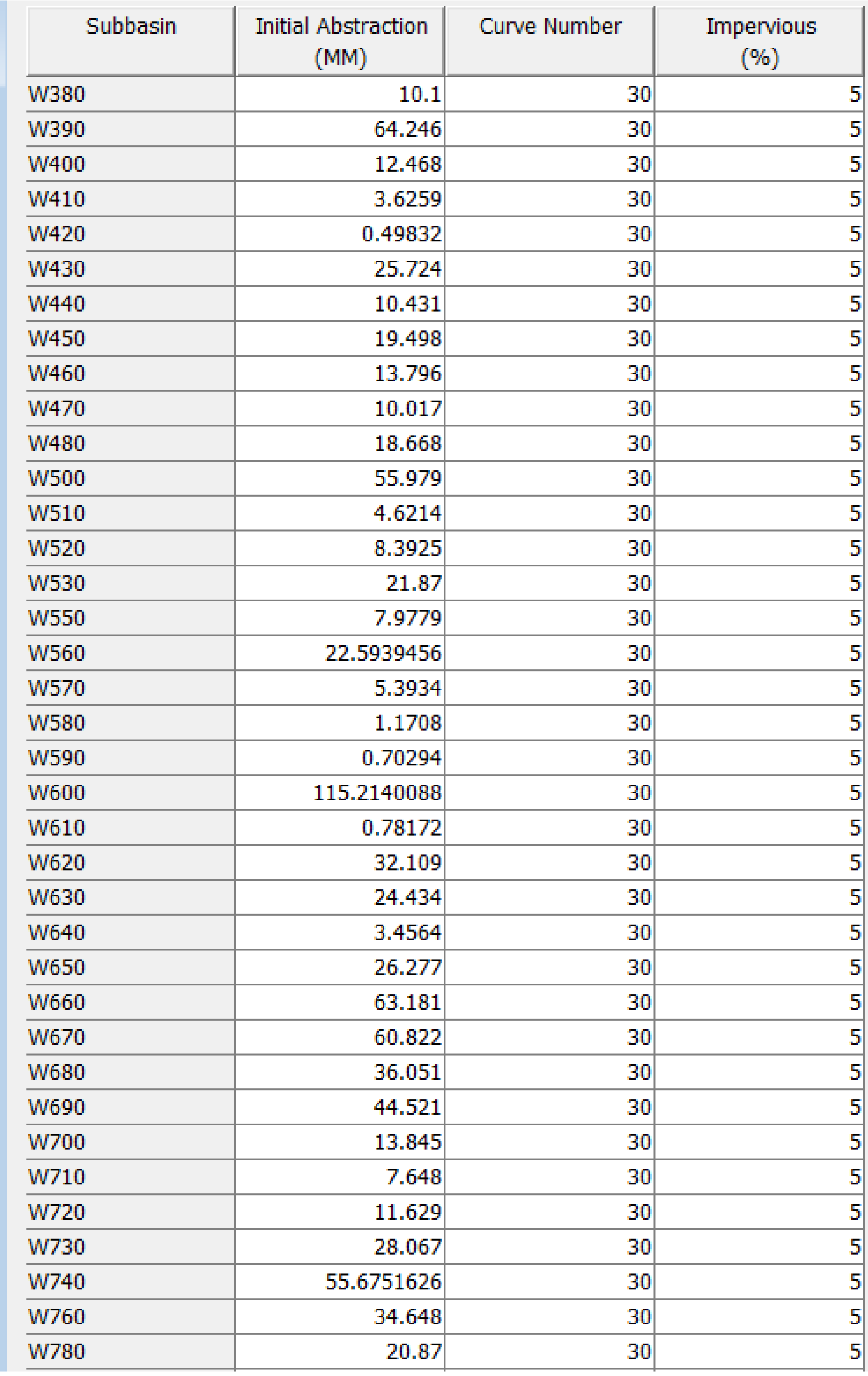
RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the hydrological model development and stimulation results for RRB are presented. The calibration and validation results of different datasets are discussed individually. Stimulation of hydrographs obtained have been compared to the observed discharge data recorded at two gauging stations: Sg Keratong (2928401) and Sg Rompin (3030401).

4.2 HEC-HMS

In the HEC-HMS model, total of 40 sub-basins, 22 reaches, including river and tributaries and 20 junction elements have been schematized for the Rompin River Basin. For each sub-basin and river reach, the lose coefficient, time of concentration and lag time have been calculated accordingly. The example of the detailed results of the calibration parameters is shown in Figure 4.1. The remaining data can be referred in Appendix D.



Subbasin	Initial Abstraction (MM)	Curve Number	Impervious (%)
W380	10.1	30	5
W390	64.246	30	5
W400	12.468	30	5
W410	3.6259	30	5
W420	0.49832	30	5
W430	25.724	30	5
W440	10.431	30	5
W450	19.498	30	5
W460	13.796	30	5
W470	10.017	30	5
W480	18.668	30	5
W500	55.979	30	5
W510	4.6214	30	5
W520	8.3925	30	5
W530	21.87	30	5
W550	7.9779	30	5
W560	22.5939456	30	5
W570	5.3934	30	5
W580	1.1708	30	5
W590	0.70294	30	5
W600	115.2140088	30	5
W610	0.78172	30	5
W620	32.109	30	5
W630	24.434	30	5
W640	3.4564	30	5
W650	26.277	30	5
W660	63.181	30	5
W670	60.822	30	5
W680	36.051	30	5
W690	44.521	30	5
W700	13.845	30	5
W710	7.648	30	5
W720	11.629	30	5
W730	28.067	30	5
W740	55.6751626	30	5
W760	34.648	30	5
W780	20.87	30	5

Figure 4.1 Calibration Parameter

4.3 Streamflow Hydrographs

In this study, the streamflow hydrographs for at the two gauging points were generated based on the daily rainfall data captured at the related stations. In brief, the rainfall data used in the analyses was from the year 2000 to 2013 as discussed in Chapter 3. For each year, the hydrographs of 2 monthly rainfall events representing the high flow and low conditions, respectively, were simulated using the HEC-HMS model. The comparison of the simulated streamflow results against the observed data are discussed according to the low and high flow conditions at each gauging stations.

4.3.1 Calibration for High Flow Conditions

December 2000 event was selected for the wet season simulation. From the observed data, it shows that the streamflow of Sg. Keratong was lower than Sg. Rompin. This is because Sg. Keratong is located at the upstream of the Rompin River Basin. The simulation pattern for both discharge stations match the observed model at the lower rainfall intensity (Figure 4.2 and 4.3). When there was high intensity of rainfall event, the observed flow seems to be underestimated the flow while the simulated result shows higher peak for the Sg. Keratong station. Besides the peak difference, the simulated streamflow shows longer lag time to peak compared to the observed. However, the simulated result presents better fit for the streamflow pattern at Sg. Rompin station except for the beginning part. This was because HEC-HMS assumed no rainfall occurred outside of the simulation time span.

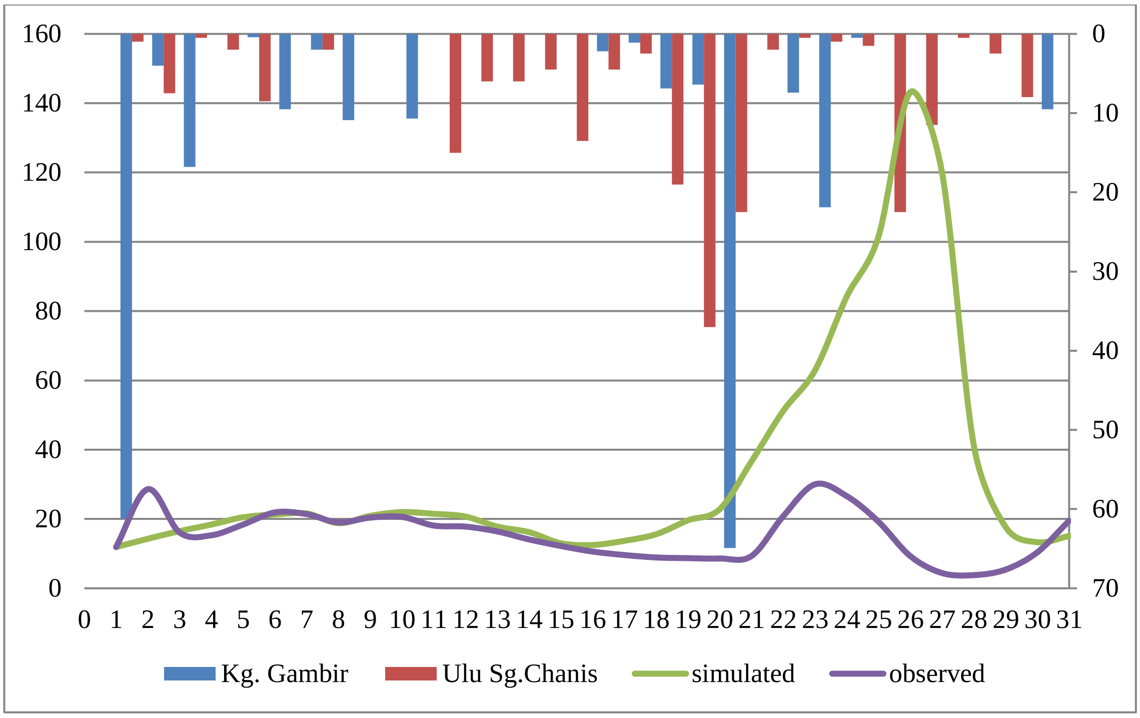


Figure 4.2 Simulated and observed flow comparing with rainfall for Sg Keratong (2928401) for December 2000

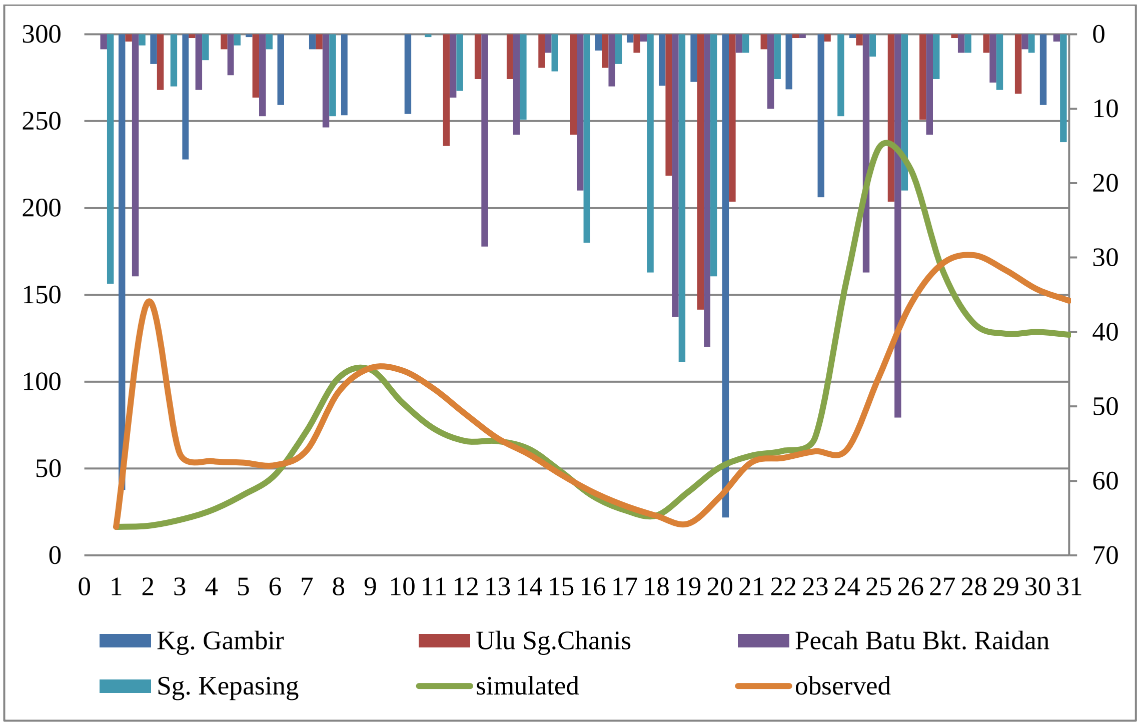


Figure 4.3 Simulated and observed flow comparing with rainfall for Sg Rompin (3030401) for December 2000

4.3.2 Validation for High Flow Conditions

Keeping the calibration parameters in the calibration process unchanged, the data on December 2012 was selected for the validation. From the results, the fitness of the streamflow between the simulated and observed present the same pattern as the calibration results. The simulated discharge at Sg. Keratong station shows fairly good fitness compared to the observed especially when there were rainfall events in which the observed showed discharge does not indicate any peak. However, for the results at Sg. Rompin, the streamflow pattern seems satisfying although the simulated streamflow indicating an overestimation on the peak compared to the observed.

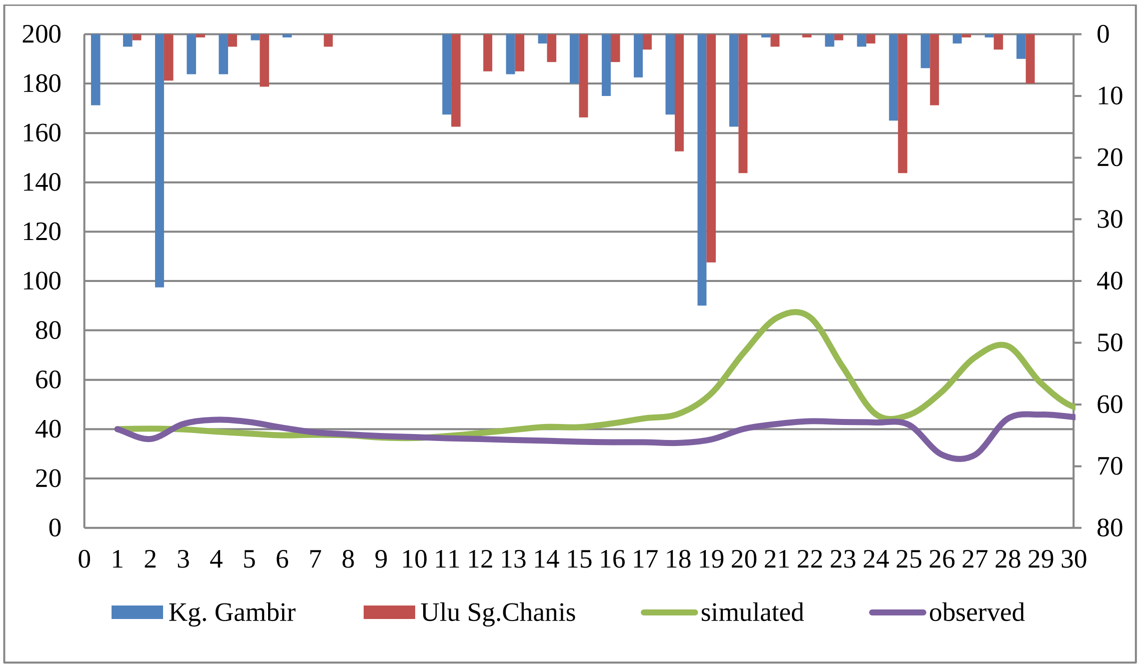


Figure 4.4 Simulated and observed flow comparing with rainfall for Sg Keratong (2928401) for December 2012

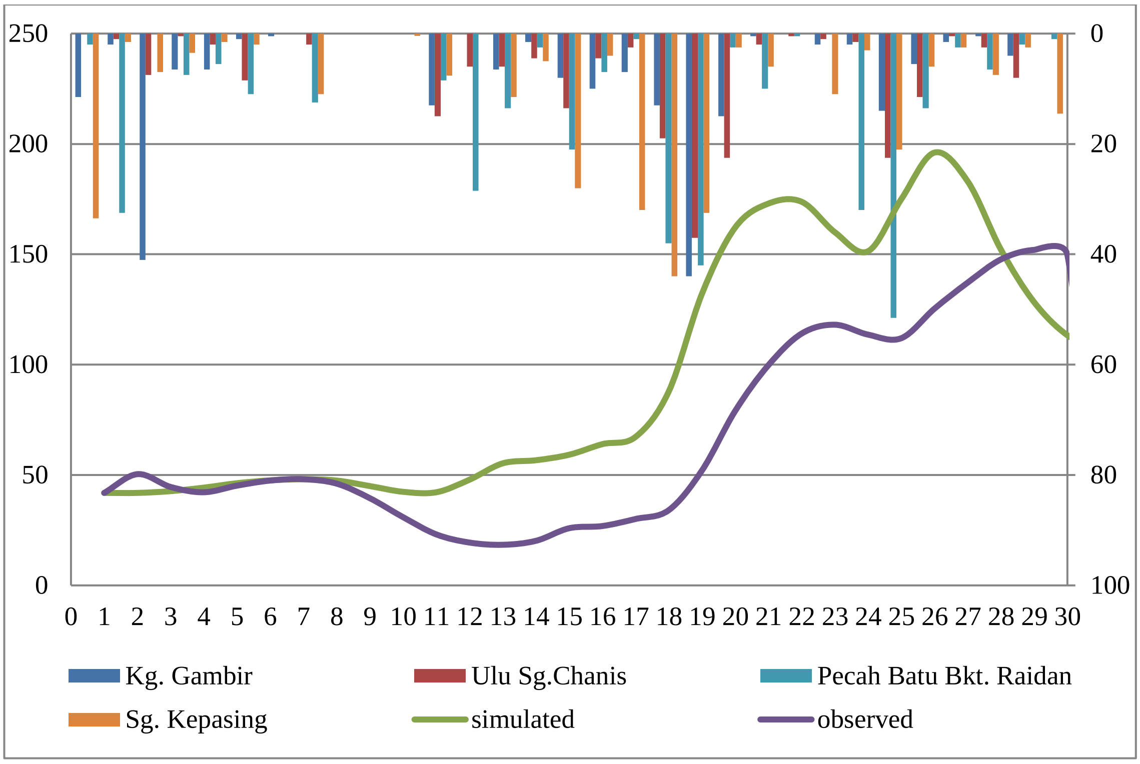


Figure 4.5 Simulated and observed flow comparing with rainfall for Sg Rompin (3030401) for December 2012

4.3.3 Calibration for Low Flow Conditions

For the low flow or drought analysis, the dry month selected for the calibration purpose is the data for June 2012 as shown in Figure 4.6 and 4.7. Opposite from the high flow streamflow pattern, the results from the HEC-HMS simulation presents better fitting at the low flow peak. However, it underestimates the lower flow at Sg. Keratong station and overestimates the baseflow at Sg. Rompin. Observing the gauged streamflow, the raw data shows uneven match with the recorded rainfall events and this may indicate low reliability in the gauging data. Nevertheless, this argument can only be hypothesized unless with rigid evident.

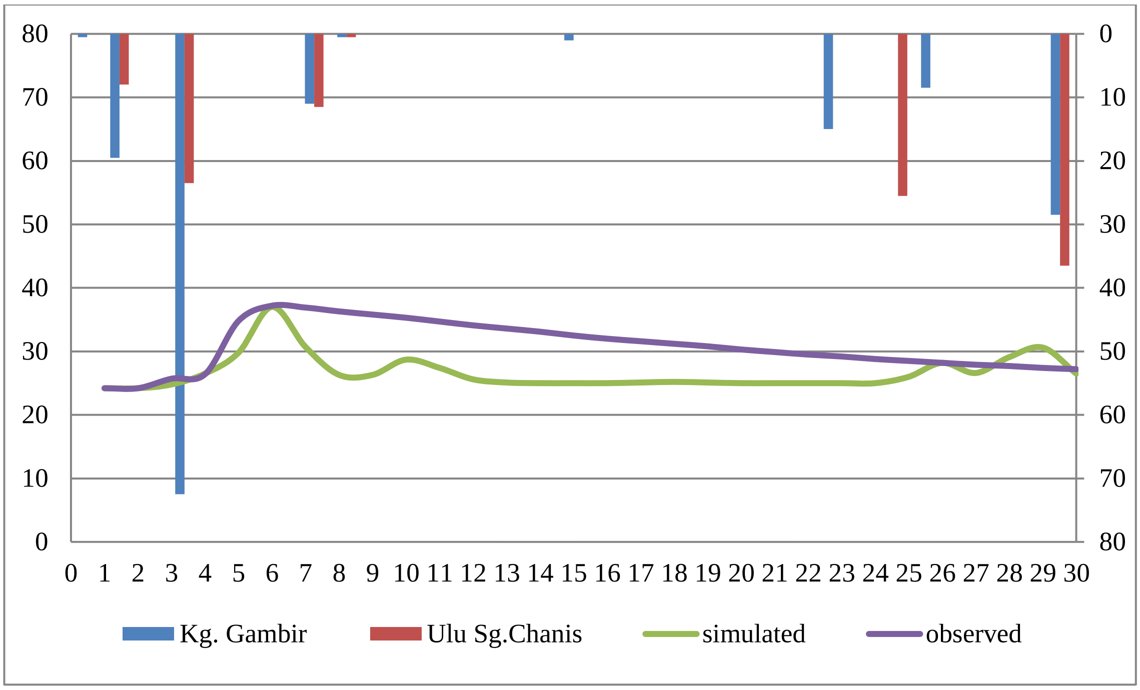


Figure 4.6 Simulated and observed flow comparing with rainfall for Sg Keratong (2928401) for June 2012

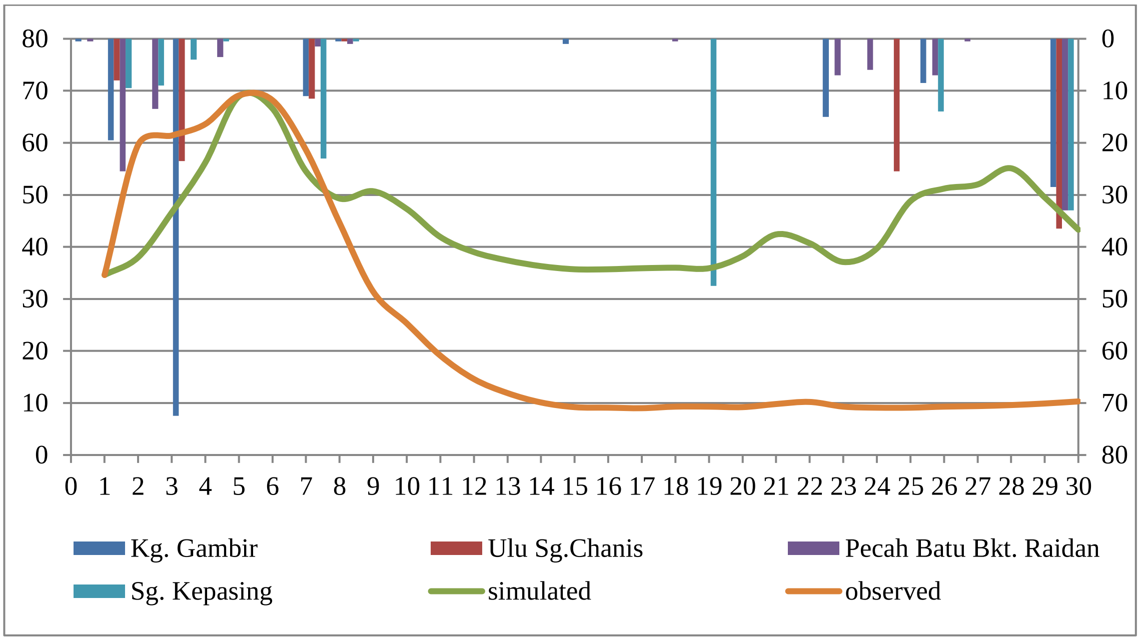


Figure 4.7 Simulated and observed flow comparing with rainfall for Sg Rompin (3030401) for June 2012

4.3.4 Validation for Low Flow Conditions

Similar to the high flow process, validation was done for the dry flow condition with the streamflow data of May 2013 was selected. For the validation, it seems that the simulated discharge is fitting well with the observed for the baseflow and the lower peak. Assessing the flow pattern at the end of the month, it is again observed that the data captured on site is not representing the rainfall events. It is obviously shown from the rainfall data that there were continuously events at the ends of the month but the observed streamflow shows no peak while the simulated discharge indicates the peak. The validation results comparison between the observed and simulated streamflow are displayed in Figure 4.8 for Sg. Keratong station and Figure 4.9 for Sg. Rompin station.

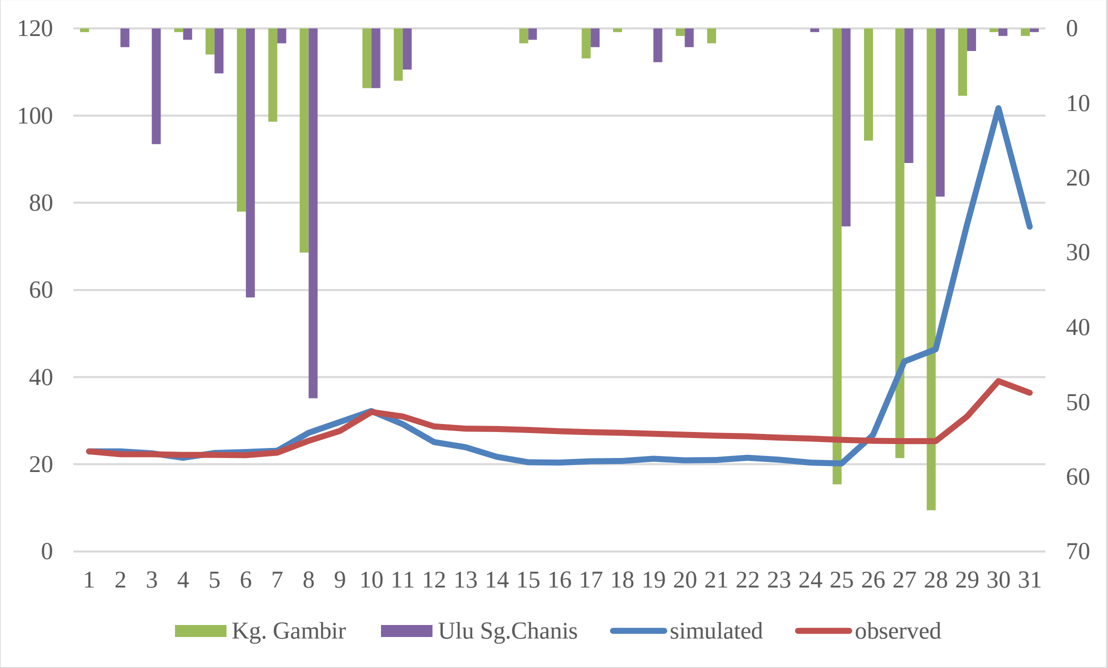


Figure 4.8 Simulated and observed flow comparing with rainfall for Sg Keratong (2928401) for May 2013

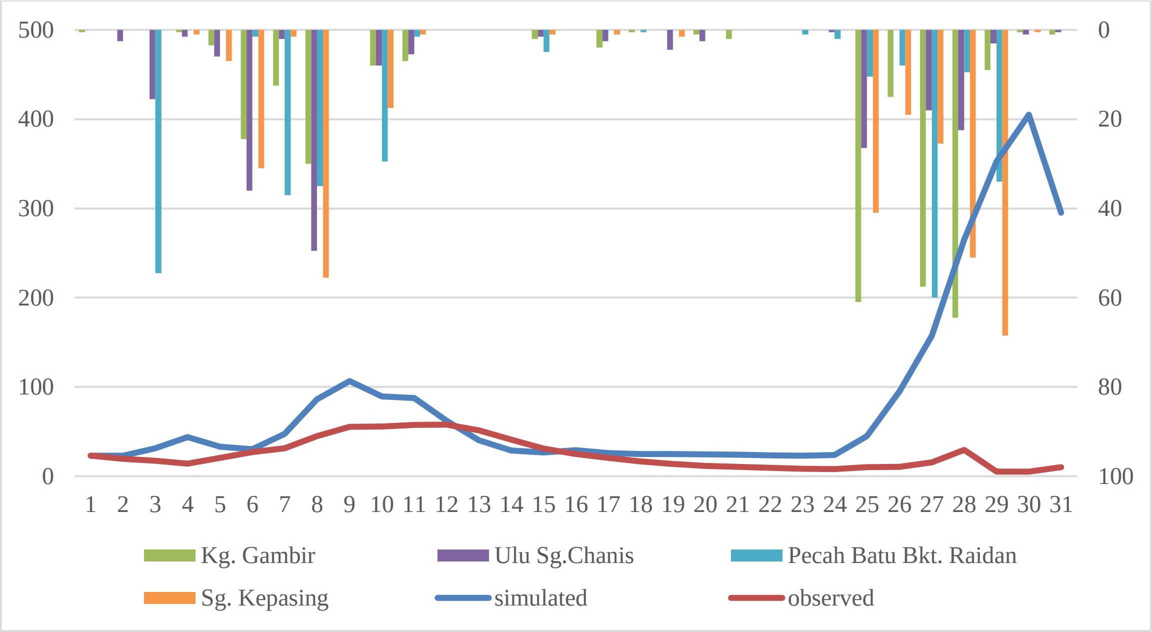


Figure 4.9 Simulated and observed flow comparing with rainfall for Sg Rompin (3030401) for May 2013

In overall, the results show that HEC-HMS with SCS Unit Hydrograph method can be applied to simulate the hydrological characteristics of the RRB with certain level of acceptance. Although the model results showed lower confident in the high flow peaks but for the low flow, they seem to be promising. Nevertheless, the streamflow pattern simulated for all the selected events were found to be matching the rainfall pattern with 2 to 3 days of lag time to peak. Oppositely, the observed streamflow patterns for all events seem to be uneven to the rainfall pattern. These uncertainty and outlier maybe due to the degree of reliability of the gauging data, or any river diversion such as ponds, water extraction or high evapotranspiration rate. Besides that, the simulated discharges were not satisfactory fitted to the observed maybe due to inappropriate selection of the calibration parameters as some data was not available.

One of the parameter that may contribute to the fairly good result is the loss coefficient of CN values. Although the parameter is crucial in this study, the soil type map for the RRB in which shall be used to generate the CN values was not available although has been applied from the related authority. Hence, the CN values in this study were estimated and adjusted based on literatures, google satellites images and topographic maps. The lacking of information on the soil type may lead to the unfitness of the simulated results against the observed data.

Since the simulation time span was carried for a month period, it maybe be more difficult to get good fit for the entire period. Data with large time interval or long period has more missing data compare to a short period. Short time frame analysis may be easier to calibrate and shall be used to obtained more desirable results.

4.4 Statistical Error Analysis

In this study, the performance of the model developed has been evaluated using the root mean square error analysis and Nash-Sutcliffe Efficiency. The statistical error has been computed for all the monthly rainfall events considered. Tables 4.1 shows the summary of the computed RMSE while Table 4.2 shows the summary of the computed NSE for the high and low flow conditions at the two gauging stations. From the tables, it shows there is a large error in RMSE and NSE. This might due to the difference that are contributed by the high peaks for both high and low flow. Lower RMSE value indicated desirable closeness of the simulated model to the observed model. The negative value of NSE indicated mean observed data is a better predictor than the simulated data.

Table 4.1 RMSE result

	Calibration		**Validation**	
	High flow	**Low flow**	**High flow**	**Low flow**
Sg. Keratong	38.67	5.49	17.23	16.63
Sg. Rompin	43.39	27.12	39.87	121.15

Table 4.2 NSE result

	Calibration		**Validation**	
	High flow	**Low flow**	**High flow**	**Low flow**
Sg. Keratong	-0.38	-2.32	-0.49	0.22
Sg. Rompin	0.39	-6.25	0.44	-0.44

CHAPTER 5

CONCLUSION

5.1 Introduction

The streamflow hydrographs for the RRB have been successfully simulated using the rainfall-runoff HEC-HMS modelling tool for 4 months of rainfall events: December 2000, December 2012, June 2012 and May 2013. From the simulated results and observed discharge comparison, the hydrological modelling approach is able to simulate the hydrograph at low flow more accurately compare to at high flow condition. Some of the results may seem satisfactory due to lower peak of the observed streamflow even during high rainfall events. This may indicate some inaccuracy in the observed data either the rainfall or streamflow readings.

Calibration processes for the monthly rainfall events selected have been completed by adjusting the calibration parameters in the HEC-HMS model. It is found that there were difficulties in fitting the simulated discharge to the observed especially at some of the peaks of the hydrographs. This unsatisfactory result might due to some parameters used were not appropriate and non-uniform distribution. Therefore, the adjustments of the calibration parameters were made by ensuring most part of the simulated hydrograph match the observed hydrograph.

In order to make sure the calibration parameters were correctly defined, validation using another sets of data were conduction. Based on the validation results, statistical error analysis using RMSE and NSE have been performed. The analyses outcomes indicate low flow perform better when using RMSE analysis whereas NSE analysis showed that high flow perform better than low flow.

Despite of some result deficiencies in the simulated hydrographs, the developed model using HEC-HMS can still be considered as a reliable tool to predict flood levels and flowrates for the RRB. This model is found to be sufficient especially for the ungauged region in the basin. However, the level of accuracy of the results are also highly dependent on the correctness at the raw input data.

5.2 Recommendation

Based on this study, there are some aspects that should be enhanced in order to improve the accuracy of the result. One of the aspect is the catchment area may divided into smaller sub-basins. This can reduce the error that will arise during simulation processes. For better adjustment of the calibration parameters, it is recommended to do ground survey to identify the exact landuse in the catchment area. Aerial photograph maybe applied. Furthermore, the coverage area of different landuses shall be calculated in detail.

Regarding the raw hydrological data collected from DID, it was found that there were plenty of missing data. These missing values shall be carefully taken care of to avoid significant errors in the analysis. Gap filling is recommended to be done using appropriate statistical measures. In this study, the calibration and validation analyses have shown that it is difficult to fit the simulated results with the observed when low and peak flow occurred. This may indicate that it might be better if the calibration is done for a certain peak and a shorter period but smaller time interval.

For future study, it is recommended to apply ad compare other transform methods in HEC-HMS such as Clark and Snyder Unit Hydrograph method to analyses the best model that can be used in the region. The performance of each method can be evaluated by comparing the result of statistical error analysis.

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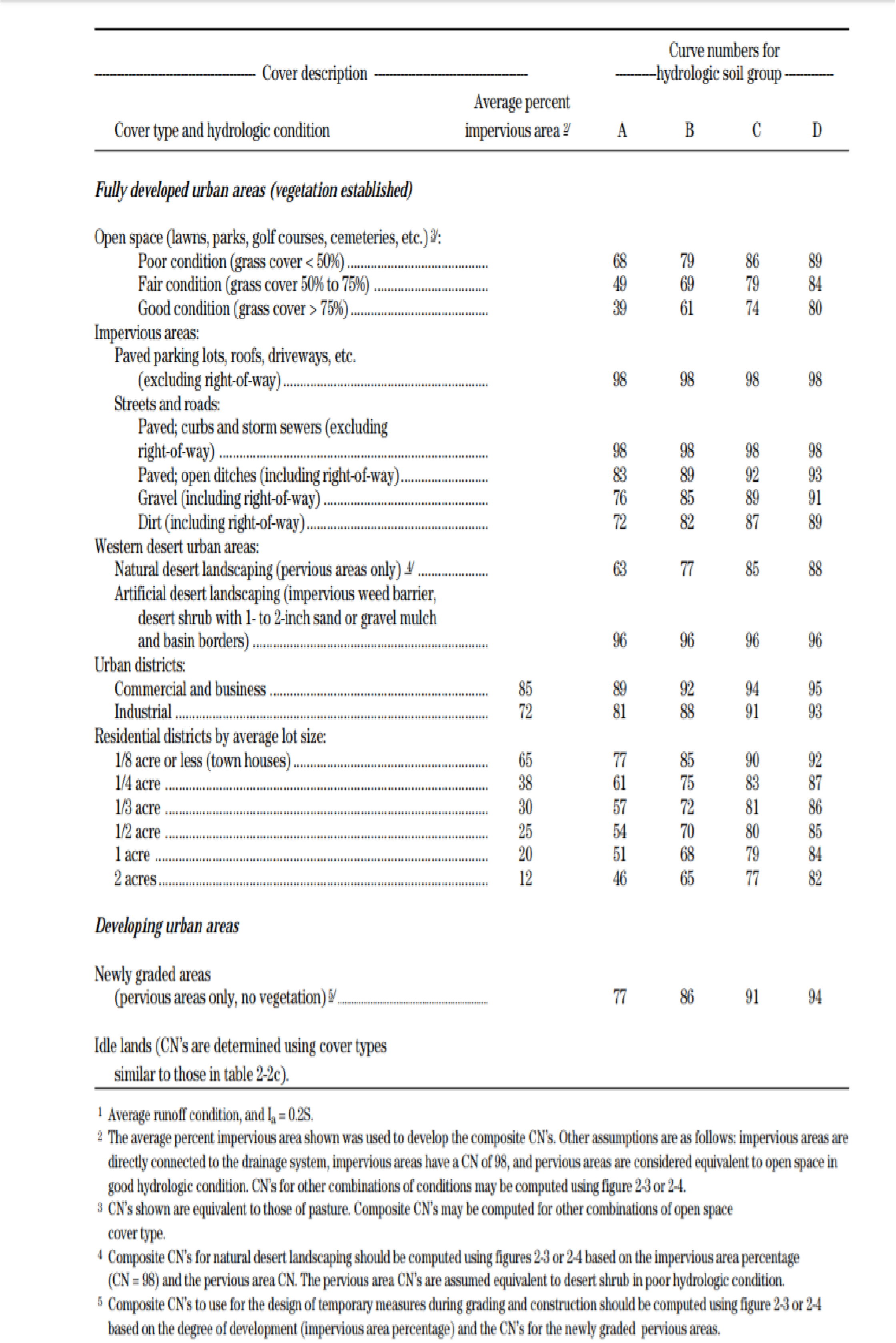
APPENDIX A
CRITERIA TO SELECT THE CN



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

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

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

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

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

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

APPENDIX B
RAINFALL DATA

High flow – December 2000

Day	2828173- Kg Gambir	2831179- Kg Kedaik	2934001- Stn Pertanian	2829001- Ulu Sg Chanis	3030178- Pecah Batu	3028001- Sg Kepasing
1	0	14.7	0	0	4.5	0
2	61.2	44.9	12.6	21.6	0	66.5
3	4	2.1	0	3.8	8.7	6.5
4	16.8	5.5	0	34.6	6.4	16.6
5	0	0	0	0.7	0	0
6	0.4	31.6	0	4.6	14.9	2.3
7	9.5	17.6	0	10.9	92.9	18.9
8	2	5.6	0	4.2	37.4	28.6
9	10.9	2.3	0	8.8	5.9	3.6
10	0	0	0	0.6	0	0
11	10.7	0	0	6.9	0	0
12	0	0	0	0	0	0
13	0	5.8	30.4	0	25.1	0
14	0	2.8	0	0	3.7	0
15	0	0.7	0	1.6	0	0
16	0	0.9	0	0	0	0
17	2.2	2.7	0	8.4	0.8	1.5
18	1.1	0	0	1.3	0.6	0
19	6.9	61.2	0	8.3	28.6	8.2
20	6.4	1.8	0	2.7	7.1	1.3
21	64.9	12.9	0	44	12.1	15.2
22	0	0.6	0	0	0	0
23	7.4	28	93.1	26.6	2.7	0.6
24	21.9	166	145.6	75.5	131	22.8
25	0.5	4.5	0	2	2.6	8.7
26	0	0	0	0	0	0
27	0	4	0	0	0	0
28	0	0	0	0	0	0
29	0	3.5	0	0	0	0
30	0	23	18.1	2.2	0	0
31	9.5	0	0	0	0	20.7

Low flow – June 2012

Day	2828173- Kg Gambir	2831179- Kg Kedaik	2934001- Stn Pertanian	2829001- Ulu Sg Chanis	3030178- Pecah Batu	3028001- Sg Kepasing
1	0.5	0	0	0	0.5	0
2	19.5	8	11	8	25.5	9.5
3	0	5	0	0	13.5	9
4	72.5	12.5	3.5	23.5	0	4
5	0	0	0.5	0	3.5	0.5
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	11	5.5	1.5	11.5	1.5	23
9	0.5	0.5	0.5	0.5	1	0.5
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	1	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	10.5	0	0	0
19	0	0	0	0	0.5	0
20	0	5.5	0	0	0	47.5
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	15	3.5	0	0	7	0
25	0	0.5	0	0	6	0
26	0	0.5	0	25.5	0	0
27	8.5	0.5	16	0	7	14
28	0	0	0	0	0.5	0
29	0	0	2	0	0	0
30	0	0	10.5	0	0	0
31	28.5	31.5	8.5	36.5	33	33

APPENDIX C
STREAMFLOW DATA

High flow – December 2000

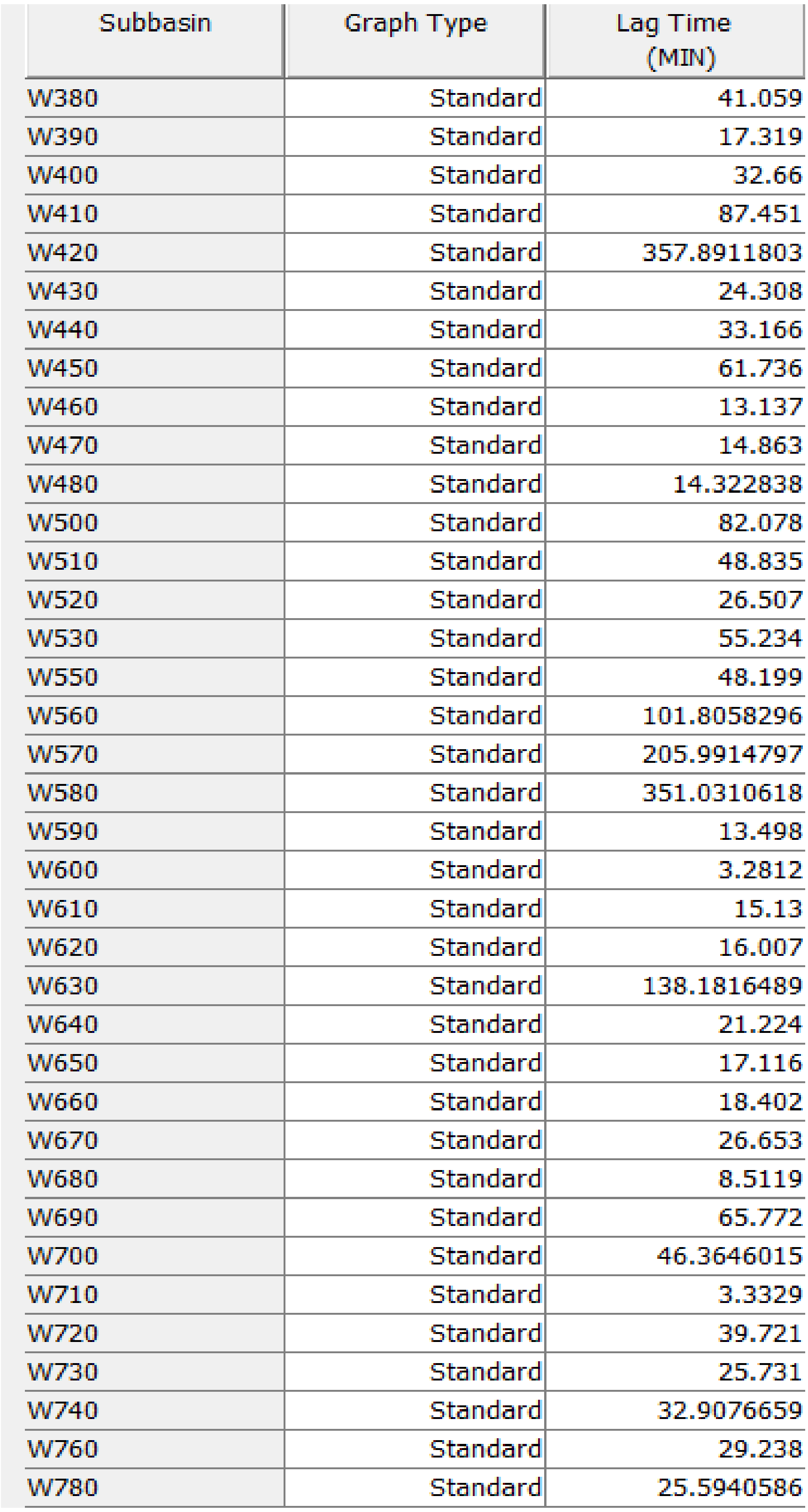
Day	2928401 - Sg Keratong	3030401 - Sg Rompin
1	23.36	58.8
2	28.62	54.3
3	16.14	53.4
4	15.33	51.9
5	18.38	60.5
6	21.9	94
7	21.36	107.8
8	19.02	106.5
9	20.35	95.9
10	20.57	81.3
11	18.13	67.5
12	17.76	58.1
13	16.44	46.6
14	14.05	36.5
15	12.2	28.7
16	10.63	22.8
17	9.56	18.2
18	8.92	33.6
19	8.67	53.5
20	8.64	56.1
21	9.28	59.9
22	20.78	60.8
23	29.97	102.2
24	26.59	144.1
25	19.18	167.8
26	9.27	172.8
27	4.37	164.2
28	3.78	153.1
29	5.41	146.6
30	10.44	145.8
31	19.53	145.4

Low flow – June 2012

Day	2928401 - Sg Keratong	3030401 - Sg Rompin
1	24.2	45.3
2	24.18	59.6
3	25.66	61.4
4	26.36	63.6
5	34.78	69.1
6	37.18	68.2
7	36.87	58.6
8	36.34	44.6
9	35.83	31.4
10	35.3	25.3
11	34.71	19.1
12	34.15	14.6
13	33.6	11.9
14	33.07	10.1
15	32.54	9.2
16	32.05	9.1
17	31.62	9
18	31.17	9.3
19	30.76	9.3
20	30.3	9.2
21	29.93	9.8
22	29.54	10.2
23	29.18	9.3
24	28.81	9.1
25	28.53	9.1
26	28.19	9.3
27	27.92	9.4
28	27.69	9.6
29	27.45	9.9
30	27.2	9.8

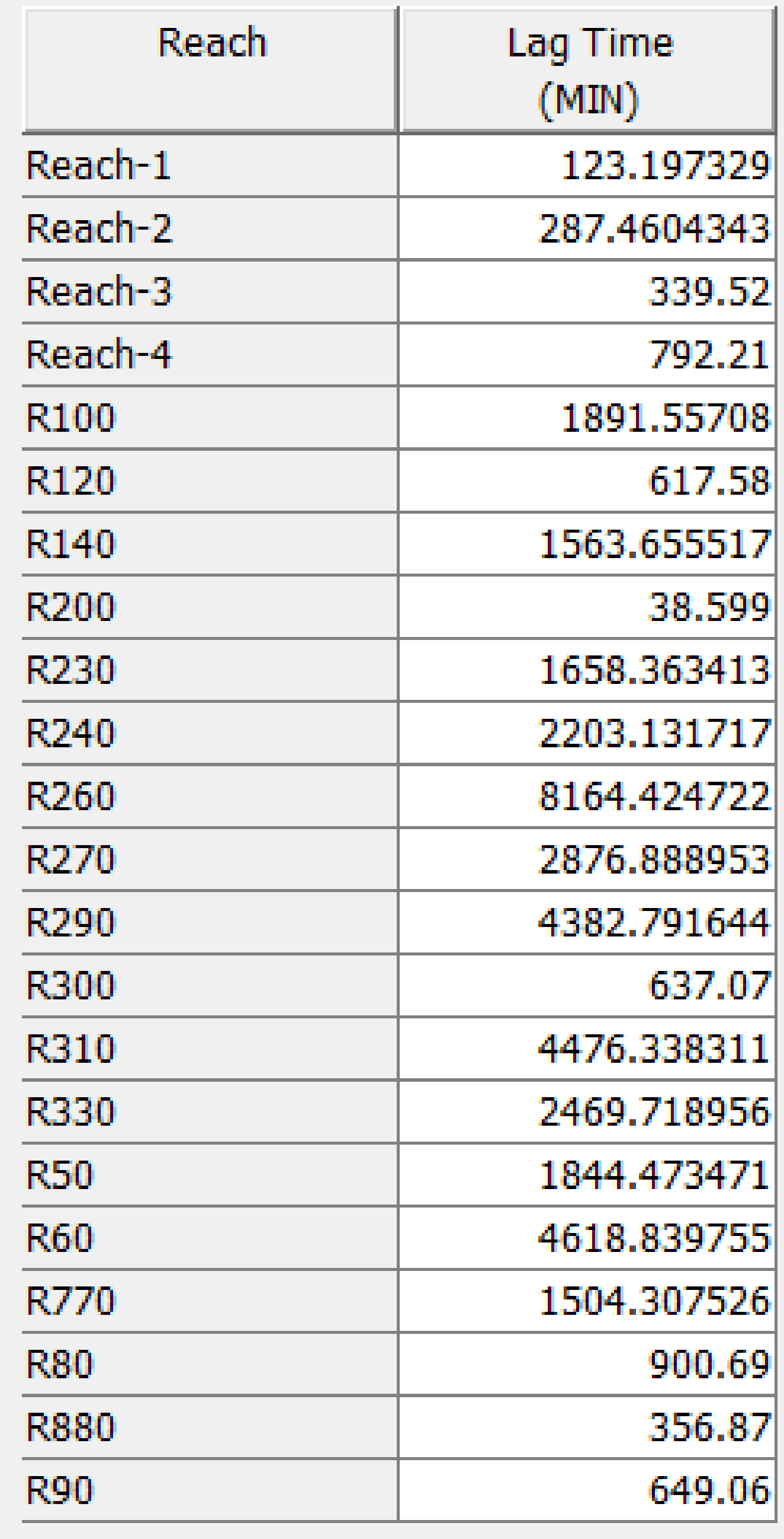
APPENDIX D
CALIBRATION PARAMETER

Basin lag time for high flow (December 2000)



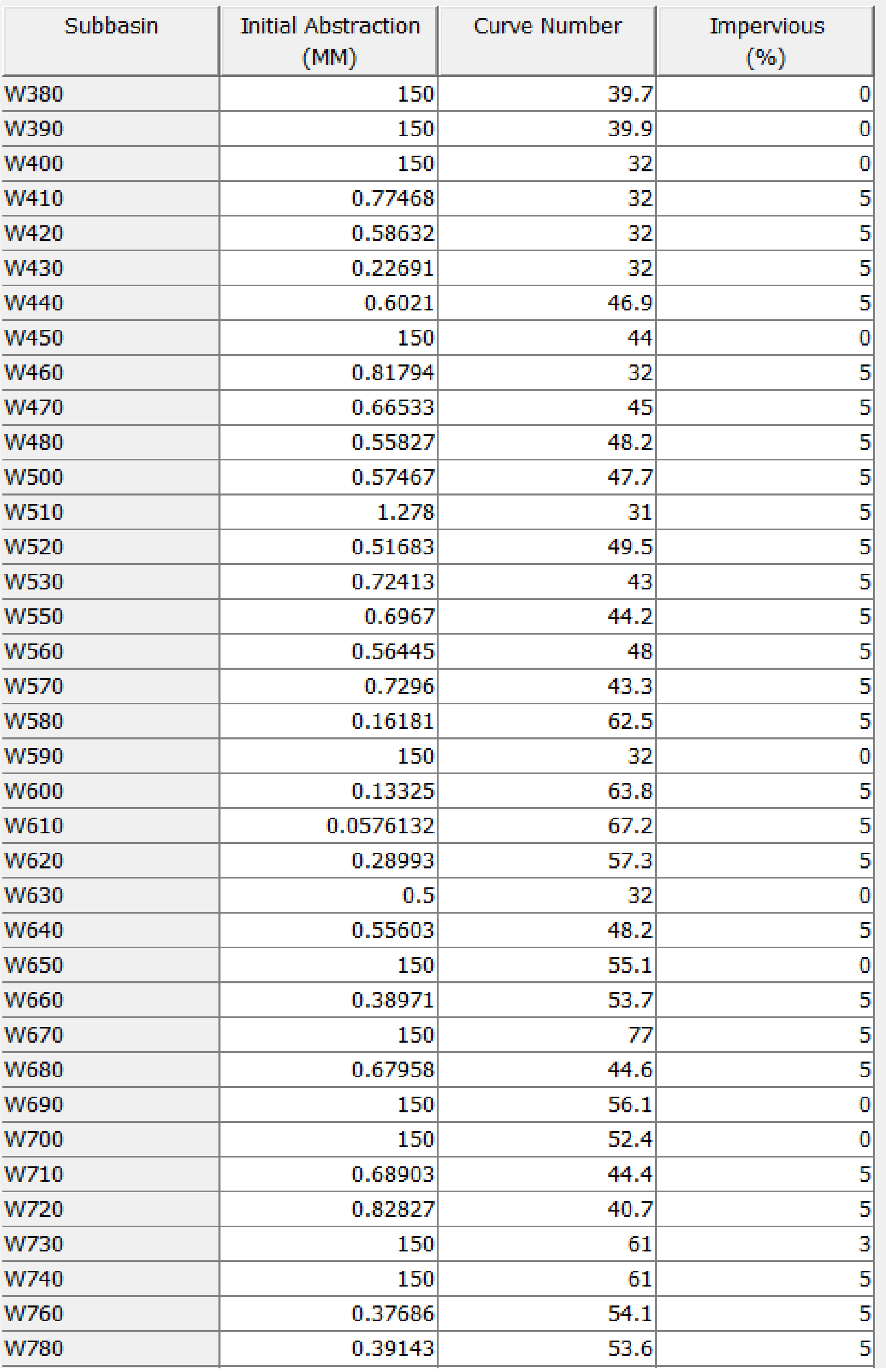
Subbasin	Graph Type	Lag Time (MIN)
W380	Standard	41.059
W390	Standard	17.319
W400	Standard	32.66
W410	Standard	87.451
W420	Standard	357.8911803
W430	Standard	24.308
W440	Standard	33.166
W450	Standard	61.736
W460	Standard	13.137
W470	Standard	14.863
W480	Standard	14.322838
W500	Standard	82.078
W510	Standard	48.835
W520	Standard	26.507
W530	Standard	55.234
W550	Standard	48.199
W560	Standard	101.8058296
W570	Standard	205.9914797
W580	Standard	351.0310618
W590	Standard	13.498
W600	Standard	3.2812
W610	Standard	15.13
W620	Standard	16.007
W630	Standard	138.1816489
W640	Standard	21.224
W650	Standard	17.116
W660	Standard	18.402
W670	Standard	26.653
W680	Standard	8.5119
W690	Standard	65.772
W700	Standard	46.3646015
W710	Standard	3.3329
W720	Standard	39.721
W730	Standard	25.731
W740	Standard	32.9076659
W760	Standard	29.238
W780	Standard	25.5940586

Routing lag time for high flow (December 2000)



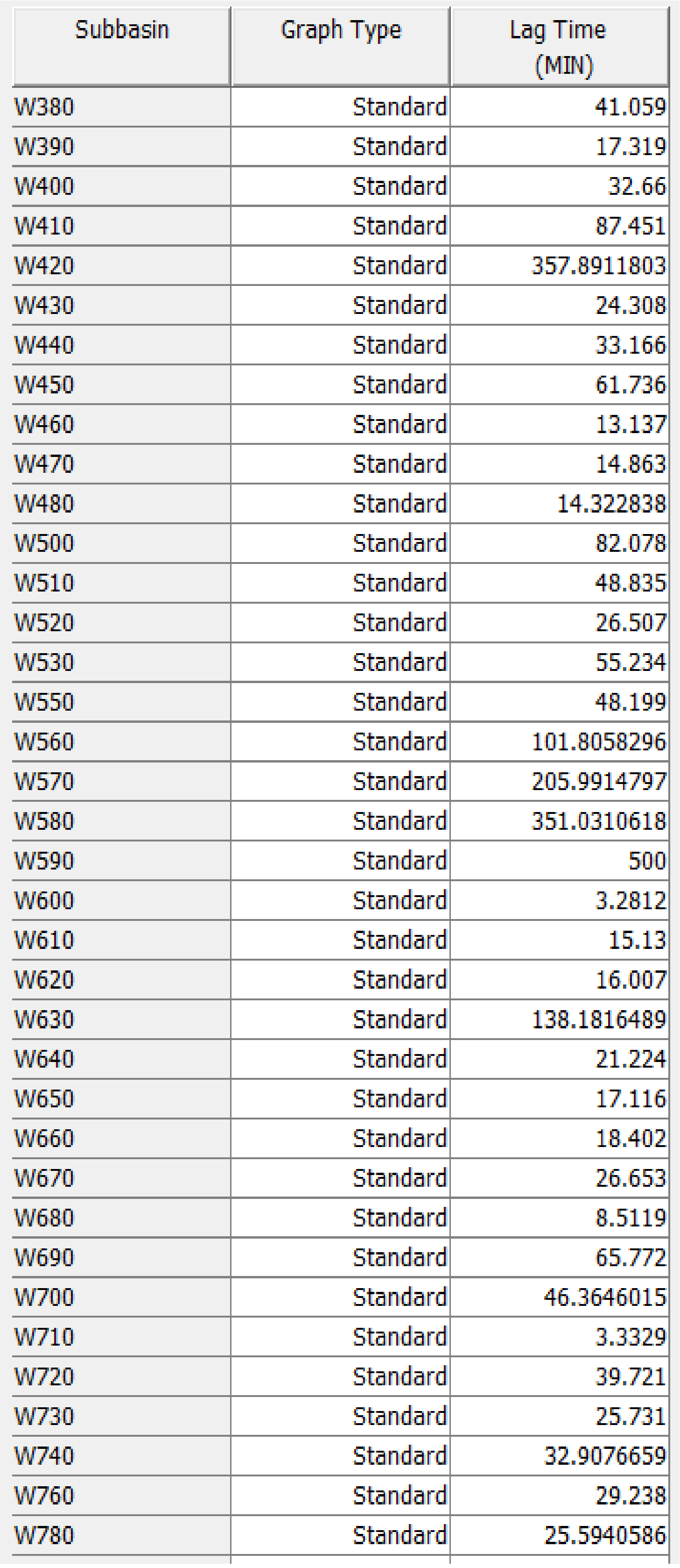
Reach	Lag Time (MIN)
Reach-1	123.197329
Reach-2	287.4604343
Reach-3	339.52
Reach-4	792.21
R100	1891.55708
R120	617.58
R140	1563.655517
R200	38.599
R230	1658.363413
R240	2203.131717
R260	8164.424722
R270	2876.888953
R290	4382.791644
R300	637.07
R310	4476.338311
R330	2469.718956
R50	1844.473471
R60	4618.839755
R770	1504.307526
R80	900.69
R880	356.87
R90	649.06

Loss parameter for low flow (June 2012)



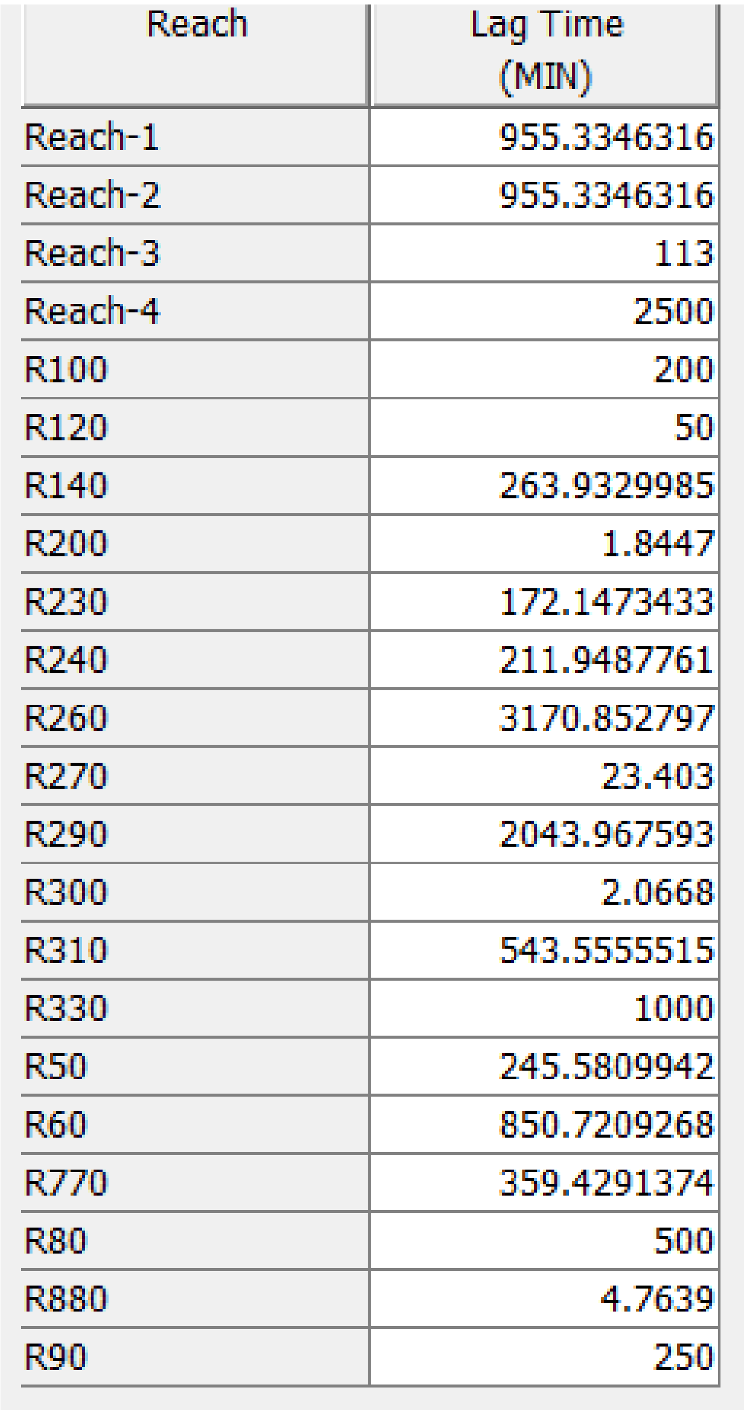
Subbasin	Initial Abstraction (MM)	Curve Number	Impervious (%)
W380	150	39.7	0
W390	150	39.9	0
W400	150	32	0
W410	0.77468	32	5
W420	0.58632	32	5
W430	0.22691	32	5
W440	0.6021	46.9	5
W450	150	44	0
W460	0.81794	32	5
W470	0.66533	45	5
W480	0.55827	48.2	5
W500	0.57467	47.7	5
W510	1.278	31	5
W520	0.51683	49.5	5
W530	0.72413	43	5
W550	0.6967	44.2	5
W560	0.56445	48	5
W570	0.7296	43.3	5
W580	0.16181	62.5	5
W590	150	32	0
W600	0.13325	63.8	5
W610	0.0576132	67.2	5
W620	0.28993	57.3	5
W630	0.5	32	0
W640	0.55603	48.2	5
W650	150	55.1	0
W660	0.38971	53.7	5
W670	150	77	5
W680	0.67958	44.6	5
W690	150	56.1	0
W700	150	52.4	0
W710	0.68903	44.4	5
W720	0.82827	40.7	5
W730	150	61	3
W740	150	61	5
W760	0.37686	54.1	5
W780	0.39143	53.6	5

Basin lag time for low flow (June 2012)



Subbasin	Graph Type	Lag Time (MIN)
W380	Standard	41.059
W390	Standard	17.319
W400	Standard	32.66
W410	Standard	87.451
W420	Standard	357.8911803
W430	Standard	24.308
W440	Standard	33.166
W450	Standard	61.736
W460	Standard	13.137
W470	Standard	14.863
W480	Standard	14.322838
W500	Standard	82.078
W510	Standard	48.835
W520	Standard	26.507
W530	Standard	55.234
W550	Standard	48.199
W560	Standard	101.8058296
W570	Standard	205.9914797
W580	Standard	351.0310618
W590	Standard	500
W600	Standard	3.2812
W610	Standard	15.13
W620	Standard	16.007
W630	Standard	138.1816489
W640	Standard	21.224
W650	Standard	17.116
W660	Standard	18.402
W670	Standard	26.653
W680	Standard	8.5119
W690	Standard	65.772
W700	Standard	46.3646015
W710	Standard	3.3329
W720	Standard	39.721
W730	Standard	25.731
W740	Standard	32.9076659
W760	Standard	29.238
W780	Standard	25.5940586

Routing lag time for low flow (June 2012)



Reach	Lag Time (MIN)
Reach-1	955.3346316
Reach-2	955.3346316
Reach-3	113
Reach-4	2500
R100	200
R120	50
R140	263.9329985
R200	1.8447
R230	172.1473433
R240	211.9487761
R260	3170.852797
R270	23.403
R290	2043.967593
R300	2.0668
R310	543.5555515
R330	1000
R50	245.5809942
R60	850.7209268
R770	359.4291374
R80	500
R880	4.7639
R90	250