ESTIMATING FLOW RATE IN GAUGED AND UNGAUGED STATION IN KUANTAN RIVER BASIN USING CLARK METHOD IN HEC-HMS

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ABSTRAK

Anggaran kadar alir dengan menggunakan simulasi hidrologik yang melibatkan model komputer adalah merupakan teknologi yang canggih dan cara ini mampu untuk meningkatkan pemahaman dan memberikan hasil yang lebih dipercayai. Pada masa kini, disebabkan oleh sumbangannya yang tidak dapat dinafikan, ia menjadi alat yang sangat diperlukan untuk mereka bentuk sebarang pendekatan pengurusan air ekologi yang mampan. 'US Army Corps of Engineers' telah mengambil inisiatif untuk membangunkan model yang stabil, HEC-HMS yang boleh digunakan untuk pelbagai simulasi hidrologi. Nilai parameter yang diperlukan untuk menyelesaikan simulasi pada asasnya bergantung kepada kaedah yang dipilih untuk kehilangan, mengubah dan aliran asas. Input data yang boleh dipercayai dan tepat diperlukan untuk memeriksa kesesuaian model untuk kawasan lokasi kajian dan tujuan penyelidikan jika tiada proses calibrate dan validasi.Walau bagaimanapun, dalam kajian ini, parameter model telah diubah dan penentukuran model dilakukan secara berasingan untuk ketiga-tiga kaedah terpilih, 'Soil Conservation Service Curve Number' bagi kaedah kehilangan, 'Constant Monthly' bagi kaedah aliran asas dan Clark Unit Hydrograph bagi kaedah transform untuk menentukan nilai parameter bagi simulasi yang paling sesuai dalam usaha untuk mendapatkan kadar aliran yang paling tinggi di setiap kawasan lembangan di Lembangan Sungai Kuantan. Langkah yang diambil setelah model yang dikalibrasi diperolehi adalah untuk menjalankan proses pengesahan untuk mengesahkan model hidrologi dan memastikan ia boleh digunakan untuk set hujan dan data aliran lain di kawasan itu untuk kejadian ribut hujan yang berlainan. Untuk setiap aliran yang disimulasi untuk proses pengesahan dan penentukuran, indeks Nash-Sutcliffe (NSE) digunakan sebagai kriteria untuk membandingkan hasil antara hidrograf daripada data asal dan simulasi. Model yang boleh diterima mempunyai rangkaian NSE di antara 0.8 hingga 1.0. Lebih dekat nilai NSE kepada 1, semakin tinggi keseragaman hidrograf simulasi dan data asal. Dalam proses penentukuran pertama, nilai NSE yang diperolehi adalah 0.81 untuk kejadian ribut pada 4 September 2010, nilai ini menunjukkan bahawa model itu dilakukan dengan baik dan cukup baik untuk digunakan. Untuk mengesahkan model yang dikalibrasi sebelum ini, proses pengesahan dilakukan dengan menggunakan set data aliran hujan dan aliran data yang berbeza dari proses penentukuran. Peristiwa hujan lebat pada 12 Oktober 2013 telah digunakan dan nilai NSE yang dikeluarkan adalah 0.91. Sebagai kaedah transformasi yang dipilih dalam kajian ini, Clark Unit Hydrograph menyelaraskan aliran dengan jayanya dan nilai parameternya mudah dan senang untuk dipenuhi. Oleh itu kaedah Clark Hydrograph dapat disyorkan sebagai kaedah transformasi terbaik untuk Lembangan Sungai Kuantan dengan 'Soil Conservation Service Curve Number' sebagai kaedah kehilangan. Oleh kerana terdapat banyak sungai yang tidak mempunyai rekod data kadar aliran yang terletak di Lembangan Sungai Kuantan, pendekatan ini boleh digunakan untuk mensimulasikan aliran sungai di kawasan-kawasan lain dengan ciri yang sama dan juga pendekatan penentukuran dan pengesahan yang sama boleh digunakan di bahagian lain kawasan tropika.

ABSTRACT

Estimating flow rate by using hydrologic simulation engaging computer model is at the cutting edge of ways to boost the understanding and provide further reliable outcomes. Nowadays, due to its undeniable contribution, it has become indispensable tools to design any ecologically sustainable water management approaches. US Army Corps of Engineers has taken an initiative to develop a stable and dependent model, HEC-HMS that could be used for many hydrological simulations. The value of parameter needed in order to complete the simulation basically depends on the method chosen for loss, transform and base flow. Reliable and precise data inputs needed to check suitability of the model for the study location area and the purpose of the research if there is no any calibrate and validate process. However, in this study, the model parameters were changed and the model calibration was performed separately for the three selected methods, the Soil Conservation Service Curve Number loss method, the Constant Monthly base flow and the Clark Unit Hydrograph for transform method to determine the most suitable simulation and to obtain the highest peak discharge for every sub basin in Kuantan River Basin. The step taken after obtaining the calibrated model is to run the validation process to validate the hydrologic model and ensure it can be used for other set of rainfall and flow data in that area for different event of rainstorms. For every flow simulated for validation and calibration process, the Nash-Sutcliffe index (NSE) was used as a criterion to compare the outcomes between observed and simulated hydrograph. The acceptable model has a range of NSE in between 0.8 to 1.0. Simply saying, the closer the value of NSE to 1, the higher the similarity of the simulated and observed hydrograph. In the first process of calibration, NSE value obtained is 0.81 for the rainstorm event of 4th September 2010, this value shows that the model is well performed and good enough to be used. In order to validate the calibrated model before, validation process was done using different data set of rainfall and stream flow from calibration process. Rainstorm event of 12th October 2013 was used and the value of NSE produced is 0.91. As the chosen transformation method in this study, Clark Unit Hydrograph simulates the flows successfully and the parameter value is easy and simple to be fulfilled. Therefore, the Clark Unit Hydrograph method could be recommended as the best transformation method for the Kuantan River Basin with the SCS Curve Number as the loss method. As there are plenty of ungauged rivers located in the Kuantan River Basin, this approach can reliably be applied in order to simulate river flows in the other areas with same characteristic and also the same approach of calibration and validation can be applied in other parts of the tropics.

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LIST OF SYMBOLS

A	Area of catchment involve
S	Average slope of that watercourse
L	Longest watercourse length in the watershed
Tc	Time of concentration
R	Storage coefficient
CN	Curve Number
Q_B	Baseflow
A_i	Area for *i*th land use type
CN_i	Curve Number for *i*th land use type
Y_i^{obs}	*i*th observed data
Y_i^{sim}	*i*th simulated data
Y_i^{mean}	Mean of observed data
n	Total number of observation data

LIST OF ABBREVIATIONS

KRB	Kuantan River Basin
DID	Department Of Irrigation And Drainage
HEC-HMS	Hydrologic Engineering Center- Hydrologic Mdelling System
GIS	Geographical Information System
ARI	Average Recurrence Interval
SWM	Southwest monsoon
NEM	Northeast monsoon
JUPEM	The Department Of Survey And Mapping Malaysia
LAT	Latitude
LONG	Longitude
DEM	Digital Elevation Model
SCS CN	Soil Conservation Service Curve Number
NSE	Nash-Sutcliffe index
WCN	Weighted Curve Number

CHAPTER 1

INTRODUCTION

1.1 Background of study

Flood events are often catastrophic leads to damages of physical and social life. From the past decades, increasing flood incidences have been observed due to variations in rainfall patterns, change climate condition. One of the main factors for occurring flood is rapid development in urban sector. Malaysia is vulnerable to flood for being its geographic location in the tropical region. The east coast part of Malaysia's flood often experiences flooding during the northeast monsoon season.

Kuantan is one of the flood vulnerable areas of peninsular Malaysia. Kuantan River Basin (KRB) is the important watershed passing through Kuantan. This basin is accountable for bring flood during the wet season by perceiving heavy rainfall fall resulting the spilling over the flow that inundate flood plain or low-laying areas causing intensified damages in terms of commercial, residential properties, roads, infrastructure, irrigation network. However, rapid development in river catchment also be responsible to produce high runoff and worsened river capability. Therefore, leads to increasing flood frequency and magnitude. According to Department of Irrigation and Drainage Malaysia (DID)'s flood reports, 2001/02, 2012/13 were the worst flood. Kuantan is expected to be worst since 1971 due to receive unexpected heavy rainfall, high tide in upstream and downstream (Zaidi et. al, 2014).

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1.2 Problem Statement

KRB has been chosen as study area. The important river of Pahang start from Sg. Lembing passing through Kuantan City and drained in to South China Sea. It covers an area of 1630km^2. The elevation range is from 0 at the mouth of watershed to 1511m in the remotest part of north-west watershed. KBR contains of several main tributaries, which drain the rural, agricultural, urban and industrial areas of Kuantan (Nasir et. al, 2012).

Since the past decades, KRB has history of experiencing the flood due to its tropical climatic condition. Inundation rain brings about spilling over of river surface runoff submerged low laying areas hampered human social and economic life. After 30 years of disastrous flood in 1971, the year 2001/02 experienced havoc flood with magnitude of 3.9 brought by continuous heavy rainfall during the northeast monsoon which hit most of the part of Peninsular Malaysia. Pahang was submerged under water after nearby rivers overflowed affected 18,000 people and 22,940km^2 of land (EKA, 2002). Right after 10 years, another worst flood condition in years 2011/12 crippled Kuantan. Sudden flood due to continuous massive rainfall affected relatively 6,000 flood victim reportedly; several roads were badly flooded, and hundreds of vehicles trapped in resulting of the poor drainage system that did not cope hefty rain (Kuala Lumpur Post, 2012). The unforeseen massive flood, recently in 2013 experienced due to prolonged heavy rainfall and land-use change brought serious peril to society, especially to low laying areas in Kuantan. Kuantan was severely afflicted. Around 14,044 people were evacuated and major damages occurred in terms of electricity, road's structure, buildings and belongings thus government suffered with significant financial cost for repairing flood damages (Jamaludin et. al, 2013). Torrential rain caused rise in level of river basin resulting increased outflow discharge.

In order to improvise the situation and prepared for an upcoming abrupt natural catastrophe, modelling system using HEC-HMS is designed to simulate hydrological data and precipitation run-off processes of watershed systems by cause of commonly used in a wide range areas.

1.3 Objective

To ensure this study is successful, two objectives have been determined. Both these objectives works as a guide line so that the outcomes of this study can be easily achieved. The objectives are:

a) To analyse hydrological data for gauged and ungauged station in Kuantan River Basin
b) To estimate the flow rate for every sub catchment area in Kuantan River using HEC-HMS

1.4 Scope of Study

The scopes of study have been determined in order to ensure that literature study is focusing on certain fields only. The limitations of this study are listed below:

1. Study area: The study area is focused on Sg Kuantan catchment area.

2. Simulation: The method used is simulating the river using gathered data from local authorities. A river network was established using Google satellite images data and GIS software. The analyses then were carried out using HEC-HMS. The simulating process was conducted to estimate the flow rate at out flow and compare with the stream flow data.

3. Method: Clark Unit Hydrograph was used for Transform Method and a simulation using 2, 5, 10, 20, 50 and 100 years of design rainfall (ARI) are done to obtain the peak discharge.

1.5 The Importance of Study

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

The modelling of the rainfall produces the flood hydrograph prediction which gives contribution to many aspects such as the hydrological planning and managing of flood event. The estimated rainfall also can be used as the guide in hydrologic design of rainfall runoff models, also makes us understand more about runoff generation process and study the factors affecting rainfall runoff which can lead to flood. Besides that, the rainfall-runoff relationship is important for hydrological analysis and design. The information generates from the study can provides information important for the regulate the increase volume of the runoff, flood events, evaluation and upgrade of existing hydraulic structure from the changing in the hydrological data and contributes to flood mitigation works process (Hilbert, 2015).

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. Hydrological study is important to control the uses of water, floods and water quality of the river in Malaysia. River play such an important role since its usage approaching 98 % compare to ground water, 2% in daily activities (Ismail, 2009).

Malaysia is known as one of the country that vulnerable to flood because of geographical location and tropical climatic condition. Global warming brings abnormal torrential rainfall, rise in sea level, which increased flood risk. Malaysia associating with 189 river basins (Mohammad, 2003). Usually, faces two monsoon periods (1) southwest monsoon (SWM); (2) northeast monsoon (NEM). NEM brings heavier rainfall. Kuantan River Basin (KRB) has chosen as study area, the important river of Pahang state passing Kuantan city and discharge into South China Sea.

KRB is one responsible factor of flooding as a result of prolonged heavy rainfall during NEM by producing surplus surface runoff that exceed from basin compensation capacity causing floods to low laying areas and hampered human social and economic life. KRB has experienced the flood in past period's incidences. It has been observed that, change climatic condition resulting abnormal rainfall pattern and perceiving anthropogenic activities following the change in flood nature and incidence getting more frequent with vary in concentration. Recently, the years 2001, 2011 and 2013 has been considered to perceive worst flood disaster after 1971 catastrophic event. According to Kuantan Municipal Council, the city is predicted to experience more extreme weather conditions in future that with change in rainfall (Zaidi et. al, 2014).

2.2 Hydrological Cycle

Hypothetically, flood in any area including Malaysia is caused by surplus amount of rainfall precipitation in a long period of time. The quintessential of hydrological or water cycle is to balance the ecosystem in order to evade natural disaster like flood and eventually when the ideal water cycle functions on the right line, the flood clearly can be prevented. Anyhow, there are few factors that may disturb the efficiency of water cycle and broke the water balance system. Since Malaysia received a few numbers of rainfalls annually, the water source condition is normally affected by weather conditions and natural water cycle (Strahler et. al, 1997). The water in the earth surface is evaporated to the atmosphere as vapour and the group of this water vapour in the atmosphere produced clouds which finally condensed and precipitate to the earth as rainfall. This process is known as precipitation (Syukri, 2009).

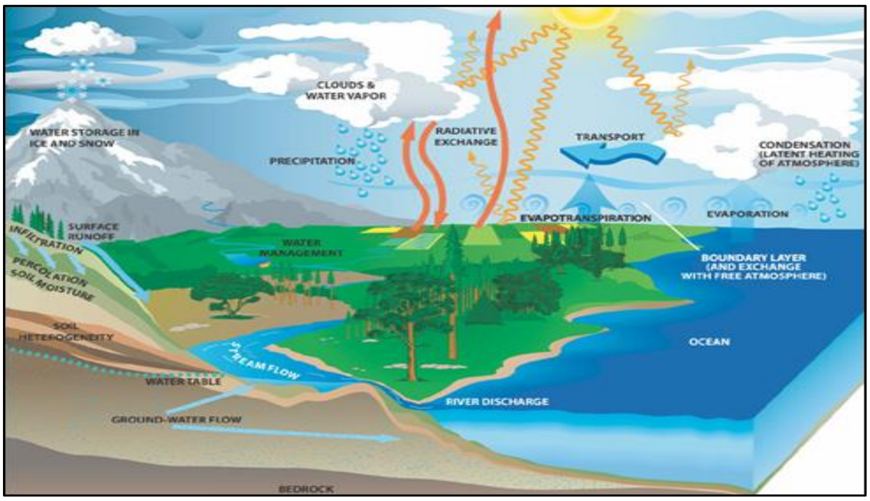


Figure 2.1 Hydrological cycle

Source: www.freshwaterinflow.org

2.3 Factors Influencing Flood

When the amount of precipitation is greater than the infiltration rate of the ground surface, runoff or overland flow will consecutively take place. The overland flow and the direct precipitation will enter the streams in an abundant amount. Inevitably, floods will occur as natural consequences. There is no consistency in the terms of amount and time which the precipitation takes place and in Malaysia, river is widely known as a number one water resource. There are several town and residential area that being developed in the widely flood plain area which is known as a hazardous area because of its potential to be flood by the water.

2.3.1 Precipitation

The most common factor of flooding is prolonged rainfall or precipitation. The ground will become saturated if the rains are continuously for a long time. Eventually when this event occurs, the soil will no longer be capable to store water, leading to increment of surface runoff. Rainwater will enter the streams rapidly compare to when the ground was not saturated and that surely leads to higher discharge levels and floods.

Likewise prolonged rainfall, short span of heavy rain can also be a sparked to floods. If there is an unexpected “burst” of heavy rain, the rainwater would not be able to infiltrate fast enough and the water will instead enter the river via surface runoff. This leads to a sudden and large increase in the river’s discharge which can result in a flash flood

Although many floods are triggered directly by precipitation just a few hours after it falls some floods can be triggered by precipitation that fell many months ago. When the stream flow for a catchment is combined with the precipitation, flood event will likely to occur. The evapotranspiration and evaporation has little influence of water balance at daily time scale compare to rainfall (L. Siriwardena et.al, 2005).

2.3.2 Urbanization

Urbanization is listed as next factor that contributed to the flood event. Logically, the infiltration rate in the urban area is drastically limited as most of the areas are being covered with concrete. As new developments cover previously permeable ground, the amount of rainwater running off the surface into drains and sewers increases dramatically. Developments encroach floodplains, obstructing floodway and causing loss of natural flood storage. Continuous development and redevelopment to higher density land uses by high land costs. The proportion of impermeable ground in existing developments is increasing as people build patios and pave over front gardens. Chan (1997) stated that the risk of flash flooding has increased because of constructing buildings, road, which heads to the impervious surface. The accretion of impervious due to increasing development densities means more run-offs (Singh and Singh, 2011).

Some of the major hydrological effects of urbanization are: (1) increased water demand, often exceeding the available natural resources; (2) increased wastewater, burdening rivers and lakes and endangering the ecology; (3) increased peak flow; (4) reduced infiltration and (5) reduced groundwater recharge, increased use of groundwater, and diminishing base flow of streams. According to natural hydrological phenomena, due to increased impervious area precipitation responds quickly reducing the time to peak and producing higher peak flows in the drainage channels (Mukherjee, 2016).

2.3.3 River Cross Section

Other factor that affects the flood is river cross section. The stable relations of velocity, depth, width, and slope to discharge at a given cross section of a river in a sub-humid environment imply a relatively stable stream bed. Yet it is obvious that channel changes do occur, the existence of flood plains and other river constructed features indicate that the river channel migrates widely in short periods of time, geologically speaking .The discharge value is varying with channel depth, width and gradient. Stream flows get deeper and faster as a discharge increase. In the other words, the flood power is depended on the river section. During heavy rainfall, the stage and discharge increase and the depth of flow are assumed to be negligible since the width-depth ratio is too small. The rates of change in mean depth and velocity are greater than change in width. Thus, the increase in discharge is directly proportional to the depth which influences the river to flow in high velocity and causing overflow or in the other words, flood. The fact is, the river is more effective with depth compare to the width (Vishwas and Pramodkumar, 2002).

2.4 River Catchment

The river catchment or drainage basin as all the land from the mountain to seashore, drained by a single river and its tributaries. Catchment areas vary greatly in size. A big river may have catchment area of several thousand square kilometers, whereas a smaller tributary will have a catchment area of only a few hectares. When the vegetation clearing took place at the river catchment area, this tending to offset increases in runoff as well as a postulated increase in the natural storage capacity within the catchment which would add to this effect (L.Siriwardena et. al, 2005)

2.5 Catchment factors

The catchment is the most significant factor determining the amount or like hood of flooding. Catchment factors are:

- Topography shape
- Size
- Soil type
- Land use

Catchment topography and shape can be determined as the time taken from rain to reach the river, catchment size, soil type and development determine the amount of water to reach river (Vishwas and Pramodkumar , 2002).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the method of running the study according to the best technique. All the concept of study, tools that were used, information data needed and suitable techniques will be clarified. Several approaches were taken into consideration throughout the study during planning and implementing the identified works to ensure study could be conducted smoothly.

First phase is the planning where a field study is required to make the research smooth. The second step was literature based review. In this stage, the technique for combining the ideas from the previous journal as reference was needed and a lot of studies were conducted. The most crucial part in this study was to figure out the best option in running the research. Next approach involve collecting data and information needed followed by the implementation of study techniques. Research area of concerned was around the catchment areas of Sungai Kuantan and the river simulations were carried out using HEC-HMS. The conclusion of overall process needs to be carried out for this study was being indicated in Figure 3.1.

3.2 Research Methodology

There are few steps needed to determine the methodology used for the research and they included:

- Set up a modelling including the main river system and basin/catchment area regarding the hydrological input.

- Insert the data for the parameter needed.

- Run the simulation.

- Get the estimated flow rate at out flow and compare with the stream flow data.

3.3 Flowchart of Methodology

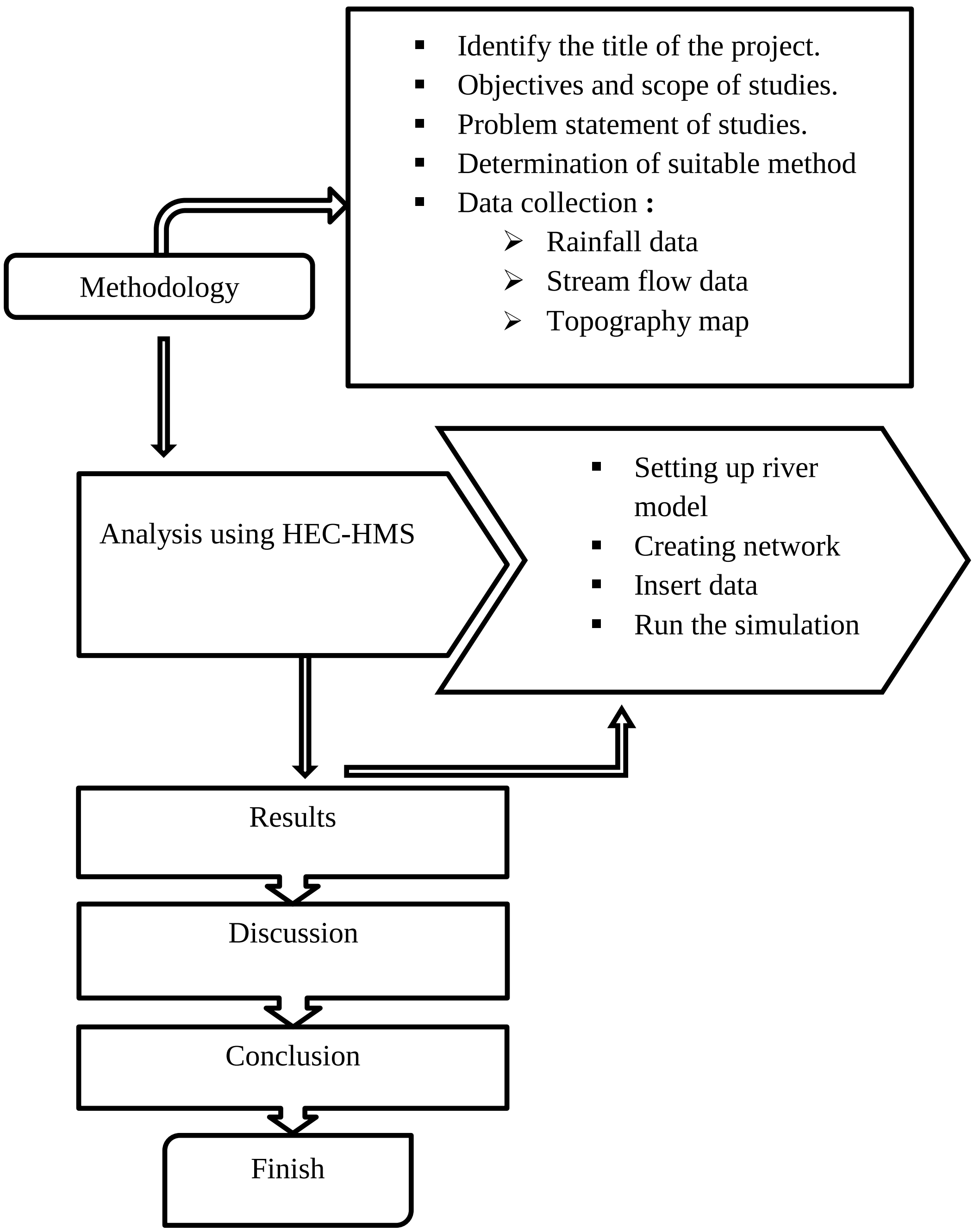


Figure 3.1 Overall processed involved in the research

3.4 Hydrological Data

For this study, the rainfall data obtained from the eight rainfall station while the stream flow data obtained from only one station. Although this is an ungauged catchment, data collection is still needed to predict the stream flow of the catchment area. HEC-HMS is used as a tool for creating hydrologic modelling of the main river and the secondary tributaries along the catchment area. The data used for HEC-HMS and its source are shown in Table 3.1.

Table 3.1 Data for HEC-HMS and the sources

Data	Sources
a. Rainfall	The Department Of Irrigation And Drainage (DID)
b. Streamflow	The Department Of Irrigation And Drainage (DID)
c. Topography	The Department Of Survey And Mapping Malaysia (JUPEM)

3.4.1 Rainfall Data

The rainfall data for this study was obtained from The Department of Irrigation and Drainage (DID). The rainfall data is available from year 2000 to year 2016. In order to achieve the definite estimation of the spatial distribution of rainfall, it is necessary to use interpolation methods. In this case, the Thiessen method was used. The rainfall data is collected from the eight rainfall station that is located within Kuantan River Basin. The Thiessen Polygon Method is being implemented to determine each rainfall station that will influenced the discharge result for every sub basin as shown in Figure 3.2**.** While Table 3.2 below shows the rainfall station used for every sub basin that being determined using Thiessen Polygon Method.

Table 3.2 Rainfall station for every sub basin

Rainfall station		**Sub basin**
Sg Lembing PCLL	3930012	Sg. Hulu Kuantan Sg Kenau
Ladang Nada	3931013	Sg Nada Sg Caru Sg Reman
Ladang Reman	3931014	Sg Panching Sg Gading
Pam Paya Pinang	3832015	Sg Pinang Sg Riau
Sk Gambang	3731018	Sg Pandan Sg Belat

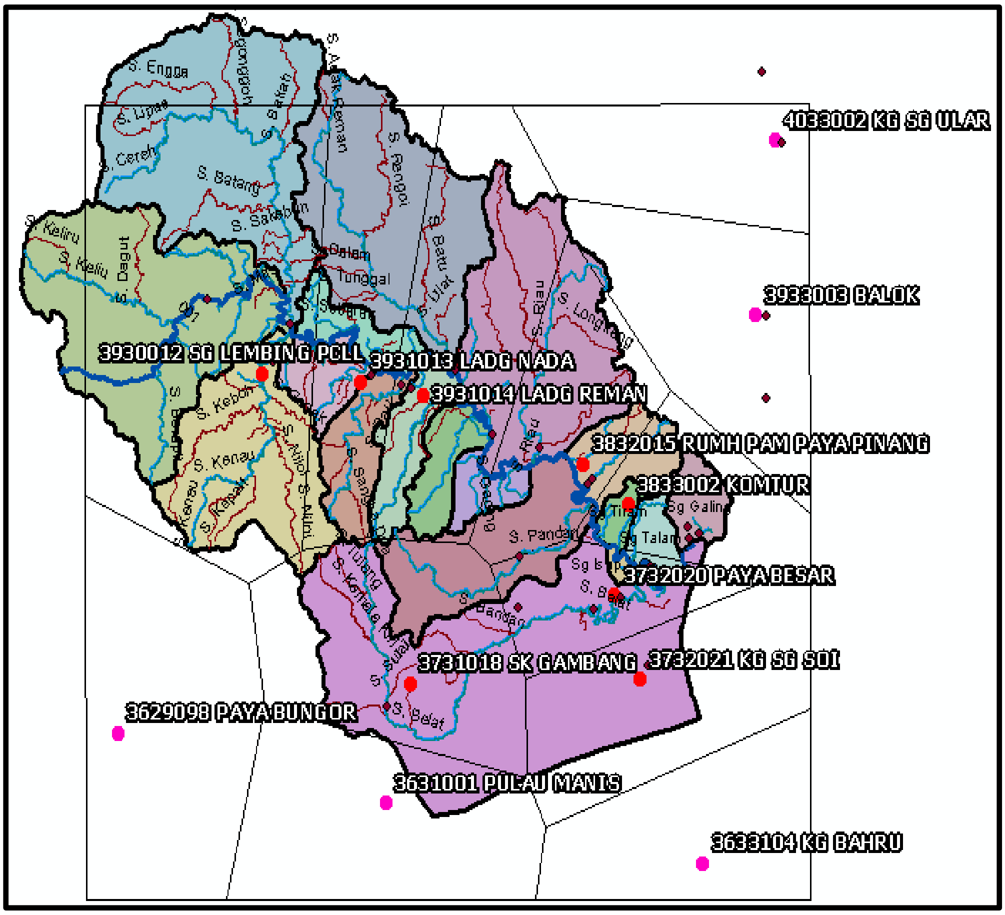


Figure 3.2 Thiessen Polygon for Kuantan River Basin

Selected rainfall stations are based on data availability for the selected storm events, percentage of missing data and the location of stations for accurate representation of the entire catchment area. The data taken is due to its availability for the research study. The sample data rainfall can be referred to **Appendix A.** Table 3.3 shows the name and rainfall station that located in Kuantan River Basin.

Table 3.3 Rainfall Station use in HEC-HMS Model

<table>
<tr><th rowspan="2">No</th><th rowspan="2">Station ID</th><th rowspan="2">Name of Station</th><th colspan="2">Coordinate</th></tr>
<tr><th>LAT</th><th>LONG</th></tr>
<tr><td>1</td><td>3732020</td><td>Paya Besar, Kuantan

</td><td>03 46 28</td><td>103 16 50</td></tr>
<tr><td>2</td><td>3931013</td><td>Ladang Nada

</td><td>03 54 18</td><td>103 06 08</td></tr>
<tr><td>3</td><td>3731018</td><td>SK Gambang</td><td>03 43 14</td><td>103 08 10</td></tr>
</table>

				
4	3833002	Pej. Jabatan Negeri Pahang 	03 49 47	103 17 24
5	3832015	Rumah Pam Paya Pinang 	03 51 16	103 15 31
6	3930012	Sg. Lembing PCCL MILL	03 54 37	103 01 58

				
7	3931014	Ladang Kuala Reman 	03 53 46	103 08 45
8	3732021	Kg. Sungai Soi 	03 43 23	103 17 54

However, due to many missing data in other rainfall stations for the particular date that being used as simulation date, the rainfall data from 3930013 Sg Kuantan @ Bukit Kenau station was used for other sub basins as well.

3.4.2 Streamflow Data

The streamflow data for this study was obtained from The Department of Irrigation and Drainage (DID). The streamflow data is available from year 1975 to year 2016. For this study, only one streamflow data that being used and the data will be used to compare with the simulated data produced by the river simulation. Table 3.4 shows the name and streamflow station use in HEC-HMS model. And since there is only one gauged station, so there is only one streamflow data and the data taken is from station 3930013 Sg Kuantan @ Bukit Kenau. The streamflow data acted as observed hydrograph in the analysis run in HEC-HMS. The other value needed for parameter in Clark Hydrograph Unit for Transform Method is manually adjusted using this data as a benchmark.

Table 3.4 Streamflow Station use in HEC-HMS Model

Station No	Station Name
3930013 	Sg. Kuantan @ Bukit Kenau

3.4.3 Predicted Data and Assumption Data

The predicted data and assumption data are curve number (CN), initial abstraction and degree of impervious that used to predict conditions during simulation's result hypothesis. Sometimes, the assumption's data must be used because of the absence of data.

3.5 River Modelling

Software identifies to undertake this research was HEC-HMS. This software is capable in running simulation for open and closed channel including taking into the structure present in the rivers. The flow chart of simulating the river is shown in Figure 3.3.

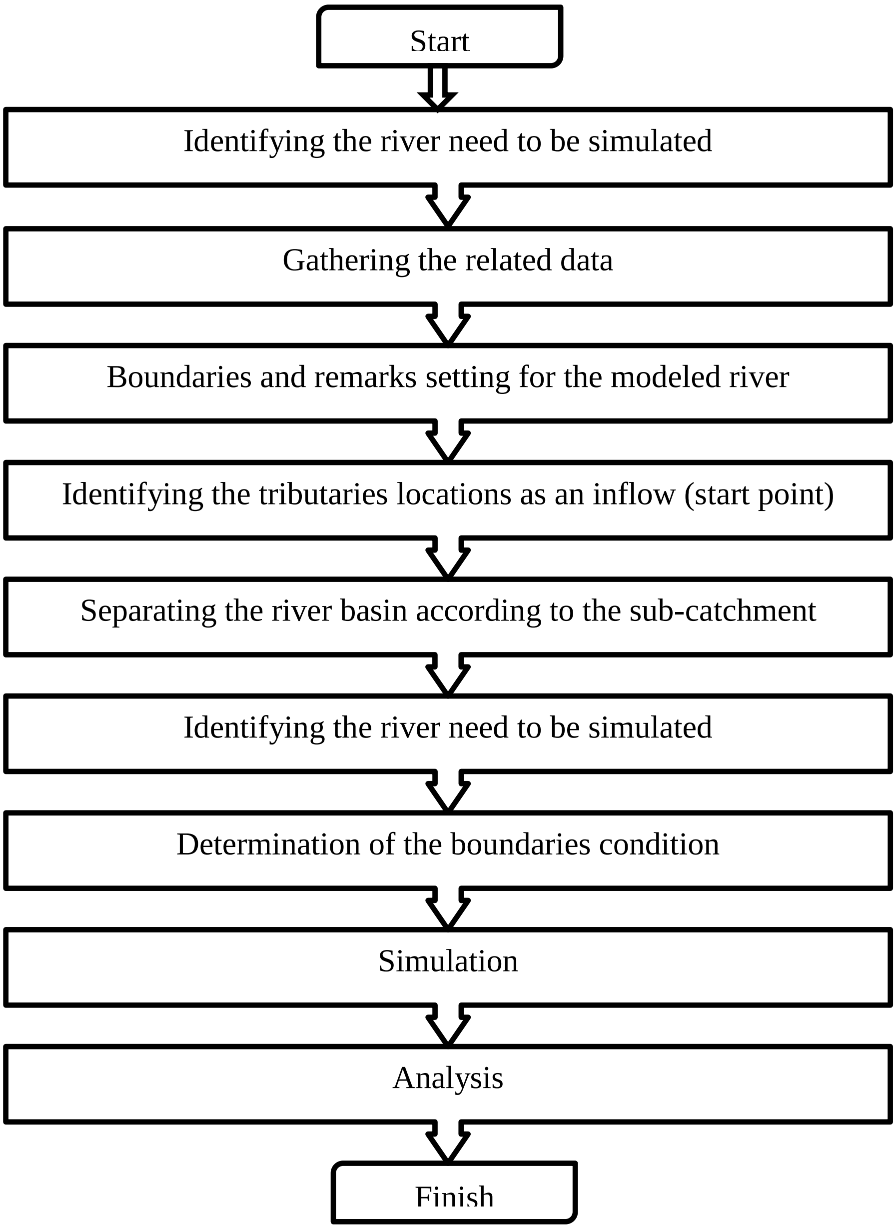


Figure 3.3 Main process flow of river modelling using HEC-HMS

HEC-HMS (Hydrologic Engineering Centre - Hydrologic Modelling System) model was developed by the US Army Corps of Engineers that could be used for many hydrological simulations. It is designed to simulate the precipitation-runoff processes of dendritic watershed systems and applicable in a wide range of geographic area for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff (Scharffenberg, 2013).

According to Kalita, the proliferation of personal computers and the development of the HEC-1 model of the U.S. Army Corps of Engineers in 1998 to a GUI (graphical user interface) based user-friendly HEC-HMS model is available in the public domain, have come as another useful tool to the field hydrologists. Unfortunately, the HEC-HMS model, or any of the many watershed models for that matter, has not found many takers due to the uncertainty involved in the estimation of parameters of the models. But, parameter estimation on a regional scale at least may be possible to switch over to watershed models like the HEC-HMS and take advantage of the high speed computer programs than spreadsheet exercises (2008).

The HEC-HMS contains four main components. 1) An analytical model to calculate overland flow runoff as well as channel routing, 2) an advanced graphical user interface illustrating hydrologic system components with interactive features, 3) a system for storing and managing data, specifically large, time variable data sets, and 4) a means for displaying and reporting model outputs (Bajwa and Tim, 2002). Any hydrological model need to be going through the process of calibration and validation with the respect to local observational data to check and ensure the suitability of the model with any other runoff and streamflow data and improved the model predictability at once (Muthukrishnan and Harbor, 2006).

3.5.1 Model Setup

ArcGIS 10.3 is used for pre-processing the collected data for the study area: land use data (from the Department of Survey and Mapping Malaysia, JUPEM). From the raw data like digital elevation model (DEM), several processes were being carried out in this software to extract the model-specific information from it. On the basis of elevation geometric algorithms, there are few hydrologic parameters that were computed such as river lengths, longest flow path, curve number (Gyori and Haidu, 2011), slope and the whole and even sub basin area.

After the particular information regarding the basin area has been obtained, the basin images will be converted to AutoCAD format. In AutoCAD software, the format will be converted to AutoCAD interchange file or “dfx” file type to enable it to be imported into HEC-HMS. This file will serve as the background map and ease the process of constructing the components like sub basin, reach, and also junction. The configuration of HEC-HMS for Kuantan River Basin is depicted in Figure 3.4.

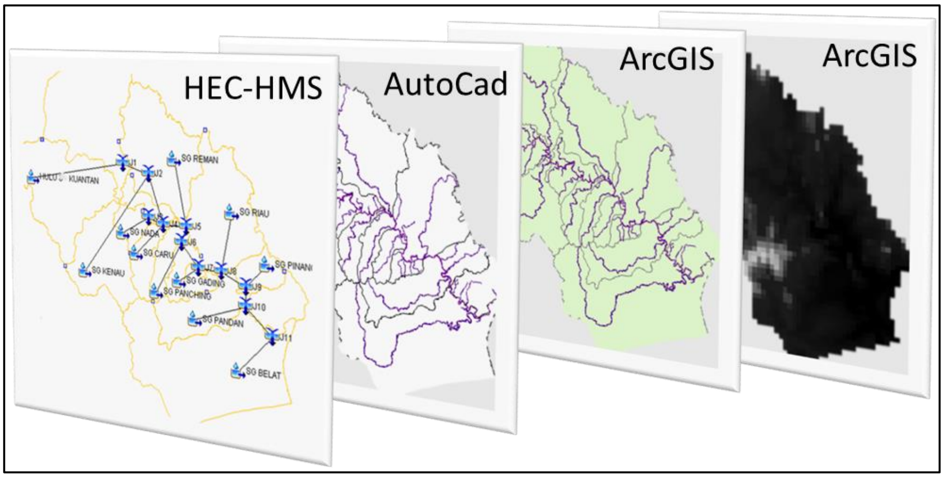


Figure 3.4 The steps on how KRB background map were produced

3.5.2 Model parameter

It is undeniable that parameter is one of the important matter that need to be taken into an account when running a hydrological model as this will affect the outcome to get the best fit result. The methods used for Kuantan River basin are SCS Curve Number, Clark Unit Hydrograph and Constant Monthly for Loss, Transform and Baseflow Method consecutively as shown in the Figure 3.5 below:

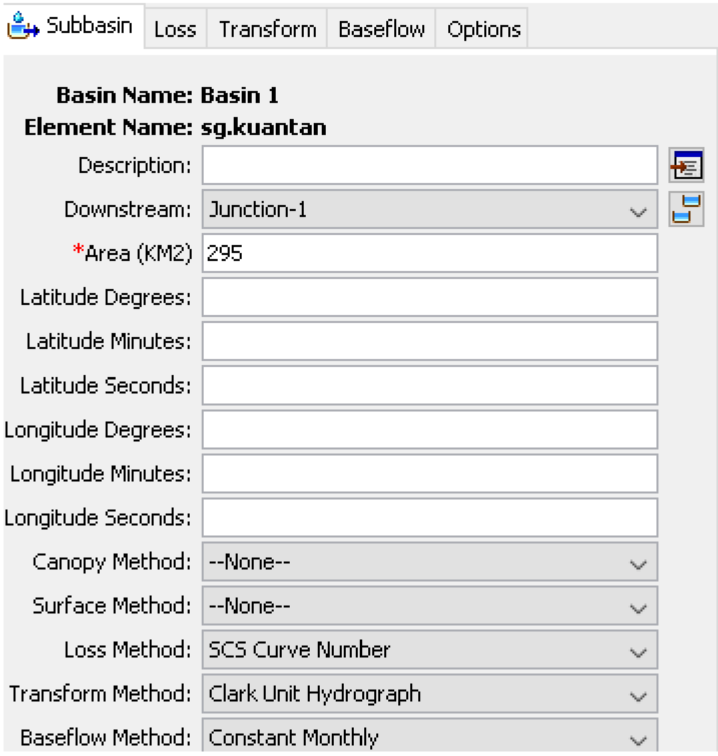


Figure 3.5 Method selected to be used in HEC-HMS

3.5.2.1 Loss Method

A total of eleven different loss methods are provided in HEC-HMS and some of these methods are designed primarily for simulating events, while others are intended for continuous simulation. Gridded Loss Methods and Soil Moisture Accounting Loss Methods are not preferred for the simulation studies because they require a high number of parameters. Among the remaining loss methods, the simplest one “SCS Curve Number” method is selected for the event based simulation studies. The method is simple and practical because it requires only three input parameters such as initial abstraction (mm), Curve Number and impervious (%) as shown below in Figure 3.6:

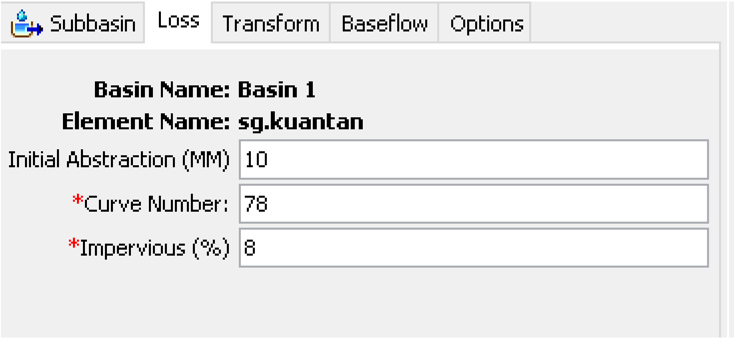


Figure 3.6 Parameter that need to be filled up for SCS Curve number as Loss Method

i. Initial abstraction or loss basically is the value to account for interception and depression storage. Eventually, there is no runoff occurs from the previous areas until this quantity of precipitation has fallen.

ii. Curve numbers were obtained from the map produced in the previous research study Rainfall Runoff Simulation Using Slope Adjusted Curve Number (CN) in Kuantan river basin by Amir Aizat Bin Jamil, July 2015 as shown in the Figure 3.7 and Table 3.5 below:

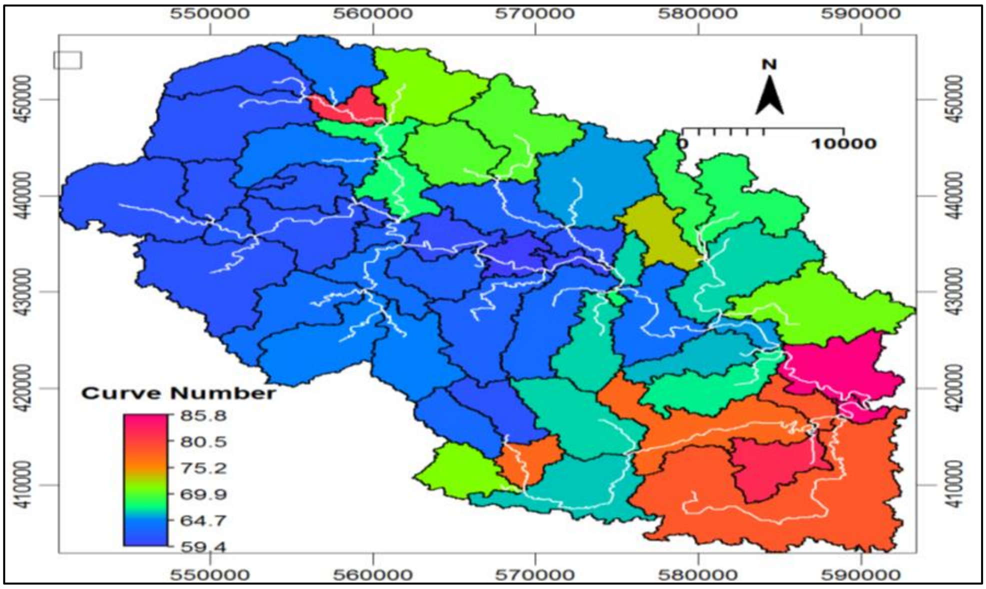


Figure 3.7 Averaged CN in sub basin of KRB

Table 3.5 List of CN used in this study

Sub basin	Curve Number (CN)
Sg Kuantan	59.4
Sg Kenau	64.7
Sg Nada	60
Sg Caru	64.7
Sg Reman	69.9
Sg Panching	64.7
Sg Gading	64.7
Sg Riau	68
Sg Pinang	69.9
Sg Pandan	65
Sg Belat	76

iii. Impervious area in percentage is represents the friction of the area that is impervious such as paved area, asphalt and concrete, rooftops and others. The guidelines on how to estimate the percentage value of impervious can be obtained in the USDA Natural Resources Service's TR-55, Urban Hydrology for Small Watersheds. The range of impervious value used is this study is between 5 until 13.

3.5.2.2 Transform Method

Next, in the total of seven different transformation methods that being provided in HEC-HMS, Clark Unit Hydrograph is the one that being selected as this has the simplest requirement to be fulfilled since some of the others method are complicated which request more inputs and data that difficult to be obtained. The Clark unit hydrograph is a synthetic unit hydrograph method. That is, the user is not required to develop a unit hydrograph through the analysis of the past observations. Instead a time versus area curve built into the program is used to develop the translation hydrograph resulting from a burst of precipitation. The resulting translation hydrograph is routed through a linear reservoir to account for the storage attenuation across the sub-basin (Halwatura, 2013).

The hydrograph parameters can be related to catchment characteristics from which the parameters are derived. These methods can be applied to ungauged catchments with similar hydrologic conditions (Hydrological Procedure No. 27, 2010). Previously, according to Cunderlik and Simonovic in 2010, Clark Unit Hydrograph is the methods that have been applied successfully to simulate long term stream flows elsewhere. It is shown here in Figure 3.8 the value for parameters that needed for transform method.

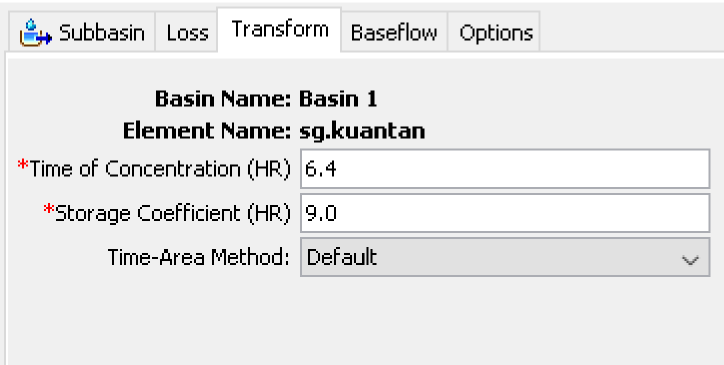


Figure 3.8 The value for parameters that needed for Transform Method

Time of concentration (Tc) is a fundamental watershed parameter. It is used to compute the peak discharge for a watershed. The peak discharge is a function of the rainfall intensity, which is based on the time of concentration. Time of concentration is the longest time required for a particle to travel from the watershed divide to the watershed outlet. The equations used for calculation time of concentration require inputs for the area (A), longest watercourse length in the watershed (L) and the average slope of that watercourse (S) .The equation is obtained from the Hydrological Procedure No. 27 (Estimation of Design Flood Hydrograph Using Clark Method for Rural Catchments). Equation 4.1 is shown as below:

$$Tc = 2.32\, A^{-0.1188}\, L^{0.9573}\, S^{-0.5074} \qquad 3.1$$

Storage coefficient (R) equation is also obtained from Hydrological Procedure No 27 (Estimation of Design Flood Hydrograph Using Clark Method for Rural Catchments). The equations used for storage coefficient require inputs for the area (A), longest watercourse length in the watershed (L) and the average slope of that watercourse (S) Most of the results revealed that the optimized Tc and R are very close with calculated Tc and R. Below is the equation of R:

$$R = 2.976\, A^{-0.1943}\, L^{0.9995}\, S^{-0.4588} \qquad 3.2$$

3.5.2.3 Baseflow Method

There are five methods for Baseflow like Recession, Bounded Recession, Linear Reservoir, Nonlinear Boussinesq and Constant Monthly. The method used in this study is Constant monthly. Figure 4.6 shows an example of value for parameter used in Sg Kuantan sub basin.

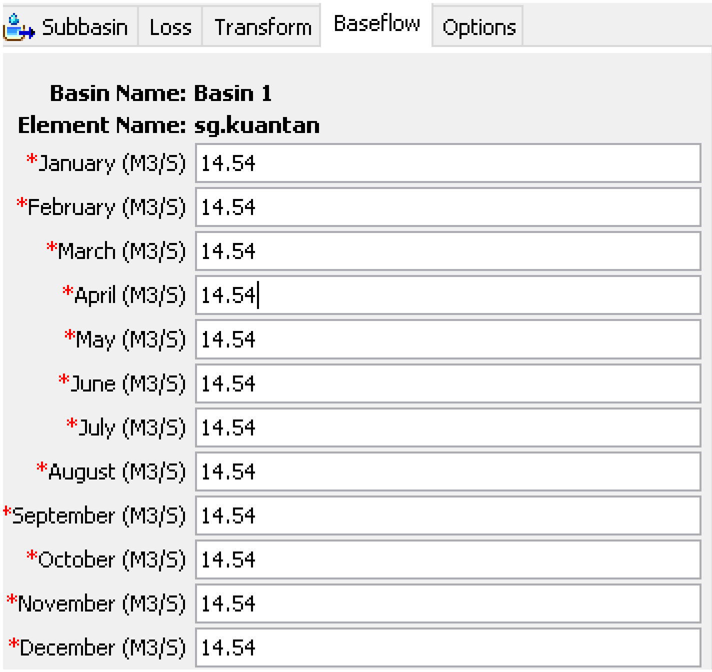


Figure 3.9 Constant baseflow for Sg. Kuantan sub basin

Below is the equation used to gain the value of baseflow for every sub basin with referencing to Hydrological Procedure No 27 (Estimation of Design Flood Hydrograph Using Clark Method for Rural Catchments).

$$Q_B = 0.11 A^{0.85889} \tag{3.3}$$

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 Introduction

In this chapter, all the data collected was analysed in order to achieve the research objectives. There are eight rainfall stations and one stream flow gauging station that were selected for this research purposes. The data was keyed in into the HEC-HMS software to be analysed using SCS Curve Number and Clark Unit Hydrograph for loss and transform method consecutively.

Generally, from the graph result of analysis, the shape of the modelled hydrograph will follows the observed hydrograph. Rainfall and runoff data in two storm event were being used to calibrate and validate the model. At last, the summary is produced to summarize the results and finding of this study.

4.2 Simulation with HEC-HMS

The model evaluation procedure included sensitivity analysis, calibration and validation. This process is carried out based on the parameters and data that have been entered previously. Figure 4.1 shows successfully run simulation in HEC-HMS.

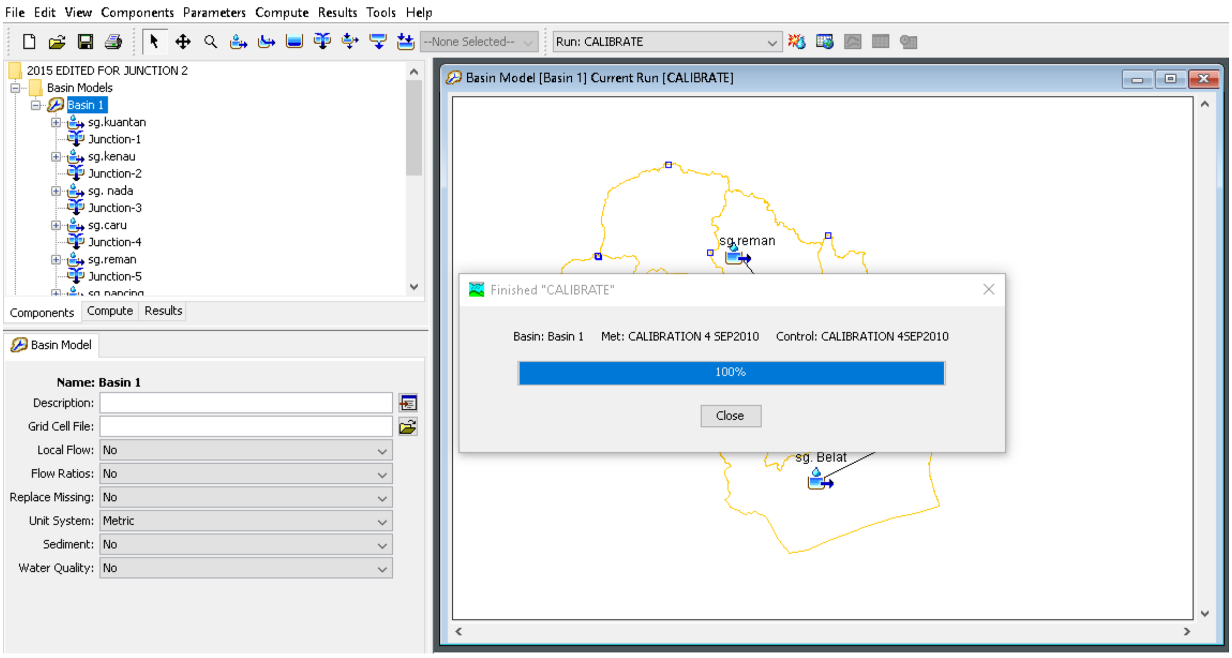


Figure 4.1 Successfully runs simulation

4.2.1 Sensitivity Analysis

. The sensitivity analysis of the model was performed to determine the important parameters which needed to be precisely estimated to make accurate prediction of basin yield. Thus, at first the model was run with the model input values (the base data file), estimated by methods presented above and base output was collected (Roy et.al, 2013). Table 4.1 shows the model parameter value during the first simulation.

Table 4.1 Value of parameters used in first simulation

Sub basin	Area (km^2)	Length (km)	Slope (m/km)	R (hr)	T_C (hr)	Baseflow (m^3/s)	Curve No.	Impervious
Hulu Sg Kuantan	295	32	6.30	13.11	12.42	14.54	59	10
Sg Kenau	136	24.3	33.74	5.53	4.60	7.47	65	10
Sg Nada	30	8.2	24.39	2.91	2.29	2.05	60	10
Sg Caru	41	18.9	16.93	7.44	5.91	2.70	65	10
Sg Reman	176	33.6	7.14	14.83	13.39	9.33	70	10
Sg Panching	39	15	29.33	4.65	3.61	2.55	65	10
Sg Gading	25	3.8	5.26	2.82	2.44	1.76	65	10
Sg Riau	164	21.9	4.57	12.04	11.24	8.78	68	5
Sg Pinang	35	8.6	11.63	4.16	3.44	2.33	70	13
Sg Pandan	66	25.7	10.90	11.30	9.39	4.04	65	10
Sg Belat	298	52.6	8.75	19.10	17.43	14.67	76	5

4.2.2 Model Calibration

After first simulation, calibration process was done. The process is varying each input parameter within prescribed range keeping the others constant and running the model. The output values were analysed to determine their variations with respect to the base output set and this is a measure of the sensitivity. The model was calibrated for the identified sensitive parameters to improve the agreement between the simulated and observed data (Roy et.al, 2013).

In this study, the hydrology model is calibrated using one storm event. The calibration process took place using event of storm on 04 September 2010 at 6.45 pm until 07 September 2010, 12.00 am and this streamflow and runoff data for this event can be seen in **Appendix A**. This is due to confirm the suitability of the assumed value for the parameter in the Kuantan River basin. The value for the observed streamflow data is being compared in Junction 2. So the sub basins that directly involved in calibration process are Sg Kuantan and Sg. Kenau. Below is the Figure 4.2 that clearly shows the direct involvement of these two sub basin towards the output value of Junction 2.

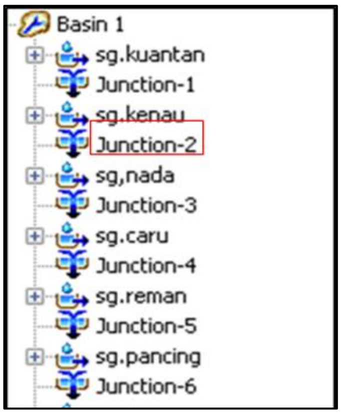


Figure 4.2 The sequence of the sub basin in Kuantan River Basin

The initial step in model calibration is a manual adjustment of model parameters using the trial-and-error method, which enables the modeler to make a subjective adjustment of parameters that gives an appropriate fit between observed and simulated hydrographs (Skhakhfa & Ouerdachi, 2016). The value of parameter for loss and transform method for both sub basins Sg. Hulu Kuantan and Sg Kenau are manually adjusted during simulation up until the hydrograph for observed and simulation obtained the similarity of the shape. The rests of the sub basin that are ungauged was adjusted using Weighted Area Method.

Manual adjustment of Curve Number (CN) was using the Weighted Area Method which based on different land uses in the study area. Calculation of weighted curve number (WCN) is shown by Equation 4.1:

$$WCN = \frac{\sum_{i=1}^{i=n} CN_i \cdot A_i}{\sum_{i=1}^{i=n} A_i} \qquad 4.1$$

Where, WCN is weighted curve number, A_i is area for ith land use type and CN_i is curve number for ith land use type. Calculated weighted curve number was used in the calibration of the model and was changed consecutively. The model simulation was performed for each curve number separately in order to find the most suitable curve number for the study area (Halwatura, 2013). The exactly same step of weighted area method is being applied for Time of Concentration (Tc) and Storage Coefficient (R) in this calibration process. Table 4.2**,** Table 4.3 and Table 4.4 below shows the parameter value of CN, Tc and R that has been modified using Weighted Area Method.

Table 4.2 Value of CN after being modified using Weighted Area Method

Sub Basin	**Area (km^2)**	**CN**	**Changes in CN value**	**New CN**	
Hulu Sg Kuantan	294.7765	59.4	18.6	78	Calibrate
Sg Kenau	135.8272	64.7	10.3	75	
Sg Nada	30.1051	60	2.28	62.3	Weighted Area Method
Sg Caru	41.3915	64.7	3.14	67.8	
Sg Reman	175.9794	69.9	13.34	83.2	
Sg Panching	38.8978	64.7	2.95	67.6	
Sg Gading	25.1832	64.7	1.91	66.6	
Sg Riau	163.9292	68	12.43	80.4	
Sg Pinang	35.0424	69.9	2.66	72.6	
Sg Pandan	66.3251	65	5.03	70.0	
Sg Belat	297.9032	76	22.59	85.8	

Table 4.3 Value of Tc after being modified using Weighted Area Method

Sub Basin	Area (km^2)	Tc	Changes in Tc value	New Tc	
Hulu Sg Kuantan	294.7765	12.42	6.02	6.4	Calibrate
Sg Kenau	135.8272	4.6	0.2	4.4	
Sg Nada	30.1051	2.29	0.04	2.3	Weighted Area Method
Sg Caru	41.3915	5.91	0.06	6.0	
Sg Reman	175.9794	13.39	0.26	13.6	
Sg Panching	38.8978	3.61	0.06	3.7	
Sg Gading	25.1832	2.44	0.04	2.5	
Sg Riau	163.9292	11.24	0.24	11.5	
Sg Pinang	35.0424	3.44	0.05	3.5	
Sg Pandan	66.3251	9.39	0.10	9.5	
Sg Belat	297.9032	17.43	0.44	17.9	

Table 4.4 Value of R after being modified using Weighted Area Method

Sub Basin	Area (km^2)	R	Changes in R value	New R	
Hulu Sg Kuantan	294.7765	13.11	4.11	9	Calibrate
Sg Kenau	135.8272	5.53	1.47	7	
Sg Nada	30.1051	2.91	0.33	3.24	Weighted Area Method
Sg Caru	41.3915	7.44	0.45	7.89	
Sg Reman	175.9794	14.83	1.90	16.73	
Sg Panching	38.8978	4.65	0.42	5.07	
Sg Gading	25.1832	2.82	0.27	3.09	
Sg Riau	163.9292	12.04	1.77	13.81	
Sg Pinang	35.0424	4.16	0.38	4.54	
Sg Pandan	66.3251	11.3	0.72	12.02	
Sg Belat	297.9032	19.1	3.22	22.32	

Numerous fit of statistical criteria is proposed in the literature for evaluating hydrological modeling results. In this study, the Nash-Sutcliffe index (Nash and Sutcliffe, 1970) is used as the criteria to compare the result between observed and simulated hydrograph. The ASCE Watershed Management Committee (ASCE 1993) recommends the Nash-Sutcliffe index for evaluation of rainfall runoff models. When the Nash Sutcliffe model efficiency coefficient is between 0 and 1, the model does better than simply forecasting. The closer the Nash Sutcliffe model efficiency coefficient to 1, the better the performance of the model (Nandalal & Ratnayake, 2010). Nash Sutcliffe model efficiency coefficient is defined as:

$$\text{NSE}=1-\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{mean}\right)^2}\right] \qquad 4.2$$

Where:

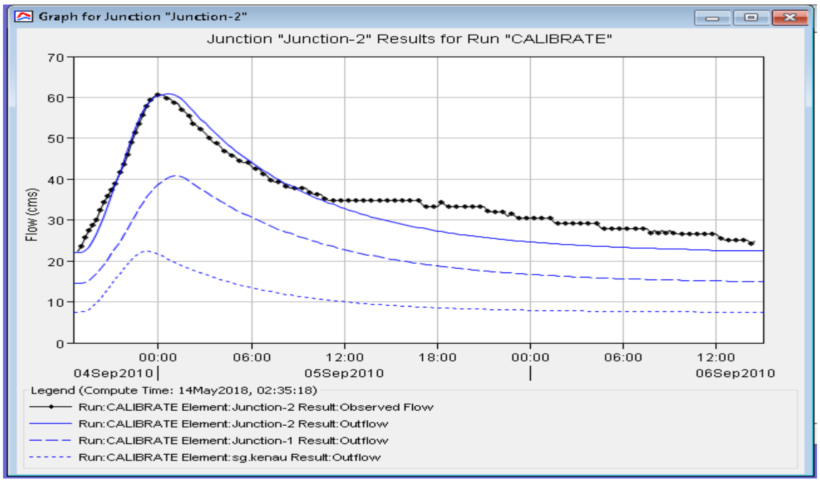
Y_i^{obs} = *i*th data being evaluated,

Y_i^{sim} = *i*th simulated data

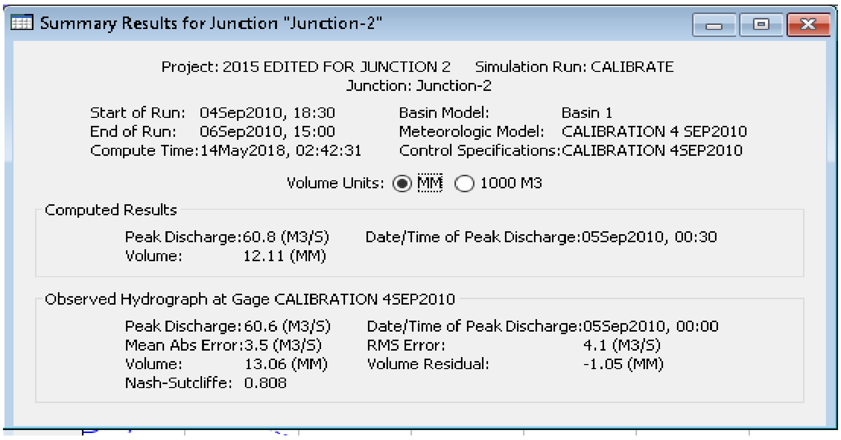
Y^{mean} = mean of observed data

n = total number of observations

Figure 4.3 a-b below shows the generated hydrograph resulted after the calibration process and the summary result of Junction 2:



(a)



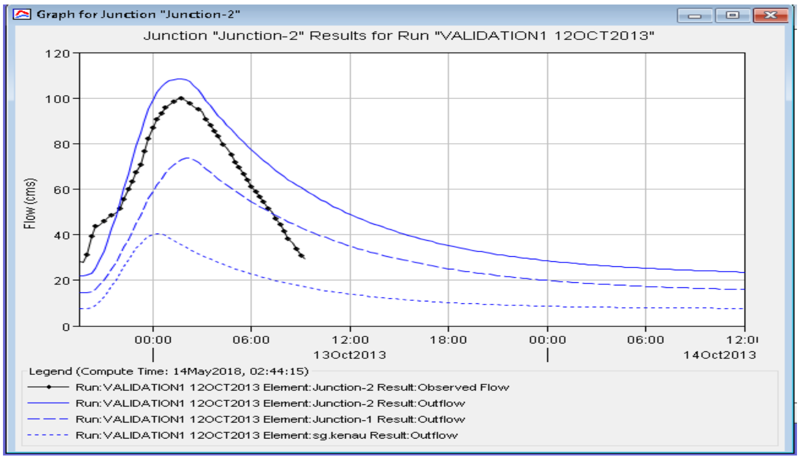
(b)

Figure 4.3 Calibration Result (a) Simulated and observed hydrograph after calibration process in Junction 2, (b) Summary result for calibration for Junction 2

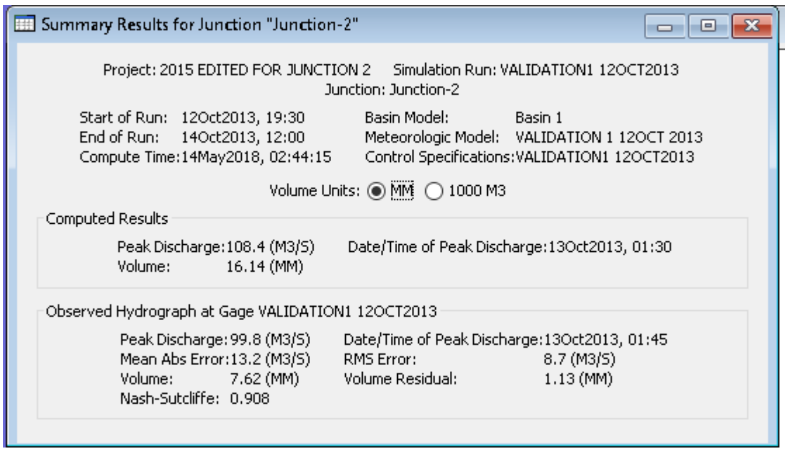
From the computed results, the shape of the observed hydrograph is represented by black dotted line and simulated hydrograph by continuous blue line. There are not much of differences between these two shapes of hydrograph and almost reach the perfect similarity. Both the maximum observed and simulated discharges in Junction 2 are 60.6m^3/s and 60.8m^3/s respectively. The model shows a good performance since the Nash-Sutcliffe value is 0.808, higher than the requirement value of 0.8 and almost to 1.0.

4.2.3 Model Validation

For the validation process, the generated hydrograph is compared with the observed discharge graph due to confirmation of the suitability assumed values in calibration process. The calibrated model parameters are validated using the different runoff and streamflow data. The data used is the storm event of 12th October 2013 at 7.30 pm up to 13th October 2013, 8.15 pm. The completed dataset of streamflow and runoff for this event is shown in the **Appendix B.** The simulated and observed hydrograph comparisons will show there are good agreements between them. Figure 4.4 a-b below shows the generated hydrograph resulted after the validation process and the summary result of Junction 2:



(a)



(b)

Figure 4.4 Validation Result (a) Simulated and observed hydrograph after Validation process in Junction 2, (b) Summary result for Validation at Junction 2

From the computed results, the shape of the observed hydrograph is represented by black dotted line and simulated hydrograph by continuous blue line. The shape of the hydrograph is almost similar and the simulated hydrograph shows a higher set of value than the observed. Both the maximum observed and simulated discharges in Junction 2 are $99.8m^3/s$ and $108.4m^3/s$ respectively. The model shows a good performance since the Nash-Sutcliffe value is 0.908, higher than the requirement value of 0.8 and almost to 1.0.

4.3 Model Results

Runoff is the result of the rainstorms and the level of occurrence along with the quantity is absolutely dependent on the type and characteristics of the rainfall events itself. The characteristics that directly influenced the rainfall events are like intensity of the rainfall, distribution of the precipitation and duration for an event. Clark Unit Hydrograph is used to analyse the data of rainfall, runoff and streamflow for gauged and ungauged sub basin in order to determine the highest or peak discharge value for every sub basin in Kuantan River Basin.

By running the simulation after validation process, the result for peak flow for every sub basin was obtained. Table 4.5 below shows the summary result for peak flow in every sub basin including junction and Figure 4.4 until Figure 4.14 shows the graph plotted the value for peak flow for simulated hydrograph for ungauged station

Table 4.5: Summary result for peak flow in every sub basin including junction

Sub basin	**Q peak m^3/s**
Ulu Sg. Kuantan	73.6
Junction 1	73.6
Kenau	40.6
Junction 2	108.4
Nada	10.4
Junction 3	118.4
Caru	8.4
Junction 4	124
Reman	18.6
Junction 5	134.9
Panching	8.2
Junction 6	142.4
Gading	7.8
Junction 7	149.9
Riau	17.8
Junction 8	160.7
Pinang	16
Junction 9	176
Pandan	9.9
Junction 10	181.8
Belat	63.7
Junction 11	203.2

The value of peak discharge is steadily increasing from Junction 1 to Junction 11 due to summation of flow from sub basin towards the junction. However, the value of peak discharge at each sub basin is not necessarily increases since it will depend on their baseflow and the value of rainfall runoff from the storm event. The lowest peak flow is at the Sg. Gading which is only 7.8m^3/s. While the highest peak flow for sub basin belongs to Ulu Sg. Kuantan, 73.6m^3/s. The value of peak flow in every sub basin may vary according to their characteristic such as river depth, and river cross – section. Below are the simulated hydrograph obtained for ungauged station.

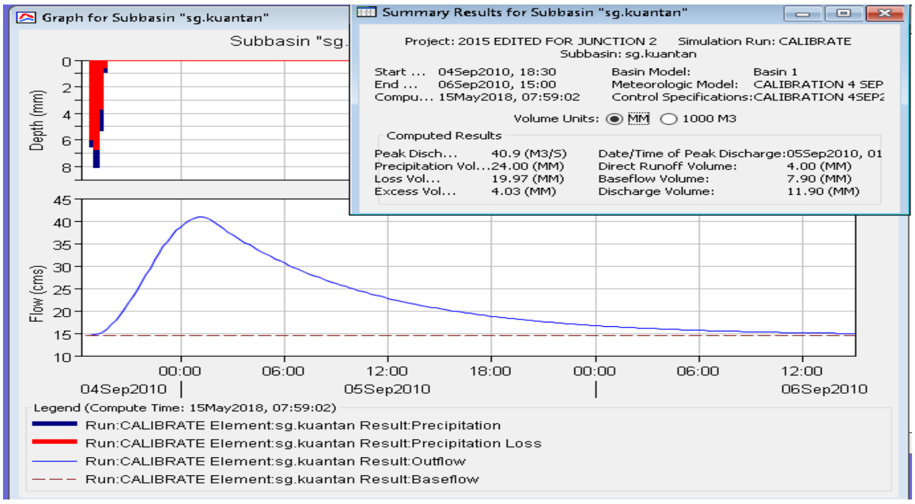


Figure 4.4 Graph of simulated outflow for Sg Kuantan

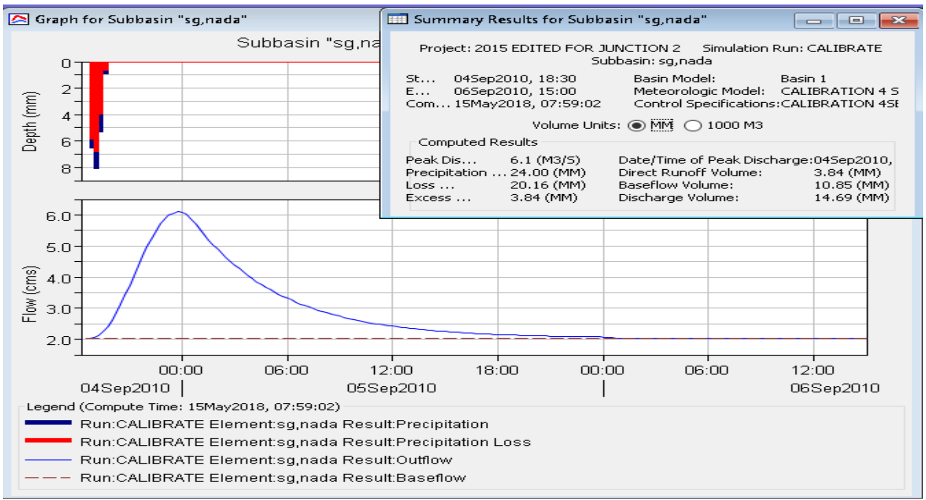


Figure 4.5 Graph of simulated outflow for Sg Nada

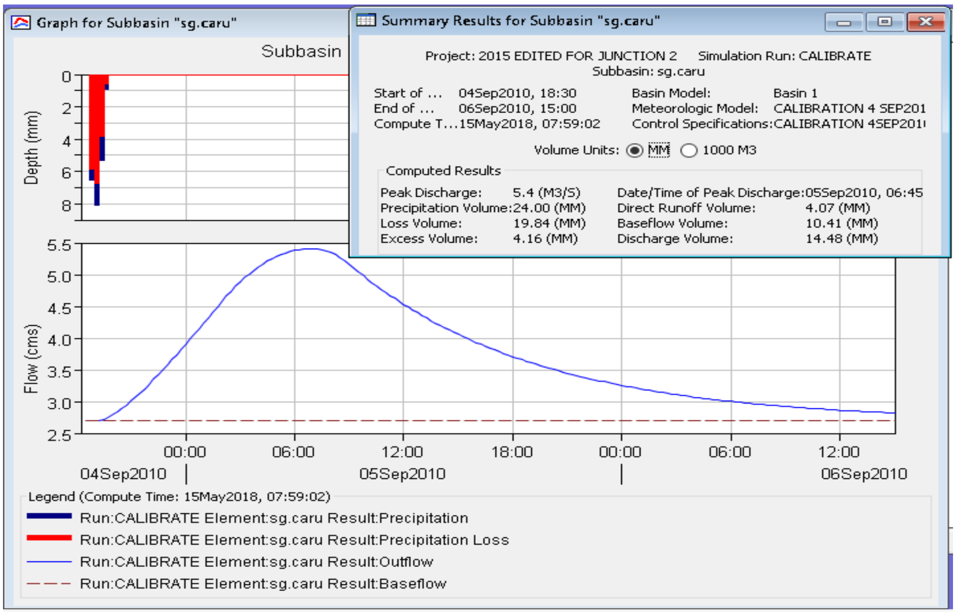


Figure 4.6 Graph of simulated outflow for Sg Caru

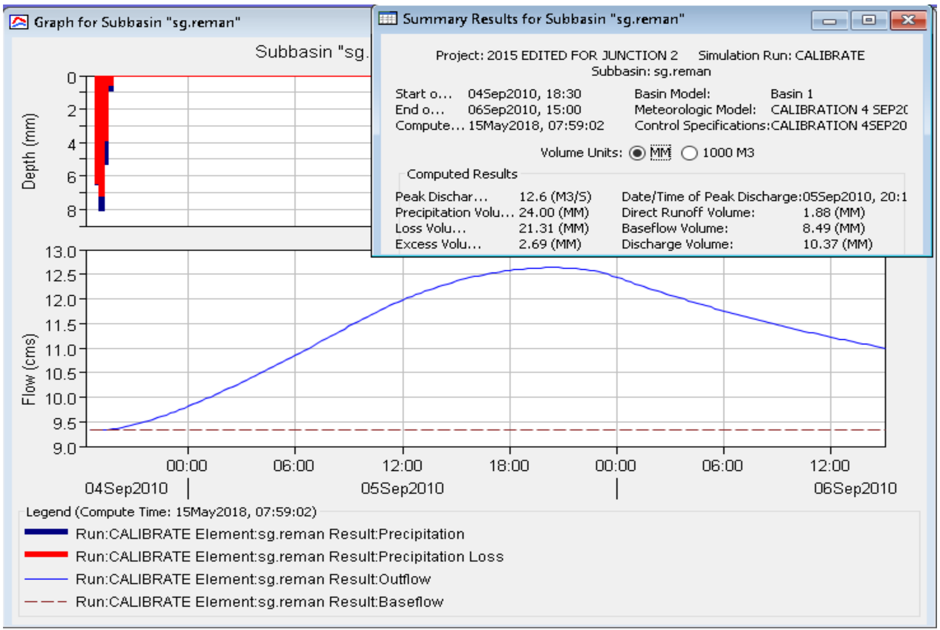


Figure 4.7 Graph of simulated outflow for Sg Reman

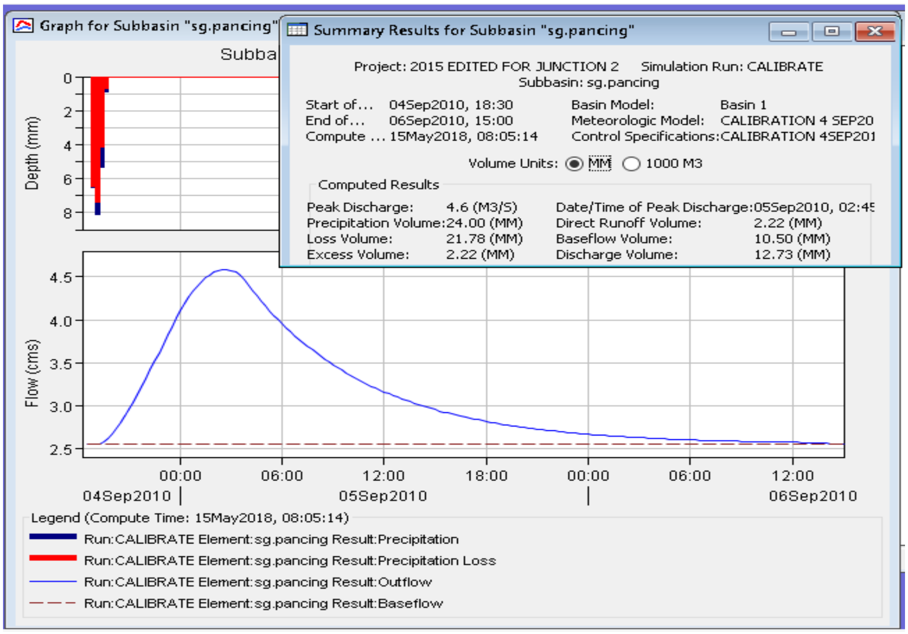


Figure 4.8 Graph of simulated outflow for Sg Pancing

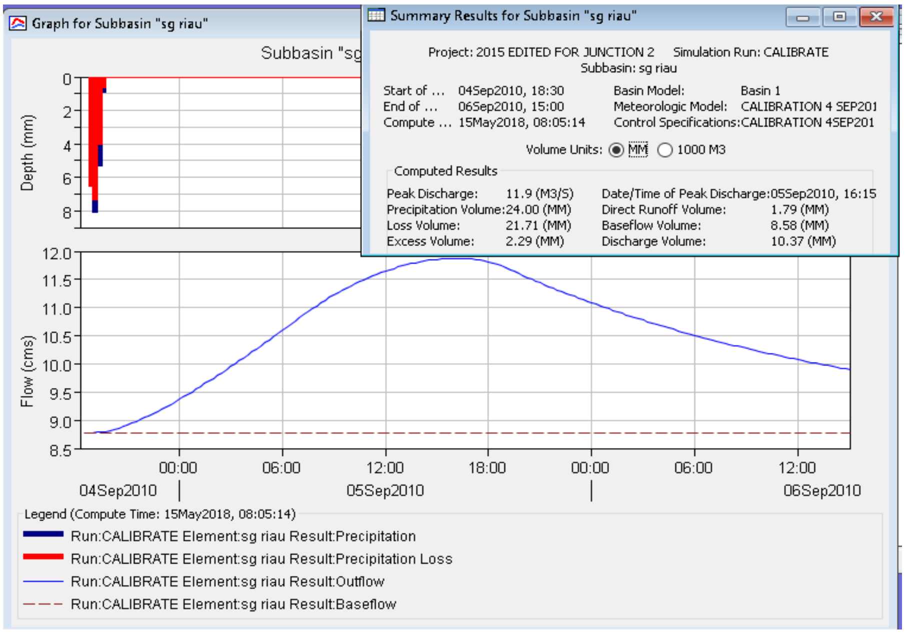


Figure 4.9 Graph of simulated outflow for Sg Riau

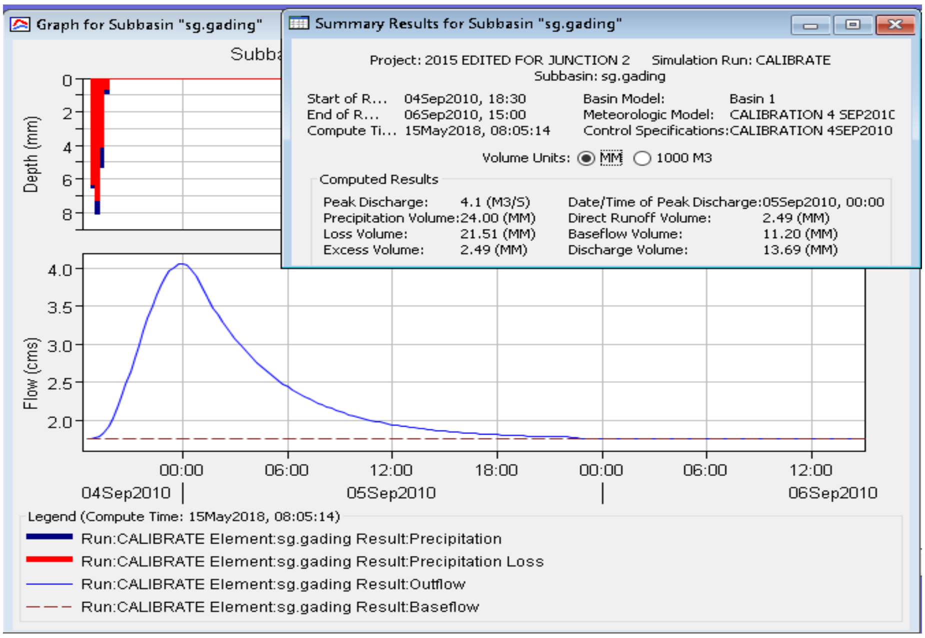


Figure 4.10 Graph of simulated outflow for Sg Gading

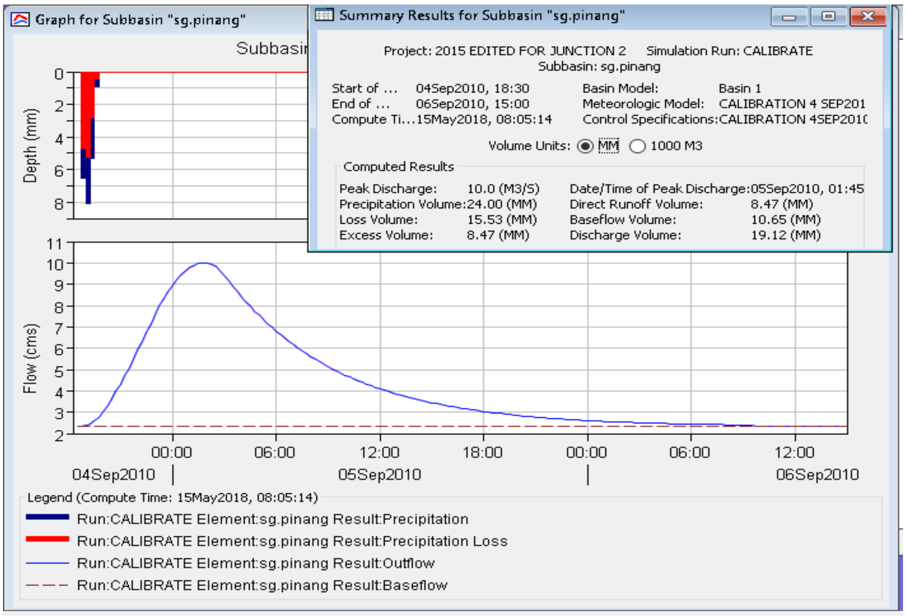


Figure 4.11 Graph of simulated outflow for Sg Pinang

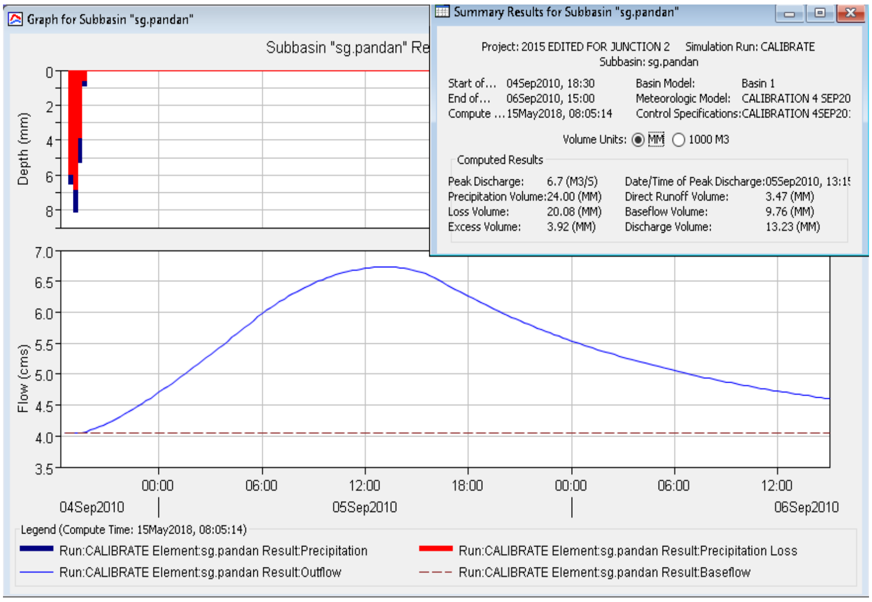


Figure 4.12 Graph of simulated outflow for Sg Pandan

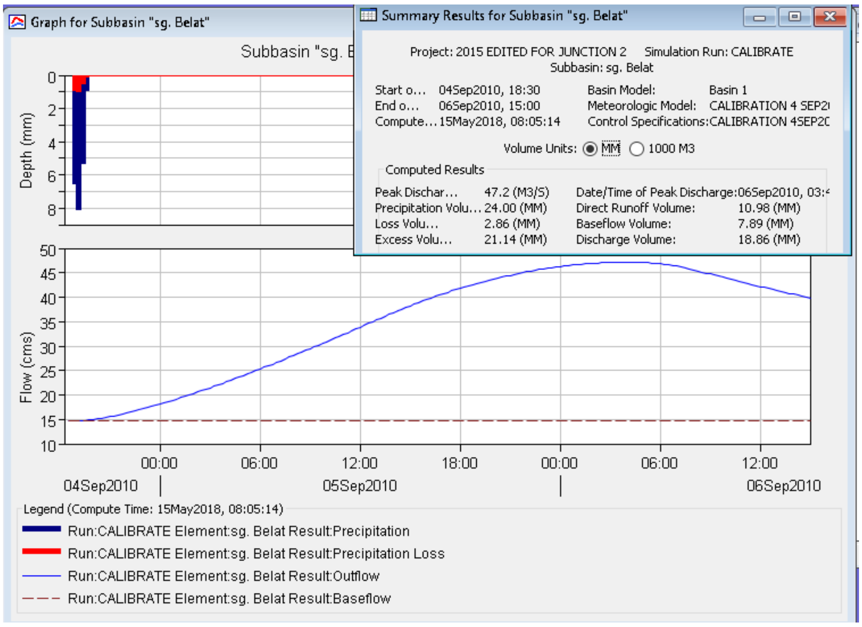


Figure 4.13 Graph of simulated outflow for Sg Belat

The plotted hydrograph with continuous blue line shows the result of simulated flow. These are the ungauged station since it is missing their observed flow unlike the result for Junction 2 that have both hydrograph, observed and simulated. By running the calibration process based on the gauged station and applying Weighted Area Method, the peak flow for others ungauged station can be estimated and obtained.

4.4 IDF Curve

The IDF Curve was plotted based on the annual highest rainfall amounts for various durations. Data from the rainfall stations are analysed using Gumbel distributions, to generate forecasts of extreme events and Intensity-Duration-Frequency (IDF) Curves. From the IDF Curve, the value of rainfall depth is sorted and extracted to be used in the simulation and see how it can affect the flowrate of each sub basin. These curves are enclosed in Figure 4.14(a) until Figure 4.14(e). For the purpose of this study, the design rainfall depth that will be used for the modelling will correspond to the 2, 5, 10, 50 and 100 ARI can be seen in **Appendix C.**

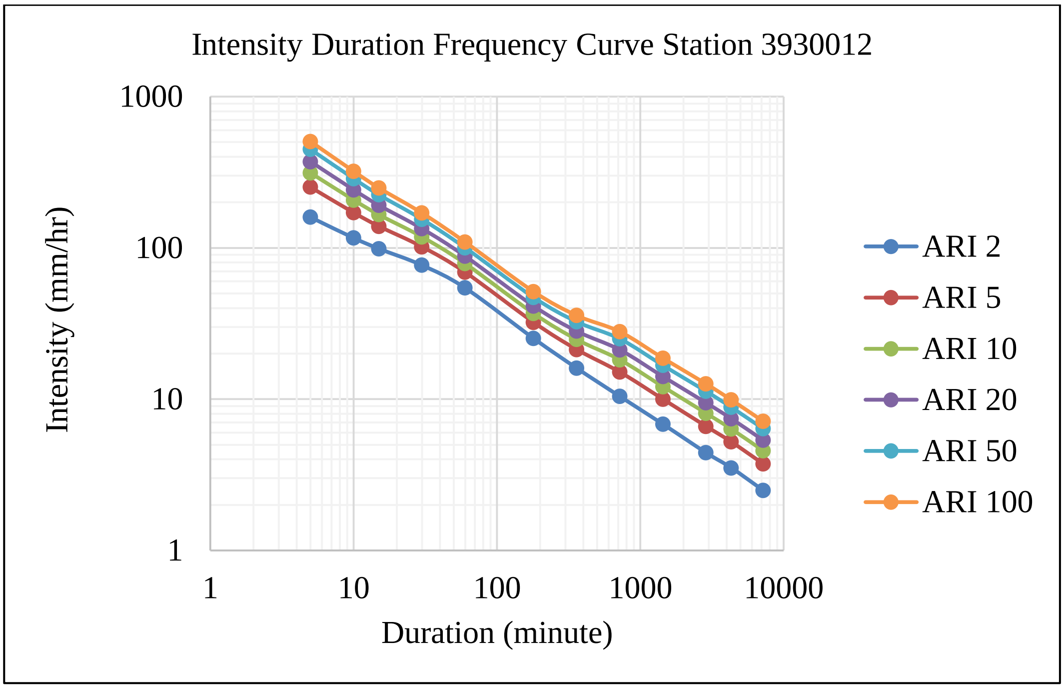


Figure 4.14(a) IDF Curve for Station 3930012(Sg. Lembing PCCL Mill (Sg. Lembing))

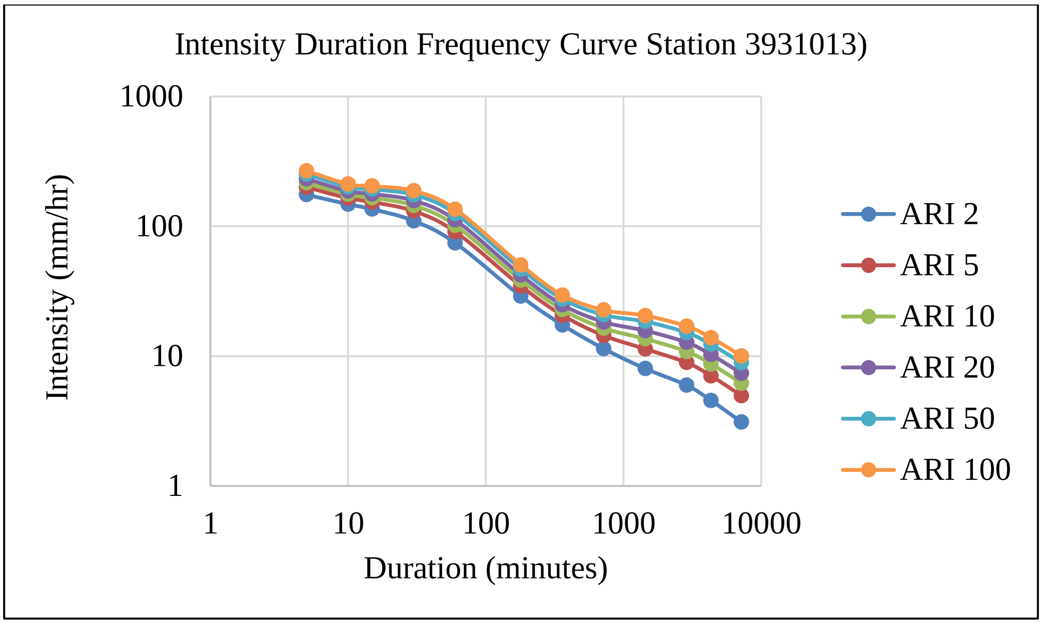


Figure 4.14(b) IDF Curve for Station 3931013(Ldg. Nada (Sg. Kuantan))

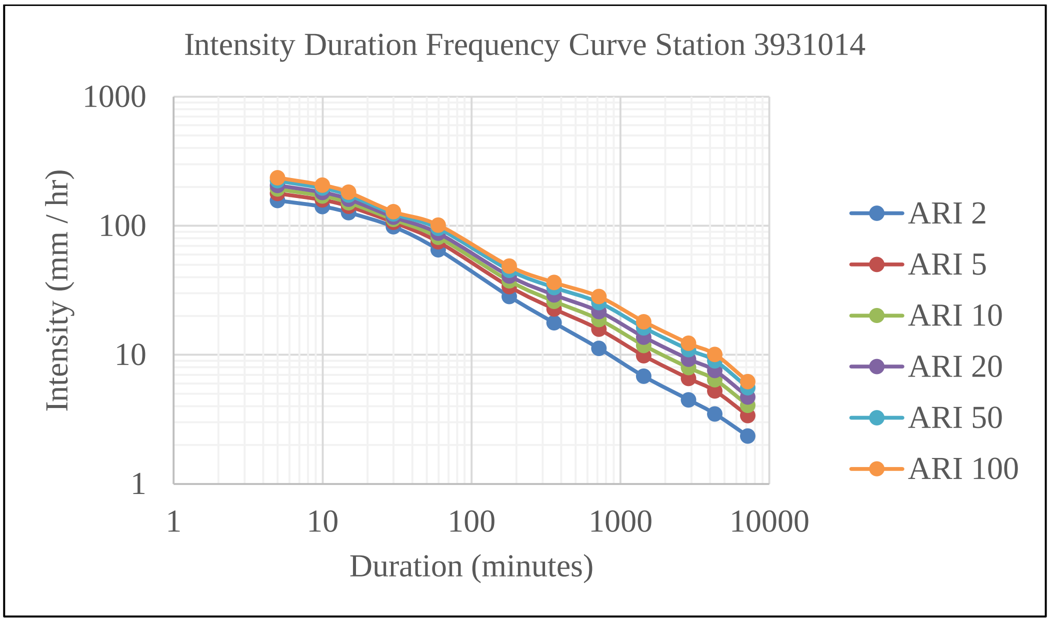


Figure 4.14(c) IDF Curve for Station 3931014(Ldg. Kuala Reman (Sg. Kuantan))

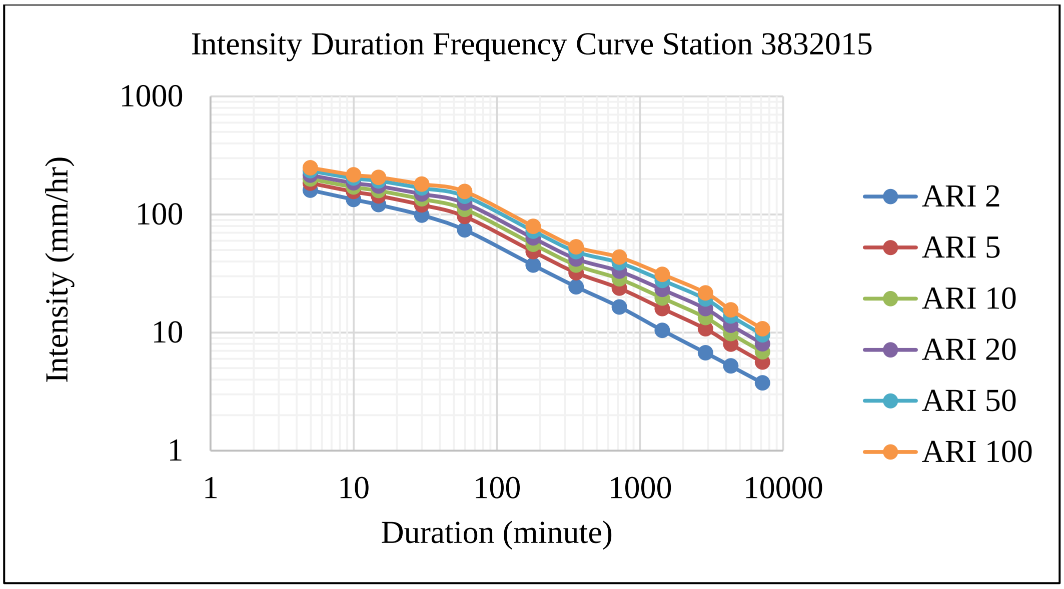


Figure 4.14(d) IDF Curve for Station 3832015 (Rancangan Pam Paya Pinang (Sg. Kuantan)

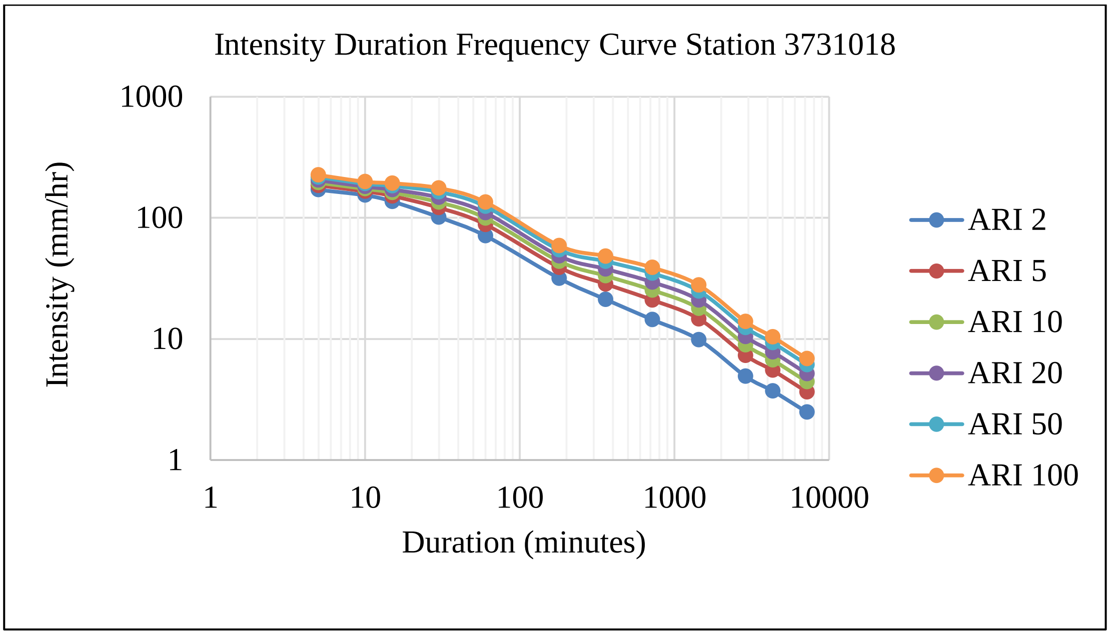


Figure 4.14(e) IDF Curve for Station 3731018 (JKR Gambang (Sg. Belat))

4.4.1 Model Results for ARI 2, 5, 10, 20, 50 and 100

The model that have been calibrated and validated was used to obtain the value of peak discharge using design ARI 2, 5,10,20,50 and 100 by running the simulation for every sub basin according to each own rainfall station assigned which based on Thiessen Polygon Distribution Method. The result from the simulation is the peak flow of the simulation hydrograph. The example of the simulated hydrograph based on each designed ARI 2, 5, 10, 20, 50, and 100 in Sg Kenau is shown in Figure 4.15 to Figure 4.20 below:

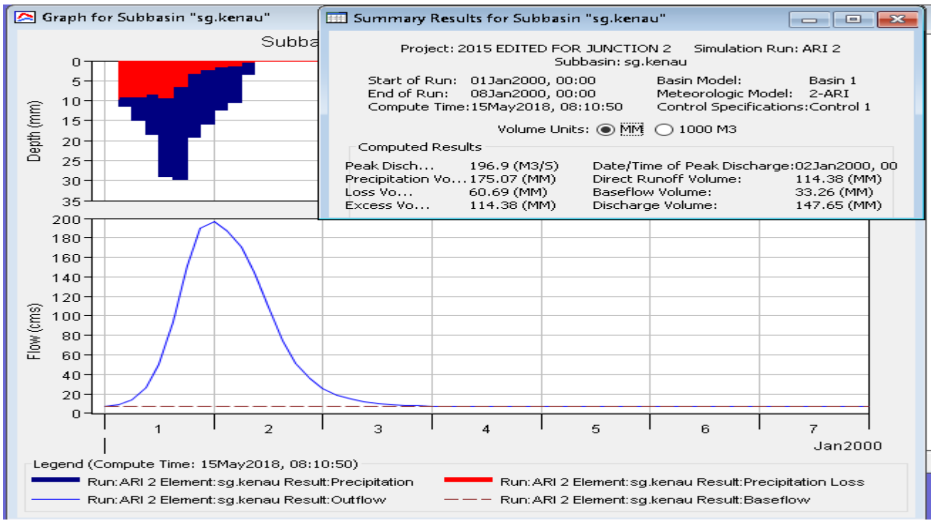


Figure 4.15 Peak flow of the designed ARI 2 in Sg Kenau

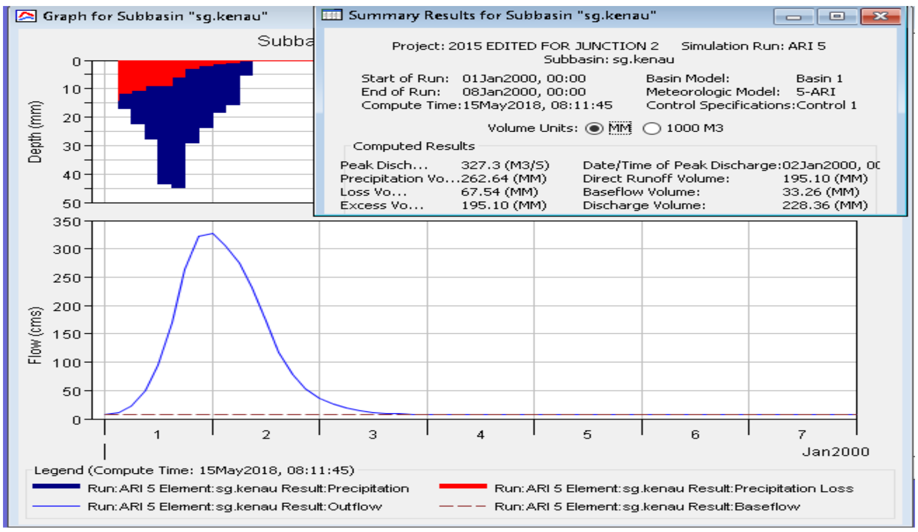


Figure 4.16 Peak flow of the designed ARI 5 in Sg Kenau

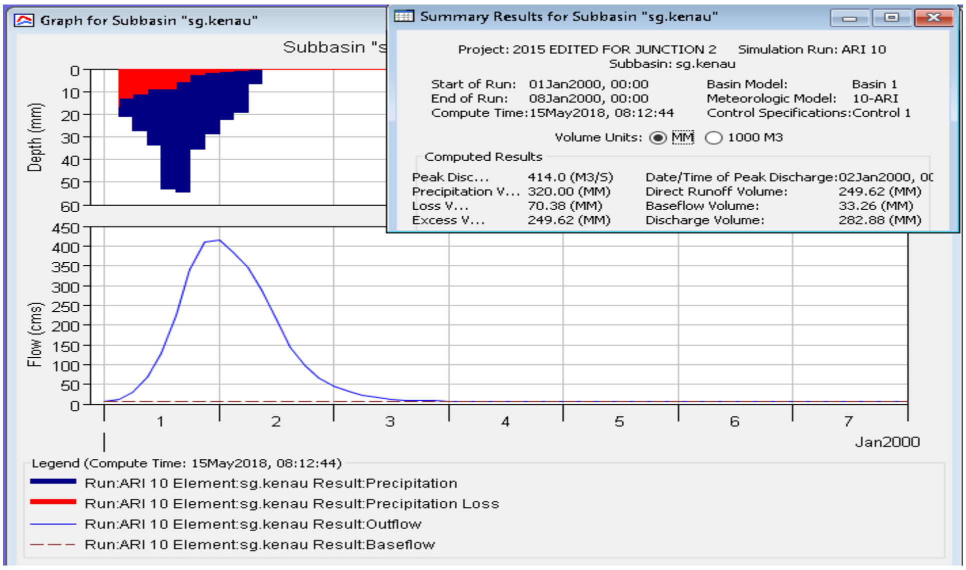


Figure 4.17 Peak flow of the designed ARI 10 in Sg Kenau

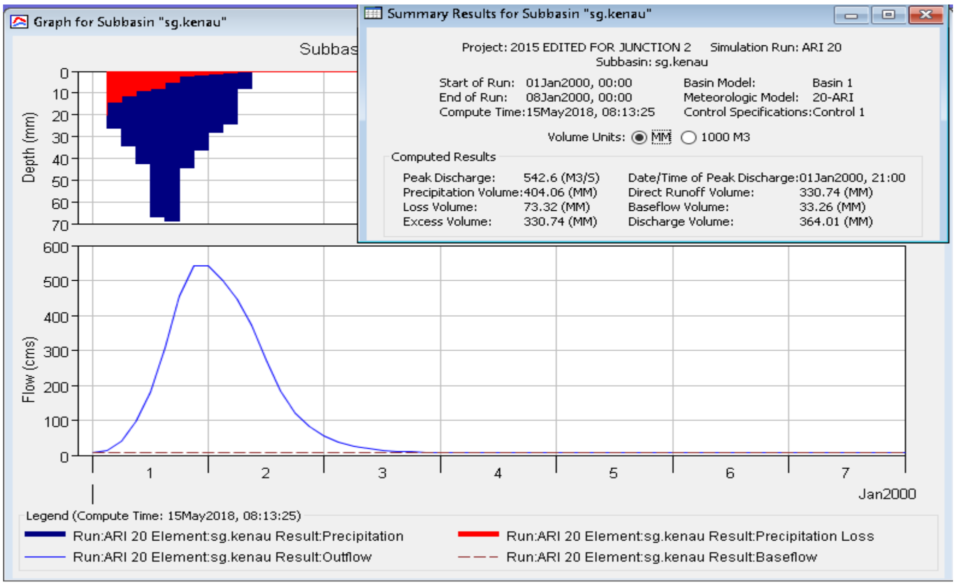


Figure 4.18 Peak flow of the designed ARI 20 in Sg Kenau

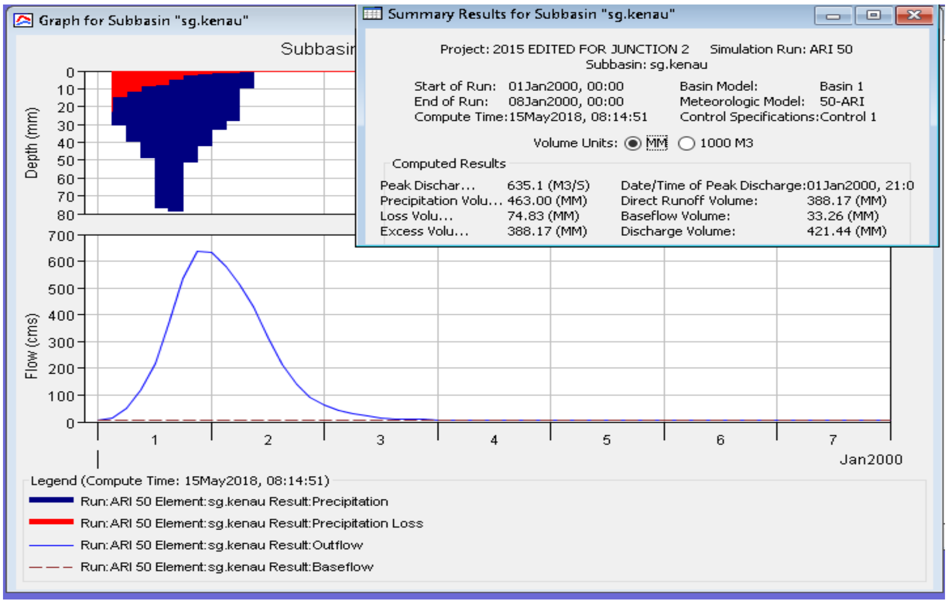


Figure 4.19 Peak flow of the designed ARI 50 in Sg Kenau

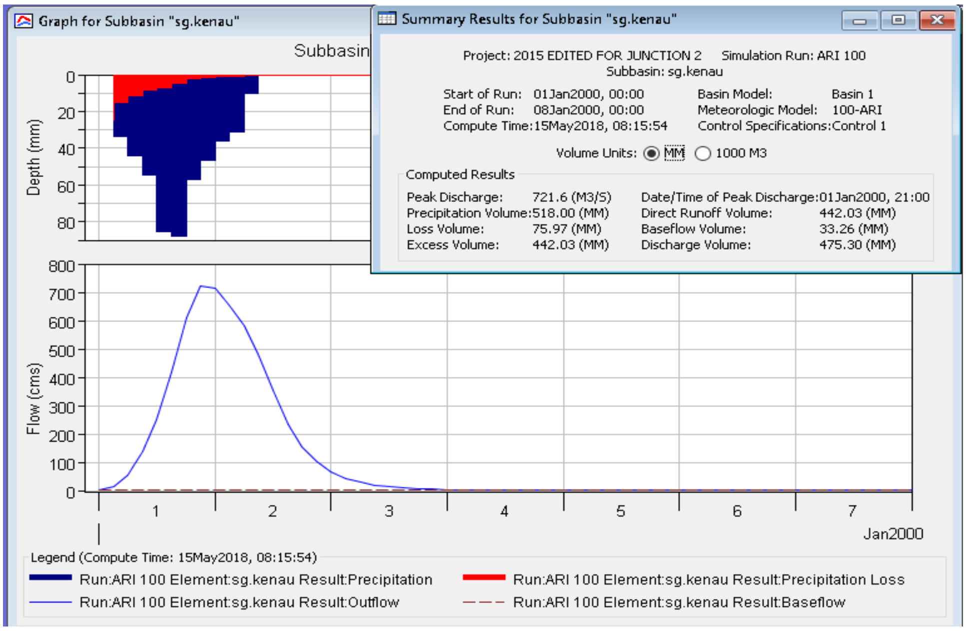


Figure 4.20 Peak flow of the designed ARI 100 in Sg Kenau

The value of rainfall depth taken from the IDF curve was inserted into the calibrated and validated model to obtain the peak flow of the event in every sub basin. As the rainfall depth increase, the river depth also will increase and this will definitely affect the peak flow value of the sub basin.

4.5 Discussion

There are few factors that may influence the flow of water into the river channel and its surrounding area. Normally, the factors that associated with this matter are the intensity of the rainstorm event, cross – section of the river channel like the depth, width, slope, and even shape. Problem regarding river flow usually occur when it overflow into the river basins which may and normally contribute to flood of the nearest areas. Even though the factor of flood at any reach of the sub basin can occur due to different factors, but in the upstream area, generally it is caused by exceeded discharge that cannot be sustained by the cross section of the river (Fauzi, 2008).

This study was conducted using HEC-HMS to estimate flow rate for gauged and ungauged station. Firstly, gauged station is the location of the river channel that has gauging equipment and able to collect the flowrate of the water flow in that particular stream and the ungauged station is vice versa. In this research of study, Kenau is the only gauged station that exists within KRB and the rests of the sub basin is ungauged. To conduct the research regarding flood and designing drainage system required the peak flow for every sub basin. It is possible for gauged station to achieve the accurate parameter value since it has observed flow from the streamflow data. In order to overcome the shortcoming for ungauged station, the estimation of flow rate using gauged station was done. The parameters such as CN, Tc and R at the gauged station were used to manipulate the parameter at the ungauged station based on Weighted Area Method.

To achieve the best performance river model, it has to undergo calibration and validation process. In calibration process, after the value of gauged station is adjusted manually to get the satisfactory simulated that coincide with observed hydrograph, the value of parameter for ungauged station is then calculated using Weighted Area method. This method is very useful in determining the parameter value for ungauged station as this method use the area of sub basin in order to find the new value for CN, Tc and R for ungauged station. Most of the value that being adjusted using Weighted Area Method shows an increment from a slightly to significant figures. Validation process is then being running to validate the calibrated model to ensure the model is suitable and applicable even in an extreme condition.

Through this study, there are several limitations factors that being discovered and restricted the model from producing the most accurate results. The first one, the rainfall data that being used for every rainfall station is only from one station, 3930013 Sg Kuantan @ Bukit Kenau station even though supposedly the data used is from each rainfall station that has been determined using Thiessen Polygon Method earlier. The missing of the completed data for the particular date in the process of calibration and validation for every rainfall station is the main reasons for this problem. Next, it has been identified that the rainfall data to be keyed in and simulated in this model have a particular pattern in order to reach the similarity between the observed and simulated hydrograph. The pattern most likely has the significant peak value at the middle of the rainfall period.

However, the results obtained can be considered satisfactory because it has the good value of Nash-Sutcliffe model efficiency index that is higher than 0.8. Based on the simulation results, it was cleared that simulated data and observed stream flow data has the relationship of 1:1. As for simulation that using designated ARI for 2, 5, 10, 20, 50 and 100 year, the analysis shown that the flow rate would increase when the depth of the river increase due to rainfall. In fact, the relationship flow rate and depth of the river can be considered as directly proportional to each other.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The main objectives in this research of study is to analyse hydrological data of gauged and ungauged in Kuantan River Basin and followed by the second objective which is to estimate the flow rate of the water catchment area of Kuantan River Basin using Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS). As for the hydrological data, it does highlight the data that being used to ensure this simulation successful such as rainfall and stream flow data. Both data need to be carefully selected for rainstorm event and determined using Thiessen Polygon Method for determination of rainfall station that involved in this study. It was successfully done in this study as there are five rainfall stations that directly involved and influenced the flow rate of the sub basin in KRB. Those five stations are station Sg Lembing PCLL, Ladang Nada, Ladang Reman, Pam Paya Pinang and Sk Gambang. As for the streamflow data, the gauged station available is only one within the KRB that is Sg. Kuantan @ Bukit Kenau. The rainfall and streamflow data from those stations were analysed to find the most suitable and completed data for particular event storm to be used in this study and the date of the event selected is 4th September 2010 and 13th October 2013 for calibration and validation process respectively.

Next, the second objective has been successfully achieved as the simulation yields the flowrate and peak flow rate for every sub basin and junction. For calibration process, both the simulated and observed hydrograph almost reach the perfect similarity in Junction 2 as these two have similar shape and there is not much of differences in the value of peak flow as it is

60.6m^3/s and 60.8m^3/s for observed and simulated respectively. While the value for Nash-Sutcliffe Index is 0.808, higher than the requirement value 0.8 and almost to 1.0. The value of peak discharge of this validated model is 99.8m^3/s and 108.4m^3/s for observed and simulated. It even achieves a better value of Nash- Sutcliffe Index of 0.908, higher than the requirement value 0.8 and almost to 1.0. The range of the CN used in this study is in between 62.3 to 85.8 and it depends on the land used of the sub basin area. Developed area tends to have higher CN and higher rainfall runoff. The value of peak discharge is steadily increasing from Junction 1 to Junction 11 due to summation of flow from sub basin towards the junction. In Junction 1, the discharge is only 73.6m^3/s and as it reach Junction 11, the discharge was accumulated and reach the value of 203.2m^3/s. The sub basin that produces the highest discharge is Ulu Sg. Kuantan, 73.6m^3/s while Sg. Gading produces the lowest value which is only 7.8m^3/s.

As discussed in the last Chapter 4, a few conclusions could be made.

1. The flow rate varies with the depth of the water and clearly represented by the directly proportional relationship with each other.
2. Based on the result and data obtained as confirmation, HEC-HMS can be reliable tool to design and simulate river flows.
3. HEC-HMS can be used as a tool to estimate and predict flood levels and flowrates for design purposes.
4. River simulation is the best way and accurate option to study the behaviour of flood and the factors that contributing to the phenomenon.

In short, this study can be classified as successful as the entire objectives were achieved though there were few limitations detected along the simulation process. By all means, this study will need further improvement for better and definite outcomes.

5.2 Recommendation

In order to attain a better simulation results, it is recommended that further simulation and analysis shall be carried out using:

1. Complete data for 8 rainfall station along the Kuantan River catchment area.
2. Obtained the river cross section/channel section data to get the clear picture of simulation that exceeds the critical line which contributed to the flood event.
3. Run laboratory scaled model and compare the result with the outcome from the computerized model simulation.

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APPENDIX A

Recorded rainfall and streamflow data for station Sg Kuantan @ Bukit Kenau (3930013) From 04th September 2010 to 6th October 2010

i) Rainfall Data

Date	Time	Rainfall Depth(mm)
20100904	184500	3.2
20100904	190000	6.5
20100904	191500	8.1
20100904	193000	5.3
20100904	194500	0.9

ii) Streamflow Data

Date	Time	Flow (m^3/s)	Water Level (mm)
20100904	184500	22.4	16.88
20100904	190000	23.6	16.89
20100904	191500	25.8	16.9
20100904	193000	27.4	16.92
20100904	194500	28.7	16.93
20100904	200000	30.1	16.94
20100904	201500	32.5	16.95
20100904	203000	34.4	16.97
20100904	204500	35.8	16.98
20100904	210000	37.4	16.99
20100904	211500	38.9	17
20100904	213000	41.6	17.01
20100904	214500	43.7	17.03
20100904	220000	45.9	17.04
20100904	221500	48.9	17.07
20100904	223000	51.4	17.09
20100904	224500	53.5	17.11
20100904	230000	55.7	17.13
20100904	231500	57.9	17.15

20100904	233000	59.3	17.17
20100904	234500	60.3	17.18
20100904	240000	60.6	17.18
20100905	1500	60.6	17.18
20100905	3000	59.8	17.17
20100905	4500	59.5	17.17
20100905	10000	58.8	17.16
20100905	11500	58.5	17.16
20100905	13000	56.9	17.15
20100905	14500	56.3	17.14
20100905	20000	55.5	17.13
20100905	21500	53.6	17.12
20100905	23000	53	17.11
20100905	24500	52.3	17.1
20100905	30000	51.2	17.09
20100905	31500	50.1	17.08
20100905	33000	49	17.07
20100905	34500	48.7	17.07
20100905	40000	47.9	17.06
20100905	41500	46.8	17.05
20100905	43000	46.5	17.05
20100905	44500	45.7	17.04
20100905	50000	45.4	17.04
20100905	51500	44.5	17.03
20100905	53000	44.1	17.03
20100905	54500	44.1	17.03
20100905	60000	42.9	17.02
20100905	61500	42.5	17.02
20100905	63000	42.5	17.02
20100905	64500	41.3	17.01
20100905	70000	40.9	17.01
20100905	71500	39.7	17
20100905	73000	39.3	17
20100905	74500	39.3	17
20100905	80000	39.3	17
20100905	81500	38.2	16.99
20100905	83000	37.8	16.99
20100905	84500	37.8	16.99
20100905	90000	37.8	16.99
20100905	91500	37.8	16.99
20100905	93000	37.8	16.99
20100905	94500	36.7	16.98
20100905	100000	36.3	16.98

20100905	101500	36.3	16.98
20100905	103000	36.3	16.98
20100905	104500	35.2	16.97
20100905	110000	34.8	16.97
20100905	111500	34.8	16.97
20100905	113000	34.8	16.97
20100905	114500	34.8	16.97
20100905	120000	34.8	16.97
20100905	121500	34.8	16.97
20100905	123000	34.8	16.97
20100905	124500	34.8	16.97
20100905	130000	34.8	16.97
20100905	131500	34.8	16.97
20100905	133000	34.8	16.97
20100905	134500	34.8	16.97
20100905	140000	34.8	16.97
20100905	141500	34.8	16.97
20100905	143000	34.8	16.97
20100905	144500	34.8	16.97
20100905	150000	34.8	16.97
20100905	151500	34.8	16.97
20100905	153000	34.8	16.97
20100905	154500	34.8	16.97
20100905	160000	34.8	16.97
20100905	161500	34.8	16.97
20100905	163000	34.8	16.97
20100905	164500	34.8	16.97
20100905	170000	33.7	16.96
20100905	171500	33.3	16.96
20100905	173000	33.3	16.96
20100905	174500	33.3	16.96
20100905	180000	33.3	16.96
20100905	181500	34.4	16.97
20100905	183000	33.7	16.96
20100905	184500	33.3	16.96
20100905	190000	33.3	16.96
20100905	191500	33.3	16.96
20100905	193000	33.3	16.96
20100905	194500	33.3	16.96
20100905	200000	33.3	16.96
20100905	201500	33.3	16.96
20100905	203000	33.3	16.96
20100905	204500	33.3	16.96

20100905	210000	33.3	16.96
20100905	211500	32.3	16.95
20100905	213000	31.9	16.95
20100905	214500	31.9	16.95
20100905	220000	31.9	16.95
20100905	221500	31.9	16.95
20100905	223000	30.9	16.94
20100905	224500	31.5	16.95
20100905	230000	30.9	16.94
20100905	231500	30.5	16.94
20100905	233000	30.5	16.94
20100905	234500	30.5	16.94
20100905	240000	30.5	16.94
20100906	1500	30.5	16.94
20100906	3000	30.5	16.94
20100906	4500	30.5	16.94
20100906	10000	30.5	16.94
20100906	11500	30.5	16.94
20100906	13000	29.5	16.93
20100906	14500	29.1	16.93
20100906	20000	29.1	16.93
20100906	21500	29.1	16.93
20100906	23000	29.1	16.93
20100906	24500	29.1	16.93
20100906	30000	29.1	16.93
20100906	31500	29.1	16.93
20100906	33000	29.1	16.93
20100906	34500	29.1	16.93
20100906	40000	29.1	16.93
20100906	41500	29.1	16.93
20100906	43000	28.1	16.92
20100906	44500	27.8	16.92
20100906	50000	27.8	16.92
20100906	51500	27.8	16.92
20100906	53000	27.8	16.92
20100906	54500	27.8	16.92

20100906	60000	27.8	16.92
20100906	61500	27.8	16.92
20100906	63000	27.8	16.92
20100906	64500	27.8	16.92
20100906	70000	27.8	16.92
20100906	71500	27.8	16.92
20100906	73000	27.8	16.92
20100906	74500	26.8	16.91
20100906	80000	27.4	16.92
20100906	81500	26.8	16.91
20100906	83000	27.4	16.92
20100906	84500	26.8	16.91
20100906	90000	27.4	16.92
20100906	91500	26.8	16.91
20100906	93000	26.5	16.91
20100906	94500	26.5	16.91
20100906	100000	26.5	16.91
20100906	101500	26.5	16.91
20100906	103000	26.5	16.91
20100906	104500	26.5	16.91
20100906	110000	26.5	16.91
20100906	111500	26.5	16.91
20100906	113000	26.5	16.91
20100906	114500	26.5	16.91
20100906	120000	26.5	16.91
20100906	121500	25.5	16.9
20100906	123000	25.2	16.9
20100906	124500	25.2	16.9
20100906	130000	25.2	16.9
20100906	131500	25.2	16.9
20100906	133000	25.2	16.9
20100906	134500	25.2	16.9
20100906	140000	25.2	16.9
20100906	141500	24.3	16.89
20100906	143000	24.8	16.9

APPENDIX B

Recorded rainfall and streamflow data for station Sg Kuantan @ Bukit Kenau (3930013) From 12th October 2013 to 13th October 2013

i) Rainfall Data

Date	Time	Rainfall Depth
12/10/2013	19:30	0.5
12/10/2013	19:45	14.3
12/10/2013	20:00	15.9
12/10/2013	20:15	3.8
12/10/2013	20:30	0.5
12/10/2013	20:45	0.5
12/10/2013	21:00	0.5

ii) Streamflow Data

Date	Time	Flow (m^3/s)	Water Level (mm)
20131012	193000	28.2	16.92
20131012	194500	27.8	16.92
20131012	200000	31.2	16.94
20131012	201500	39.3	17
20131012	203000	43.6	17.03
20131012	204500	44.1	17.03
20131012	210000	46.1	17.05
20131012	211500	47.4	17.06
20131012	213000	48.5	17.07
20131012	214500	49.6	17.08
20131012	220000	51.6	17.1
20131012	221500	55.6	17.13
20131012	223000	59.9	17.17
20131012	224500	63.3	17.2
20131012	230000	67.4	17.24
20131012	231500	70.8	17.27
20131012	233000	76.7	17.33
20131012	234500	82.2	17.38

20131012	240000	86.8	17.42
20131013	1500	90.6	17.45
20131013	3000	93.2	17.48
20131013	4500	95.7	17.5
20131013	10000	97.1	17.51
20131013	11500	98.4	17.52
20131013	13000	99.6	17.53
20131013	14500	99.8	17.53
20131013	20000	98.8	17.52
20131013	21500	97.5	17.51
20131013	23000	96.3	17.5
20131013	24500	95.1	17.49
20131013	30000	93.8	17.48
20131013	31500	90.6	17.46
20131013	33000	88	17.43
20131013	34500	85.6	17.41
20131013	40000	83.4	17.39
20131013	41500	79.6	17.36
20131013	43000	78	17.34
20131013	44500	75.1	17.32
20131013	50000	71.9	17.29
20131013	51500	69.6	17.26
20131013	53000	66.6	17.24
20131013	54500	64.2	17.21
20131013	60000	61.2	17.19
20131013	61500	58.8	17.16
20131013	63000	56.7	17.14
20131013	64500	54.5	17.12
20131013	70000	51.4	17.1
20131013	71500	50	17.08
20131013	73000	47.1	17.06
20131013	74500	44.5	17.03
20131013	80000	41.4	17.01
20131013	81500	38.3	16.99
20131013	83000	36.5	16.98
20131013	84500	33.8	16.96
20131013	90000	31	16.94
20131013	91500	29.3	16.93

APPENDIX C

Design Rainfall Depth from IDF Curve

i) Station 3930012 (Sg. Lembing PCCL Mill (Sg. Lembing))

Design Rainfall (mm) Data for Various Strom Durations (minutes)						
ARI/ Minute	2	5	10	20	50	100
5	13.29	21	26.1	31	37.33	42.08
10	19.37	28.5	34.55	40.35	47.85	53.48
15	24.69	34.76	41.42	47.82	56.09	62.29
30	38.39	50.85	59.11	67.02	77.27	84.95
60	54.33	69.02	78.74	88.07	100.15	109.2
180	75.64	96.66	110.58	123.92	141.2	154.15
360	96.14	127.78	148.72	168.81	194.82	214.31
720	125.11	181.3	218.49	254.17	300.35	334.96
1440	163.88	239.85	290.14	338.38	400.82	447.61
2880	212.22	317.41	387.05	453.85	540.32	605.11
4320	252.83	375.55	456.8	534.72	635.6	711.2
7200	299.29	448.32	546.99	641.62	764.13	855.93

ii) Station 3931013 (Ladang Nada (Sg. Kuantan))

Design Rainfall (mm) Data for Various Strom Durations (minutes)						
ARI/ Minute	2	5	10	20	50	100
5	14.59	16.64	18.01	19.31	21	22.27
10	24.65	27.46	29.33	31.12	33.43	35.17
15	33.85	38.43	41.47	44.38	48.15	50.98
30	55.08	65.42	72.27	78.84	87.35	93.72
60	74.44	90.74	101.53	111.88	125.28	135.32
180	86.64	103.85	115.25	126.17	140.32	150.92
360	104.34	123.78	136.65	148.99	164.96	176.93
720	136.61	172.67	196.54	219.44	249.08	271.29
1440	191.98	272.37	325.59	376.64	442.72	492.24
2880	285.78	427.46	521.25	611.22	727.68	814.95
4320	327.77	507.15	625.91	739.81	887.27	997.76
7200	372.04	594.51	741.78	883.04	1065.91	1202.95

iii) Station 3931014 (Ladang Kuala Reman (Sg. Kuantan))

Design Rainfall (mm) Data for Various Strom Durations (minutes)						
ARI/ Minute	2	5	10	20	50	100
5	13.09	14.84	16.01	17.12	18.57	19.65
10	23.48	26.42	28.36	30.22	32.63	34.44
15	31.61	35.3	37.74	40.08	43.11	45.38
30	49.08	53.13	55.81	58.38	61.71	64.21
60	65.21	74.84	81.21	87.32	95.23	101.16
180	84.81	101.14	111.96	122.34	135.77	145.83
360	105.98	135.84	155.61	174.57	199.12	217.51
720	134.23	188.84	224.99	259.67	304.55	338.19
1440	163.09	235.36	283.21	329.1	388.51	433.03
2880	214.76	314.55	380.6	443.96	525.98	587.45
4320	250.58	377.62	461.72	542.39	646.82	725.07
7200	280.36	404.21	486.2	564.84	666.65	742.94

iv) Station 3832015 (Rancangan Pam Paya Pinang (Sg. Kuantan))

Design Rainfall (mm) Data for Various Strom Durations (minutes)						
ARI/ Minute	2	5	10	20	50	100
5	13.37	15.33	16.63	17.87	19.48	20.68
10	22.29	25.96	28.39	30.72	33.74	36
15	30.15	35.88	39.67	43.3	48.01	51.53
30	49.16	60.16	67.44	74.43	83.47	90.24
60	73.72	95.76	110.36	124.35	142.47	156.05
180	111.34	145.12	167.47	188.92	216.68	237.48
360	145.89	191.88	222.34	251.54	289.35	317.69
720	197.2	283.7	340.96	395.89	466.99	520.27
1440	249.24	381.68	469.36	553.45	662.32	743.9
2880	322.6	514.11	640.9	762.5	919.93	1037.9
4320	373.24	571.75	703.16	829.21	992.38	1114.66
7200	447.15	671.31	819.71	962.04	1146.31	1284.38

v) Station 3731018 (JKR Gambang (Sg. Belat)

Design Rainfall (mm) Data for Various Strom Durations (minutes)						
ARI/ Minute	2	5	10	20	50	100
5	14.21	15.44	16.25	17.03	18.05	18.8
10	25.62	27.63	28.96	30.23	31.88	33.12
15	34.12	37.9	40.41	42.81	45.91	48.24
30	50.65	60.66	67.29	73.65	81.88	88.05
60	71.1	88.17	99.48	110.32	124.36	134.88
180	94.93	116.83	131.34	145.25	163.26	176.75
360	127.15	170.63	199.41	227.02	262.76	289.54
720	173.31	251.8	303.77	353.61	418.14	466.49
1440	236.06	351.69	428.24	501.66	596.71	667.93
2880	236.06	351.69	428.24	501.66	596.71	667.93
4320	267.91	396.49	481.61	563.26	668.96	748.16
7200	298.01	438.54	531.58	620.81	736.33	822.9